Cumulative Doctoral Thesis / Kumulative Dissertation

Process Safety 2030 / Prozesssicherheit 2030

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I declare in lieu of oath, that I wrote this thesis and performed the associated research myself, using only literature cited in this volume. If text passages from sources are used literally, they are marked as such.

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"Salus populi suprema lex esto."

"The safety of the people shall be the highest law."

Marcus Tullius Cicero ~50 BC

Table of Contents

English Abstract

The cumulative dissertation reflects on how process safety and related strategies can contribute to a safer industrial and socially engaged safety culture and thus bring positive changes in companies, organizations as well as in society in terms of safety, resilience and sustainability.

The individual papers of the cumulative dissertation highlight interdisciplinary approaches to process safety, hazard, risk management, risk prediction, training and communication. In the long term, process safety techniques should find their way into the working world outside of large companies. Especially SMEs (Small- and medium-sized enterprises) are addressed here.

The dissertation brings together selected articles and texts on current operational and social challenges and presents the results of Alexander Stolar's dissertation project "Process Safety 2030". Projects and texts are brought together in the interaction of research, review and practice, looking at them from the complexity of changing perspectives or stakeholders.
Although process safety initiatives have existed for many years, they have hardly found their way into smaller companies to date. The interaction of people, methods and operations is crucial. An essential question is therefore how to support companies, and which techniques are suitable and accepted. The goal is a safer, more resilient and sustainable working and processing environment.

The scientific articles are preceded by an introductory text that provides an explanatory introduction to the topic of process safety and its many influences. Using the development of a modern biorefinery as an example, many important health, safety and environmental aspects are discussed to ensure development in a sustainable direction.

The conclusion summarizes what process safety can do and exactly where there is still room for improvement. It is a call for educational institutions, stakeholders, and companies to engage and network for best practices and a common realization of a safer, more sustainable, more fair, and more resilient future.

Deutsche Kurzfassung

Die kumulative Dissertation reflektiert darüber, wie Prozesssicherheit und damit verbundene Strategien zu einer sichereren industriellen und sozial engagierten Sicherheitskultur beitragen können und damit positive Veränderungen in Unternehmen, Organisationen und in der Gesellschaft in Bezug auf Sicherheit, Resilienz und Nachhaltigkeit bewirken.

In den einzelnen Beiträgen der kumulativen Dissertation werden interdisziplinäre Ansätze zu Prozesssicherheit, Gefährdung, Risiko, Risikoerwartung, Training und Gefahrenkommunikation beleuchtet. Langfristig sollen Prozesssicherheitstechniken außerhalb von Großunternehmen Einzug in die Arbeitswelt halten. Hier sind insbesondere KMU (Klein- und Mittelunternehmen) angesprochen.

Die Dissertation versammelt ausgewählte Artikel und Texte zu aktuellen betrieblichen und gesellschaftlichen Herausforderungen und stellt die Ergebnisse des Dissertationsprojekts "Prozesssicherheit 2030" von Alexander Stolar vor. Projekte und Texte werden im Zusammenspiel von Forschung, Review und Praxis zusammengeführt und aus der Komplexität wechselnder Perspektiven beziehungsweise Interessensvertreter betrachtet.
Obwohl es seit vielen Jahren Initiativen zur Prozesssicherheit und zum Risikomanagement gibt, haben sie in kleineren Unternehmen bisher kaum Einzug gehalten. Das Zusammenspiel von Menschen, Techniken und Abläufen ist entscheidend. Eine wesentliche Frage ist daher, wie Unternehmen unterstützt werden können, bzw. welche Techniken geeignet und akzeptiert sind. Das Ziel ist eine sicherere, resilientere und nachhaltigere Arbeitswelt.

Den wissenschaftlichen Beiträgen ist ein einleitender Text vorangestellt, der erläuternd in das Thema Prozesssicherheit und deren Einflüsse einführt. Am Beispiel der Entwicklung einer modernen Bioraffinerie werden viele wichtige Gesundheits-, Sicherheits- und Umweltaspekte diskutiert, um die Entwicklung in eine nachhaltige Richtung zu gewährleisten. Im abschließenden Text ist zusammengefasst, was Prozesssicherheit leisten kann und wo genau es noch Verbesserungsbedarf gibt. Es ist ein Aufruf an Bildungseinrichtungen, Interessenverbände und Unternehmen, sich für Best-Practice-Beispiele und eine gemeinsame Verwirklichung einer sichereren, nachhaltigeren, gerechteren und widerstandsfähigeren Zukunft zu beschäftigen und zu vernetzen.

List of Figures

List of Tables

List of Abbreviations and Symbols

ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Possible
BAT	Best available technology
CBRN	Chemical, Biological, Radiological & Nuclear
CBRNE	Chemical, Biological, Radiological, Nuclear & Explosive
CCA	Cause and Consequence Analysis
ETA	Event Tree Analysis
FMEA	Failure Mode and Effect Analysis
FTA	Fault Tree Analysis
HACCP	Hazard Analysis and Critical Control Points
HAZOP	HAZard and OPerability Analysis
HRA	Human Reliability Analysis
LOPA	Level Of Protection Analysis
MCDA	Multi-Criteria Decision Analysis
PHA	Primary or Preliminary Hazard Analysis
OSHA	Occupational Safety and Health Administration of the United States of America
RCA	Root Cause Analysis
SWIFT	Structured What-IF Technique
SME / SMEs	Small- and medium-sized enterprises
TESEO	Tecnica Empirica Stima Errori Operatori

Publications and conference papers

This cumulative dissertation is based on the following publications:

Journal Articles

A. Stolar and A. Friedl, "Process safety for sustainable application," *Int. J. Reliab. Qual. Saf. Eng.*, vol. 28, no. 5, p. 40, 2021, doi: https://doi.org/10.1142/S0218539321500339;
Double-blind peer reviewed;

A. Stolar and A. Friedl, "Graphical process safety techniques for strengthening safety and resilience in Austrian SMEs," *Int. J. Bus. Contin. Risk Manag., vol. 13, no. 3 in press, 2023;*
Double-blind peer reviewed;

A. Stolar and A. Friedl, "Live Agent Training as an important process safety measure to strengthen resilience in hazardous (CBRN) work situations,", *Journal of Emergency Management*; accepted;
Double-blind peer reviewed;

A. Stolar and A. Friedl, "Process safety and green chemistry as a resilience concept - An Organosolv biorefinery case study.,", *International Journal of Sustainable Manufacturing*; submitted April, 3rd, 2023.
Double-blind peer reviewed;

Conference contributions

A. Stolar, "Visual Safety Analysis Techniques for Emergency Responders," in *ICRP International Conference on Recovery After Nuclear Accidents - Radiological Protection Lessons from Fukushima and Beyond*, 2020, p. 5. | Reviewed paper and lecture;

A. Stolar, "Risky language - or a common language for risk communication and process safety?," in *Proceedings of the 16. Minisymposium Verfahrenstechnik & 7. Partikelforum*, 2020, p. 4, doi: 10.34726/565. | Reviewed paper, poster and lecture;

A. Stolar, "Real-World Training for Hazardous Activities: Use or Lose your SOPs for Occupational and Legal Safety," in *6th International Symposium on the System of Radiological Protection*, 2022 | Poster and abstract;

I Introducing chapters

1 Motivation

"*Jetzt ist schon wieder was passiert.*" [1] (German for "*Something has happened again.*"), is a bad sign for the beginning of a story. And this statement, which is familiar to many people, is even worse when it comes up in the working environment.

The growth of the economy has always been characterized by developments in technology and improvements in productivity. But new technologies or sizes of production facilities also brought new hazards to people, facilities, the neighbourhood and the environment. Partly out of self-protection and partly out of fear of self-destruction, so-called process safety techniques were developed many decades ago and implemented in everyday industrial work. Originally called loss prevention, the focus here was clearly on the loss of large-scale facilities and military applications. It was not until later that people were also considered, first as an asset and later also as an asset to be protected in the sense of health protection and safety.

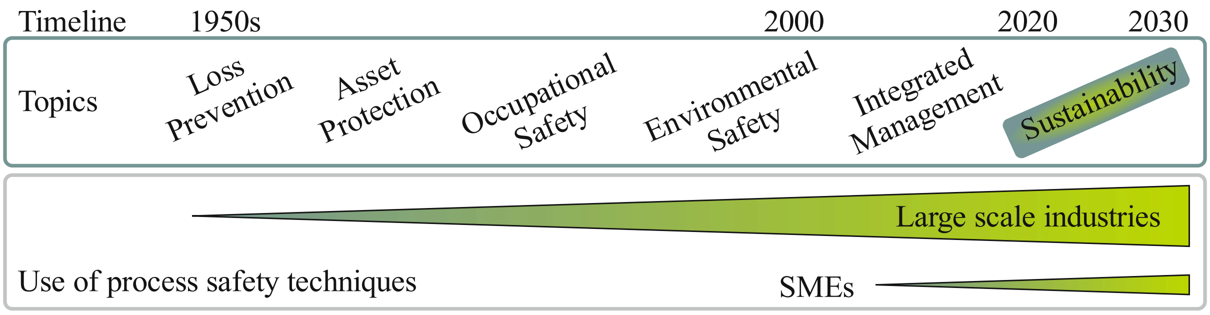

Figure 1: Timeline on use and implementation of process safety techniques

Gradually, in parallel, more and more of these techniques of plant and process safety developed in the large-scale industry and in hazardous plants, with a particular focus on different applications. These were separated into the analysis of accidents as well as for prevention.

Today we have arrived at a time when we are already feeling the excessive use of our natural resources in a negative way.

A basic motivation of this thesis is to make process safety techniques more widely available and accepted. These tools, often referred to in different contexts as risk management procedures or hazard evaluations, can also be achieved to prevent or evaluate deviations from, for example, climate-friendly or sustainable goals of an operation. It should be noted that an operation, which does not run safely, cannot be sustainable by definition, simply because of the waste or downtime it generates.

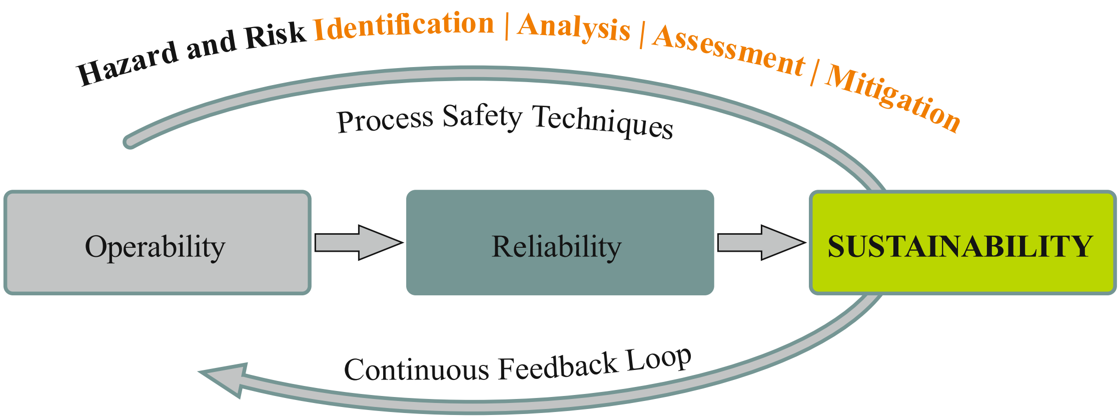

Figure 2: From operability to sustainability

Even though these evaluation tools have gained acceptance in large-scale industry, SMEs still have a lot of catching up to do. Many smaller companies, for example, have had themselves certified or accredited to ISO 9001 or other standards to demonstrate their quality awareness. However, these efforts often do not include concrete techniques or instructions to achieve real improvements in existing processes, but are often simply the fulfillment of formal requirements. The author works for several companies as an external safety officer and notices avoidable risks and easily achievable improvements here on a daily basis. Here is another gap that can be filled with those process safety techniques. It is necessary to evaluate which techniques seem to be the most suitable and how they can be implemented and communicated in the most accepted way.

Of course, process safety is not only based on the techniques used. Process safety requires people who work on and support these processes. This is where risk perception as well as targeted and comprehensible risk communication comes into play in order to be able to pursue the goals of process safety.

A targeted application and acceptance of these techniques can, with correct risk perception, risk evaluation and the implementation of measures, help us to make our working environment more effective, safer and at the same time more sustainable.

Companies need to develop a more holistic way of thinking. Process safety begins in the company and ends in the private sphere. It cannot be in the interest of the company if people get injured in their private lives or, on their way. This could cause them to be absent from the workplace, threatening planned work processes that they influence or which rely on them. The environmental influence concept can also be strengthened via multipliers in the working environment. Incidents such as possible blackouts affect companies and private individuals in a similar way. How do you get to the company? What do you have to do? How do the children get home from school? Can you still communicate electronically?

These and many other process safety issues are there to be dealt with in cooperation with companies and the community in order to strengthen our common resilience.

2 Aim and scope

In the large-scale industry, the military, in nuclear power plants and other high-risk fields, numerous methods and techniques have been developed over the past decades to improve process safety and risk management. These have been continuously developed and combined with each other.

The aim of this dissertation is to evaluate existing procedures and to form approaches for new procedures or the implementation of proven procedures in new areas on a scientific basis. Since most of these process safety techniques can only be mastered by very experienced personnel or at high cost, they are mainly in use in the field of large-scale industries or hazard-prone operations. The aim is to find new techniques or approaches that allow general implementations in small- and medium-sized enterprises in a broad range of applications and improve the safety situation as well as quality, resilience and sustainability. Furthermore, the interactions with other disciplines of technology as well as in the field of human factor evaluation with social sciences, risk communication or training shall be considered. It is not just the techniques that need to be evaluated. A lack of risk perception, communication and training cannot be made up by process safety techniques. Poor communication alone can lead to the failure of a system or operation.

Figure 3: Dilemma - Visibility of the escape route or fire protection?

A small example of a faulty risk perception from an assisted living community illustrates the skewed picture that often exists. The manager of the facility was afraid of an official authority inspection and a possible fine because of a defective escape route light. So, without further delay, existing 100-watt bulbs were used in place of the burned-out 10-watt bulbs, which led to a fire alarm the same day, because smoke from the scorched light, shown in Figure 3, set off the smoke detectors. None of the people involved in the repair were aware that faulty repairs could be a risk. Such risk perception naturally also diminishes risk assessment and is dependent on prior professional training, but also on social factors, attitudes to life and the personal as well as the companies safety culture.

As part of the research to achieve this dissertation, four double-blind reviewed papers, two reviewed conference papers as well as posters and presentations were created, which dealt within the scope of process safety topics or techniques, communication, training, green chemistry and inherent safety as well as emergency response.

The research question is how process safety can be strengthened and generally improved and which influences need to be addressed. Are there process safety techniques that can be implemented in a targeted manner in SMEs and that contribute to an improvement of process safety in these companies?

3 Methodology of this thesis

The starting point for the dissertation research and development is the analysis of the existing literature. In the context of the first paper "Process safety for sustainable applications" [2], the state of technology / state of the art is surveyed by means of literature searches in the relevant search engines. Among them are the search engines Scopus, Elsevier Science, Mendeley, BASE, Semantic Scholar, RefSeek and Google Scholar. The main search terms refer to "process safety", "loss prevention", "risk management", "resilience engineering" and "sustainability". Iteratively influenced by the results, the search is supplemented and extended via literature references from the obtained results.

Figure 4: Search terms for the state of the art search

In the context of the scientific papers and the conference papers and proceedings the search area is extended by terms, which stand in the context of the respective publication. This can be found in the respective papers and includes topics such as "resilience in high hazard activities", "process safety techniques for SMEs", "live agent training", "real world training", "controlled language", "green chemistry", and "inherent safety".

In two of the papers, surveys are conducted among stakeholders and groups of persons to achieve and prove the scientifically based statements, which contribute to the development of better methods and possibilities for implementations. [3], [4]

In the Live Agent Training paper [3] a design science research method is used to iteratively improve training for workers in high hazard situations.

With the help of the different papers within the scope of the dissertation, a framework is to be built around influences that affect process safety, which will support research and the improvement of usability, for example in SMEs.

Another paper reviews and discusses the concepts of green chemistry, green engineering and inherent safety as well as similar conceptual approaches for safety and "greenness" and applies them to the lignocellulosic feedstock biorefinery from the TU Wien (Vienna University of Technology), with the help of a case study. It produces innovative new lignin materials which can be valorized in cosmetic and pharmaceutical products. For a successful economical implementation of the production of new lignin products from a lignocellulosic feedstock the valorization of the rest of the biomass is also crucial.

4 Fundamentals

In order to write about process safety, it must be made clear that this topic is a broad one. It is interdisciplinary and includes several disciplines that are strongly linked to loss prevention, resilience engineering, risk management, reliability management and business continuity management.

For clarification and delimitation a few definitions should serve:

Risk management according to ISO 31000:2018 Risk management - guidelines [5]:

> *"... coordinated activities to direct and control an organization with regard to risk."*

Resilience according to Hollnagel, et al. [6]:

> *"A system is resilient if it can adjust its functioning prior to, during, or following events (changes, disturbances, and opportunities), and thereby sustain required operations under both expected and unexpected conditions."*

Process safety in the interpretation of the CCPS (Center for Chemical Process Safety) [7]:

> *"A disciplined framework for managing the integrity of operating systems and processes handling hazardous substances by applying good design principles, engineering, and operating practices.*
> *Process Safety focuses on efforts to reduce process safety risks associated with processes handling hazardous materials and energies. Process Safety efforts help reduce the frequency and consequences of potential incidents. These incidents include toxic or flammable material releases (loss events), resulting in toxic effects, fires, or explosions. The incident impact includes harm to people (injuries, fatalities), harm to the environment, property damage, production losses, and adverse business publicity."*

All of these disciplines, and also the methods and techniques associated with them, have the common goal of identifying and mitigating hazards and the resulting risks. This means working resiliently with a reliable system, with acceptable or tolerable risks.

The influences that are prevalent in these error reduction strategies are diverse and are usually analysed and evaluated by several experts. A simplified representation of the influencing factors can be presented using the 10 M method, which is shown in Figure 5.

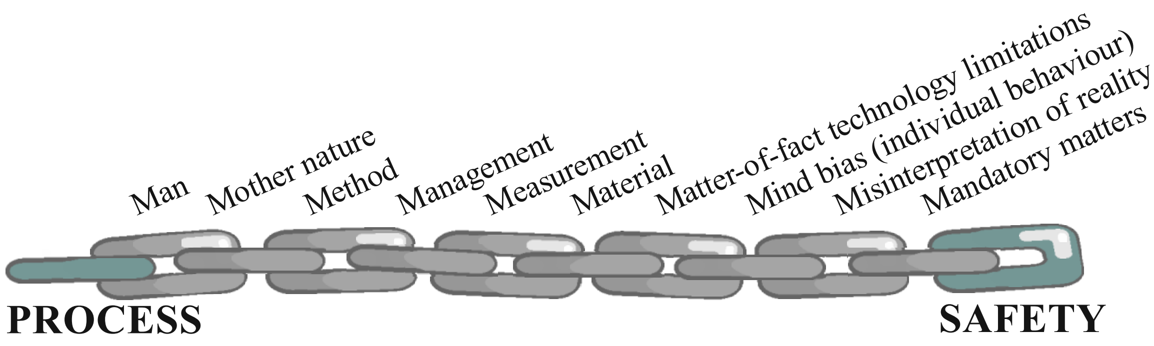

Figure 5: 10 M for process safety

The Occupational Safety and Health Administration of the United States of America (OSHA) has proposed 14 main process safety influences in its standard 1910.119 - Process safety management of highly hazardous chemicals. [8] These are shown in Figure 5. In addition to traditional process safety issues, they also include topics such as trade secrets and contractors.

- Employee participation
- Process safety information
- Prozess hazard analysis
- Operationg procedures
- Training
- Contractors
- Pre-startup review
- Mechanical integrity
- Hot-work permit
- Management of change
- Incident investigation
- Emergency planning and response
- Compliance audits
- Trade Secrets

Figure 6: 14 key elements of U.S. OSHA Process Safety Management [8]

In the field of accident analysis, the so-called Swiss Cheese Model, which was postulated by James Reason, has proven itself over the years. [9]–[12] It is a pictorial representation of influences, latent and active human errors, but also system errors whose concatenation leads to a negative event. The figurative depicted cheese slices with holes represent barriers to prevent the system from being affected negatively. However, as in real life, these barriers have weak points, which are represented by the holes in the cheese. In combination with several holes, a hazard can penetrate these barriers. Latent errors include management errors, which in combination with unsafe actions of individuals can lead to system failure. Of course, it must be noted that this picture of accident causation is limited and represents only a highly simplified part of the reality. As Reason himself also stated: *"The pendulum may have swung too far in our present attempts to track down possible errors and accident contributions that are widely separated in both time and place from the events themselves."* [13] Despite this limitation, the model can be used well for overviews or training purposes, because it is easy to understand and descriptive.

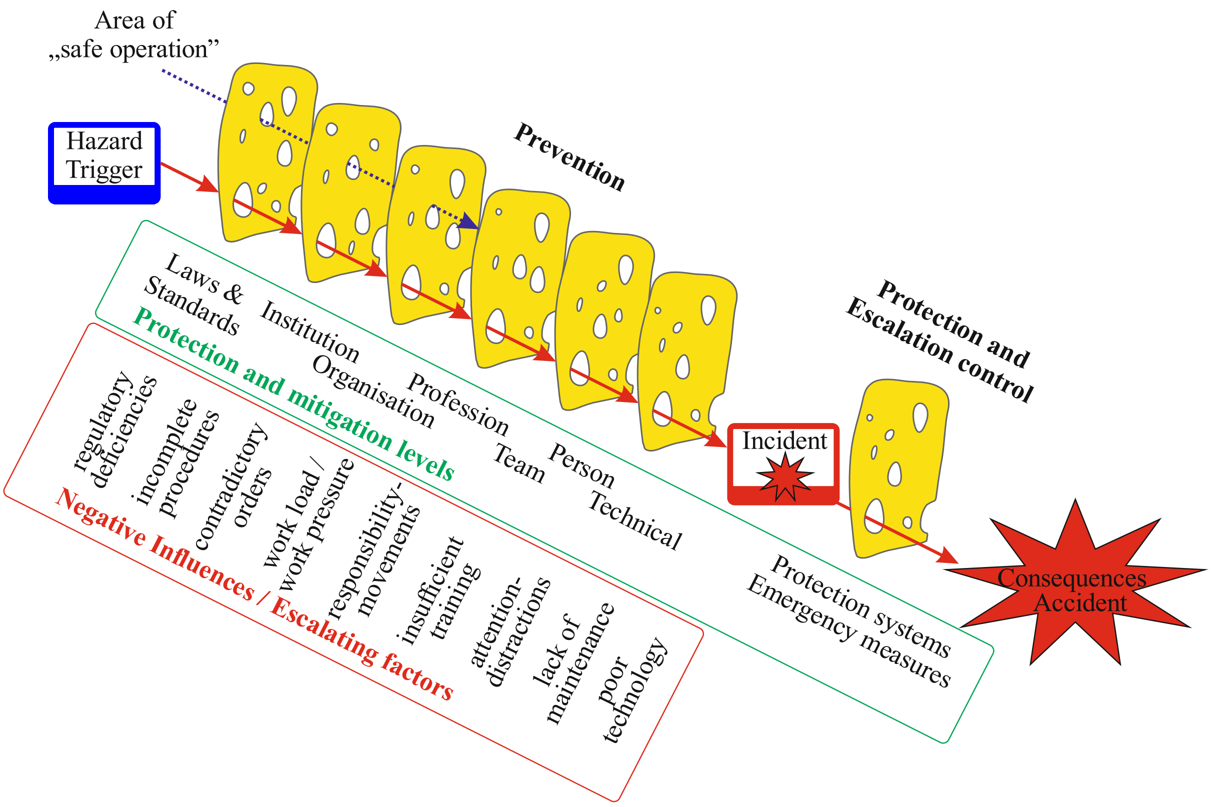

Figure 7: Swiss Cheese Model after reason. Source: Stolar, Friedl [4]

Both the simplified model shown in Figure 5 and Figure 7 illustrate the wide variety of influences that affect process safety. In the following, some essential factors or so-called safety principles that are usually considered in process safety are listed and presented in detail in the following subchapters.

Some safety principles and influences collected from different sources [14]–[22] are summarised as follows:
Safety barriers, factors and margins of safety, experience and feedback, risk and safety indicators, human factors, risk communication, risk perception, safety automation, precaution, SOPs, human-machine interaction, quality principles, safety cases and learning from accidents, safety culture, inherent safe design, maintenance and inspections, standards and regulations, external hazards, quantitative & qualitative risk analysis and techniques, cost-benefit, reliability methods, ALARA & BAT principles, behaviour-based safety, emergency plans and crisis management, and managing the unexpected.

Process safety in practical application is a complex interaction of all these areas and influences!

4.1 Controlled language

Language is the basis for purposeful communication, but it can also become a source of errors in the case of ambiguity or inaccurate interpretation.

Many serious accidents like the Tenerife airport disaster or a severe chlorine gas release [9], [23]–[26] can be traced back to ambiguities in the language. For this reason, the military and also the air traffic have soon relied on a so-called controlled language. Also the industry is more and more using a controlled language, because of safety and the translatability is simplified too. [27]–[31]

In the field of risk management and process safety, it is important to be precise when formulating the approaches and limits of a system or requirement.
The author has experienced it himself, when he carried out a FMEA (Failure Mode and Effect Analysis) together with colleagues, that 2 teams examined the same components, but two different functions of the components. The statement of work was not clear.
It is not only that tasks can be understood differently, they can also lead to unintended results or gaps in safety planning. Therefore, it is important to use controlled language early in the work as part of analyses and definitions. Controlled language is characterized by a vocabulary that is not ambiguous and therefore also prohibits words. For example, the word "run" can have fifty-seven different meanings in English. [23], [32]–[34] Controlled languages use restricted grammar rules and vocabularies to reduce or eliminate ambiguity and complexity. For the benefit of non-native speakers and readers, they are often used to simplify technical communication.
An example of a controlled language is the ASD-STE100 Simplified Technical English (STE). [35]

Some rules for controlled languages are: [35]

- Use approved words
- Write short and grammatically simple sentences
- Use nouns instead of pronouns
- Use determiners
- Use active instead of passive

Examples of non-approved writing and approved writing are:

- Non-STE: The indicator light turns red.
- STE: The color of the indicator light turns to red.

- Instead of "exceed" - "more than" should be used
- Non-STE: Ensure indication does not exceed 400 kilograms.
- STE: Make sure that the indication is not more than 400 kilograms.

- Non-STE: Perform a leak test before start.
- STE: Before start, do the leak test.

Controlled language can be helpful in different scenarios of communication. This can be e.g. safety communication, consensus communication and crisis communication. These are different applications for different audiences. A simple and clear language can promote common understanding. [36]–[41]
Standard operation procedures and work permits should be written by using a controlled language. [34]

4.2 Process safety techniques

Over the decades especially since about 1950, many different process safety or hazard analysis, and risk management types and techniques have developed. In the beginning, the military used such techniques to make weapon systems safer. Followed by the process industry's loss prevention techniques, designed to make processes more efficient and safer. Next to the techniques, the analysis types refer to the stage of development in which the analysis takes place. For example, in the concept stage, in the final design stage or in the operational stage. Often the decommissioning is taken into account, because in the example of nuclear power many parameters have to be considered due to the dismantling and disposal of radioactive parts. The process safety techniques are used in the respective phase to identify and evaluate the hazards and risks, as well as their effects, in order to take appropriate measures. Process safety techniques should monitor the requirements for technical systems as well as organizational systems in a structured, hierarchical manner.

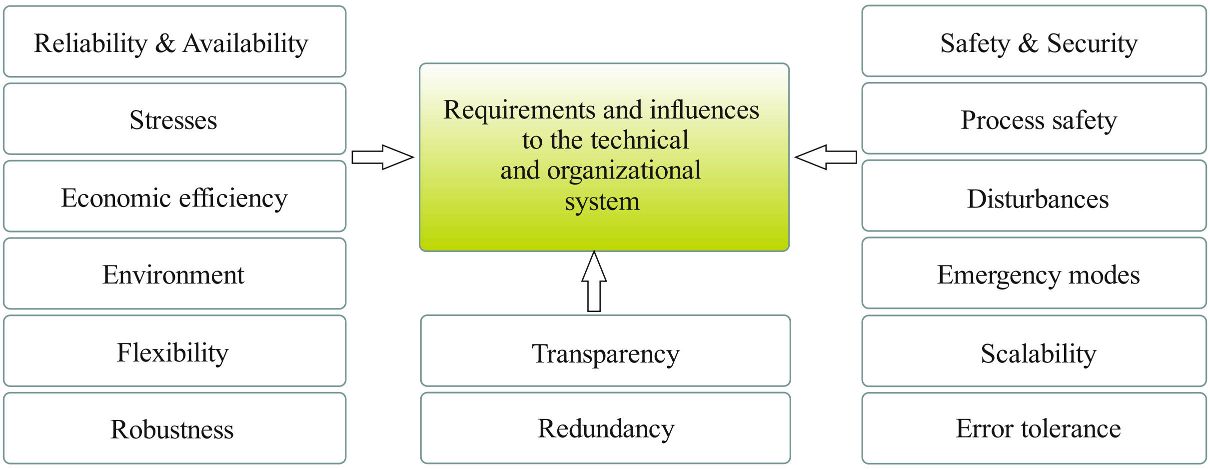

Figure 8: Some requirements and influences on technical and organizational systems

Table 1 shows a selection of techniques that are widely used internationally and which are included in the ISO 31000 - Risk management [5]. There are many 100 techniques in the literature, which are variations or combinations of about three dozen techniques, which are shown in Table 1: Process safety techniques; Adapted from: Stolar & Friedl [4]. [2], [5], [48]–[53], [12], [19], [42]–[47]

Table 1: Process safety techniques; Adapted from: Stolar & Friedl [4]

Tools and Techniques	Risk Assessment Process					Included in ISO 31010
	Risk Identification	Risk Analysis			Risk Evaluation	
		Consequence	Probability	Level of Risk		
Brainstorming (What if)	SA[1, 2]	NA[1], A[2]	NA[1],A[2]	NA[1]	NA[1, 2]	ISO
Structured or semi-structured interviews	SA[1]	NA[1]	NA[1]	NA[1]	NA[1]	ISO
Delphi	SA[1, 2]	NA[1], A[2]	NA[1], A[2]	NA[1]	NA[1, 2]	ISO
Checklists	SA[1, 2]	NA[1, 2]	NA[1, 2]	NA[1]	NA[1, 2]	ISO
Primary or Preliminary hazard analysis (PHA)	SA[1, 2]	NA[1], A[2]	NA[1],A[2]	NA[1]	NA[1, 2]	ISO
Hazard and Operability Studies (HAZOP)	SA[1]	SA[1], A[2]	A[1], A[2]	A[1]	A[1],NA[2]	ISO
Hazard Analysis and Critical Control Points (HACCP)	SA[1]	SA[1], A[2]	NA[1], A[2]	NA[1]	SA[1], A[2]	ISO
Environmental risk assessment	SA[1]	SA[1]	SA[1]	SA[1]	SA[1]	ISO
Structured What if Technique (SWIFT)	SA[1, 2]	SA[1], A[2]	SA[1], A[2]	SA[1]	SA[1], NA[2]	ISO
Scenario analysis	SA[1]	SA[1]	A[1]	A[1]	A[1]	ISO
Business impact analysis	A[1]	SA[1]	A[1]	A[1]	A[1]	ISO
Root cause analysis (RCA)	NA[1]	SA[1]	SA[1]	SA[1]	SA[1, 2]	ISO
Failure mode effect analysis (FMEA)	SA[1, 2]	SA[1], A[2]	SA[1], A[2]	SA[1]	SA[1], A[2]	ISO
Failure mode effect and criticality (FMECA)	SA[2]	A[2]	A[2]		SA[1]	
Fault tree analysis (FTA)	A[1, 2]	NA[1, 2]	SA[1, 2]	A[1]	A[1],NA[2]	ISO
Event tree analysis (ETA)	A[1, 2]	SA[1], A[2]	A[1], SA[2]	A[1]	NA[1, 2]	ISO
Cause and consequence analysis (CCA)	A[1, 2]	SA[1,2]	SA[1, 2]	A[1]	A[1], NA[2]	ISO
Cause-and-effect analysis	SA[1]	SA[1]	NA[1]	NA[1]	NA[1]	ISO
Layer of protection analysis (LOPA)	A[1], NA[2]	SA[1], A[2]	A[1], SA[2]	A[1]	NA[1], SA[2]	ISO
Decision tree	NA[1]	SA[1]	SA[1]	A[1]	A[1]	ISO
Human reliability analysis (HRA)	SA[1]	SA[1]	SA[1]	SA[1]	A[1]	ISO
Bow tie analysis	NA[1], A[2]	A[1, 2]	SA[1],A[2]	SA[1]	A[1, 2]	ISO
Reliability centered maintenance	SA[1, 2]	SA[1, 2]	SA[1, 2]	SA[1]	SA[1],A[2]	ISO
Sneak circuit analysis	A[1]	NA[1]	NA[1]	NA[1]	NA[1]	ISO
Markov analysis	A[1]	SA[1]	NA[1]	NA[1]	NA[1]	ISO
Monte Carlo simulation	NA[1, 2]	NA[1],SA[2]	NA[1],SA[2]	NA[1]	SA[1],NA[2]	ISO
Bayesian statistics and Bayesian Nets	NA[1]	SA[1]	NA[1]	NA[1]	SA[1]	ISO
FN curves	A[1]	SA[1]	SA[1]	A[1]	SA[1]	ISO
Risk indices	A[1]	SA[1]	SA[1]	A[1]	SA[1]	ISO
Consequence/probability matrix	SA[1]	SA[1]	SA[1]	SA[1]	A[1]	ISO
Cost/benefit analysis	A[1]	SA[1]	A[1]	A[1]	A[1]	ISO
Multi-criteria decision analysis (MCDA)	A[1]	SA[1]	A[1]	SA[1]	A[1]	ISO
TESEO	SA[2]	SA[2]	SA[2]	SA	SA[2]	-
Reliability, availability, maintainability analysis (RAM)	SA[2]	SA[2]	SA[2]	SA	A[2]	-
Quantitative risk assessment (QRA)	A[2]	SA[2]	SA[2]	SA	SA[2]	-
Risk matrix / ALARP	NA[2]	NA[2]	NA[2]	A	SA[2]	-
Pre-startup safety review	SA[2]	A[2]	A[2]	A	SA[2]	-

SA…Strongly applicable; NA…Not applicable; A…Applicable; [1]: [54]; [2]: [55]

The techniques are variously applicable with different objectives. Some are for the mere detection of hazards, others side for the calculation of a risk. Some techniques are simple and easy to learn, others require hard-to-obtain long-time data and computer simulations. As can be seen in the Table 1, different sources view applicability differently.

While simple techniques can be widely used, SMEs often find them unfeasible to use due to staffing, training and cost requirements.

As Stolar and Friedl show [4], the acceptance towards many techniques would be very high, but there is a lack of time and resources for the implementation. A common deficiency is also the flawed or diminished risk perception of "We don't need this." [4]

Many techniques are nearly similar but differ due to the origin. Many inductive techniques attempt to explore and evaluate possible outcomes of a scenario. Others deductively try to reproduce an accident, for example, to generate data and experience for the future and to make future systems or applications safer.

With regard to the naming of the techniques in internationally relevant standards, it should be noted that these techniques, referred to here as process safety techniques, are also mentioned in other groups of standards as risk management methods, resilience management methods, reliability methods, or procedures and analyses. Unfortunately, there is no direct common language, which brings us back to the controlled language topic.

Translations from English into other languages often result in strange variations of names for these techniques, which cannot be retranslated into English. It is recommended to use the English versions of standards such as the ISO standards for research and international cooperation. Thus, in non-English language standards, techniques can be found which are only recognizable on closer examination of the procedure, but not on the basis of the name.

The different methodologies can be applied to different problems. The level of detail is also different. For example, certain mathematical methods, especially quantitative ones, cannot be used if data or the level of detail of a process to be evaluated has not yet been determined. [55]

What these techniques have in common is that they are usually used in a comprehensive interaction between risk identification, risk analysis, risk assessment and risk mitigation.

Figure 9: The interaction of the different tasks of process safety

- Risk identification is the process of finding hazards and deviations, as well as their causes, which can lead to a possible loss of control and damage.
- Risk analysis determines the extent of damage or the categories of economic or other consequences. Semi-quantitative or quantitative calculations of the probability of occurrence of scenarios can be performed here. The prerequisite is a fully controlled process and experience with the process, as well as necessary statistical data.
- Risk assessment evaluates the risk in combination with the probability of occurrence and the extent of damage in relation to an acceptable or tolerable risk. It is about the appropriateness and the urgency of measures.
-

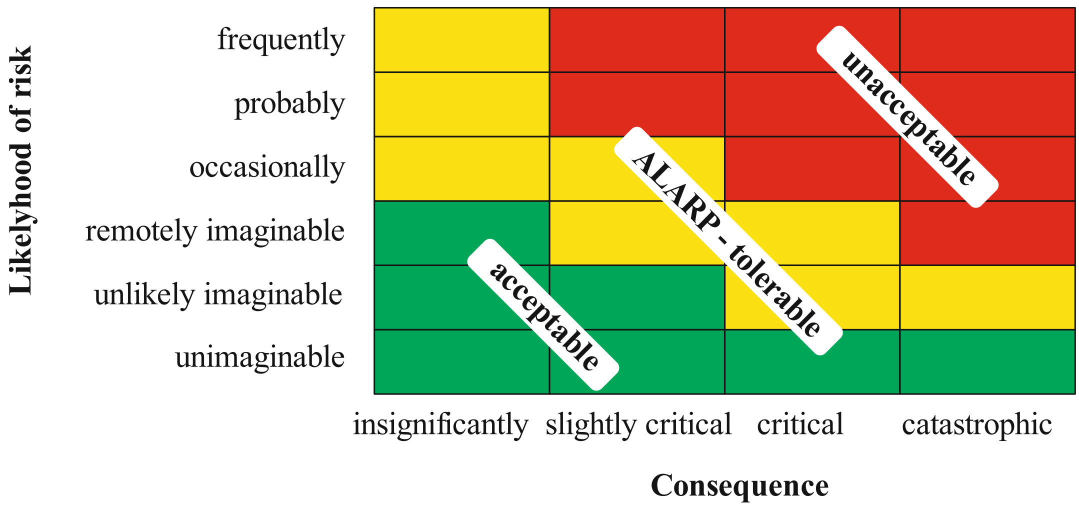

Figure 10: Risk matrix

The risk matrix shown in Figure 10 is an example of an assessment aid. The matrix can have many more gradations. However, the classical ones are usually 4x4 or 5x5. Thus, in some techniques, several independent matrices are used to make an assessment. For example, in an FMEA, two matrices are used with the properties "severity of failure to probability of occurrence" as well as "severity to probability of detection of the cause".

- Risk mitigation is about reducing the impact of potential risks by developing a plan to manage, eliminate, or limit as much as possible risks and their potential impact.

All these levels are in a feedback loop and influence each other.

Regarding the wording, the terms used are often substituted with the term hazard instead of risk, whereby it should be noted that the exact definition of

Risk = Hazard • Probability of Occurrence.

While common checklists are often used because of their simplicity, other visual process safety techniques for improving safety are available. Two examples in Figure 11 and Figure 12 are the FTA (Fault tree analysis) [21], [56]–[58] and the Bow-tie analysis [59]–[64]. While the first graph represents a logical flow with deterministic conditions, the bow-tie analysis attempts to represent a graphical flow with a barrier management. Compared to textual methods, a bow-tie analysis has the advantage that, if a barrier fails, it can be recognized visually which one is still intact.

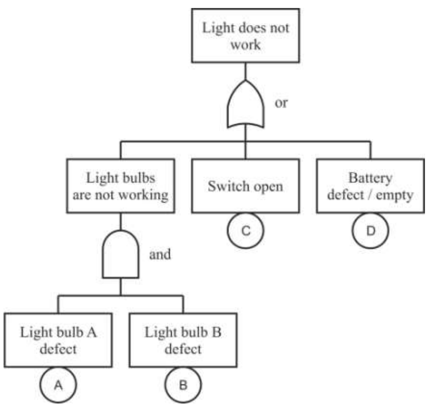

Figure 11: FTA - Fault tree analysis

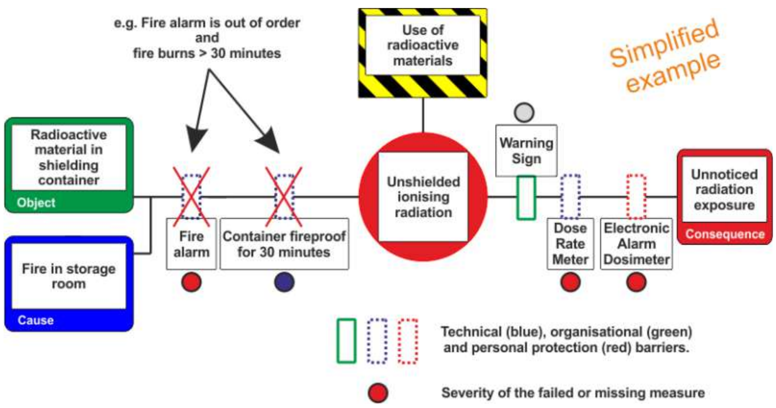

Figure 12: Bow-tie analysis, Source: Stolar [65]

The fault tree analysis (FTA) in Figure 11 shows the possibility of failure of an emergency lighting lamp, for example. It shows the possibilities that it fails. Light bulb A (A) and B (B) are redundant. The failure of one lamp does not cause a complete failure. However, if both lamps fail or are switched off (C), or the battery fails (D), this will result in a complete failure of the light. Such a fault tree analysis can be performed both qualitatively as in the picture, but also quantitatively. If the necessary reliability data is available, for example from manufacturers or through experience, failure probabilities can be inserted and calculated.

The bow-tie analysis in Figure 12 deals with the storage or use of a radioactive source. A fire releases unattenuated radiation through a container defect and exposes a person, present on site. As safety barriers to prevent the container from being destroyed by fire, there is an early fire detection system (smoke detector with fire alarm) and the container is also fire resistant for 30 minutes.

Assuming that the fire cannot be successfully extinguished within 30 minutes, a release of unattenuated radiation may occur. This would have the consequence that persons can be exposed to ionizing radiation unnoticed. To prevent this, there is a radiation warning sign at the entrance to the room as an organizational measure. In addition, a dose rate meter and an alarm dosimeter must be used when entering the room. The two measuring devices are in a certain sense a redundant safety. Even if one device fails, the other will still detect the increased radiation level and protection measures can be taken.

Another approach is the HAZOP (hazard and operability analysis). It tries to find deviations in node points or systems based on a process flow chart. For this purpose keywords from a controlled vocabulary are used and the possible deviations are considered. E.g. "NO flow in the cooling liquid line". A goal is to recognize, where these deviations could come from, what are the consequences and how can they be mitigated or prevented. [21], [66]–[69]

Table 2: HAZOP example

Node	Guide Word	Element	Deviation	Possible causes	Consequences	Safeguards	Comments	Actions required	Action allocated to
3.1.2.	NO	Cooling liquid (water)	NO cooling liquid flow	Cooling liquid reservoir 1 empty	Overheating and explosion. Release of product into the environment.	None shown	Situation not acceptable	Installation of a low-level-alarm in reservoir 1 and a temperature sensor with emergency shut down or overpressure-release in vessel 2.	Mr. XY

The HAZOP analyzes the chain of events in both directions (cause and consequences). The FMEA, which is very similar to the HAZOP, only searches for unknown effects ("bottom-up") for an assumed cause. The FMECA (Failure Mode Effects and Criticality Analysis) extends the FMEA to include concrete failure rates, instead of a subjective assessment.

The AcciMap approach combines a graphical representation of an accident causation in the context of the persons, entities and influences involved. It is well suited for accident analysis and serves as an illustrative example of a failure in a socio-technical system.
Socio-technical systems (STS) are an approach to the design and analysis of complex organizational work but also to the analysis of incidents that takes into account the interaction between people and technology at different levels.

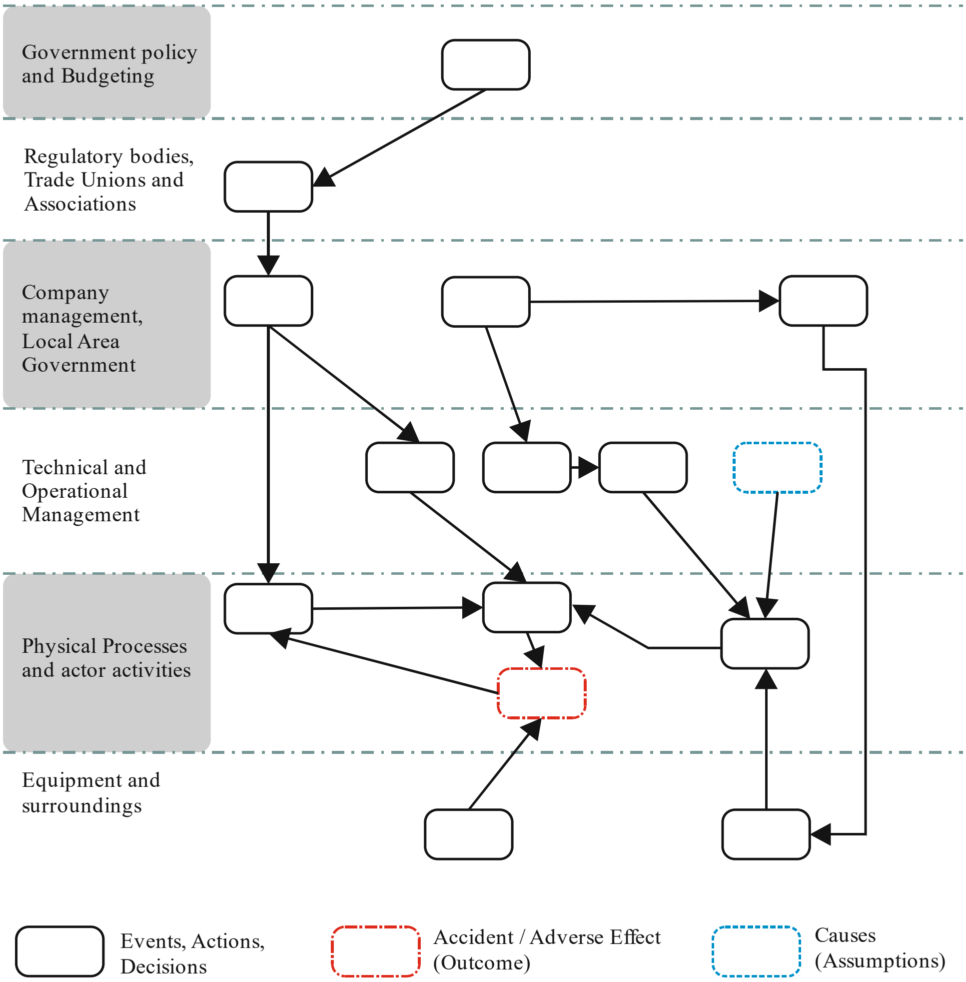

Figure 13: AcciMap

Many more techniques and their practical application can be found in the attached papers. [2], [4], [65] Also examples, where the application of process safety techniques is used to obtain or ensure more sustainability. For example, the Green HAZOP is used to evaluate deviations in processes with regard to sustainability. [2], [70] There are a number of other techniques, but they depend on data and are more commonly used in large-scale industry or electronic components.

- The goal in using Markov chains is to give probabilities for the occurrence of future events. Markov chains are suitable for modeling random state changes of a system, if one has reason to believe that the state changes only influence each other over a limited period of time.
- A Bayesian network is a graphical model that shows a set of variables and their dependencies. A Bayesian network can be used to predict from an event that has occurred the probability that one of several known causes is responsible for it.
- A Monte Carlo simulation (computer simulation) is a model used to predict the probability of a variety of outcomes of events. Monte Carlo simulations help explain the effects of risk and uncertainty in predictive and forecasting models.

4.3 Risk perception, mind-bias and safety culture

Safety culture is first described by Zohar [71] around 1980 and defined in the IAEA report on the Chernobyl disaster [72].

But what is safety culture? It is an interplay of personal behaviour, personal risk perception, organizational culture, cultural influences and management. And a fragile interplay within an organization. [73]–[78]

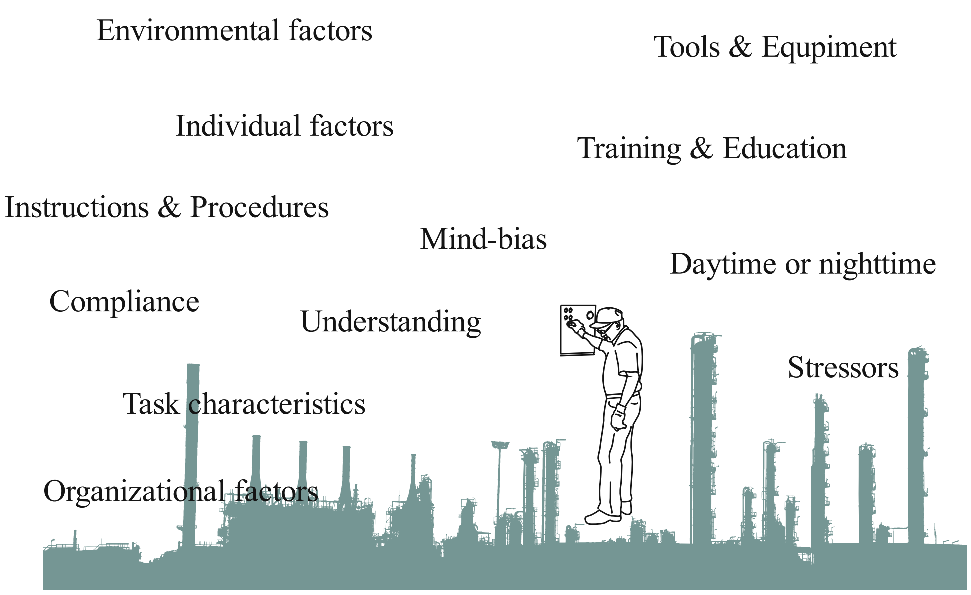

Figure 14: Examples of influencing factors on personal safety culture

Personal risk perception is influenced by the personal environment, personal background and the social structure. [79]–[83] There are different types of risks we experience: Actual risk refers to the objectively quantifiable aspects of risk. This includes aspects such as the probability, the impact, and the severity of an occurrence. Perceived risk is a subjective assessment of the individual. [84]–[86]

Thus, mismatches in risk perception often exist. Many fear nuclear power and possible nuclear accidents, but are dauntless heavy smokers. It is a personal faulty estimation of risk. The fact that smoking brings multiple hazards and risks does not need to be described in detail here and can be read about. [87]

Strengthening the safety culture requires interaction within the company. Studies have shown that a visible safety culture, e.g. with slogans, already contributes to the joint action.

Figure 15: The "other" safety slogan concept

A positive contribution to improvement is also provided by an open culture of discussion about improvements and the review of incidents. In many companies, small mishaps are simply swept under the table. "Nothing happened." The right way would be to report and clarify the incident in order to learn from it and create improvements to avoid dangers and minimize risks. [73], [88], [97]–[104], [89]–[96]

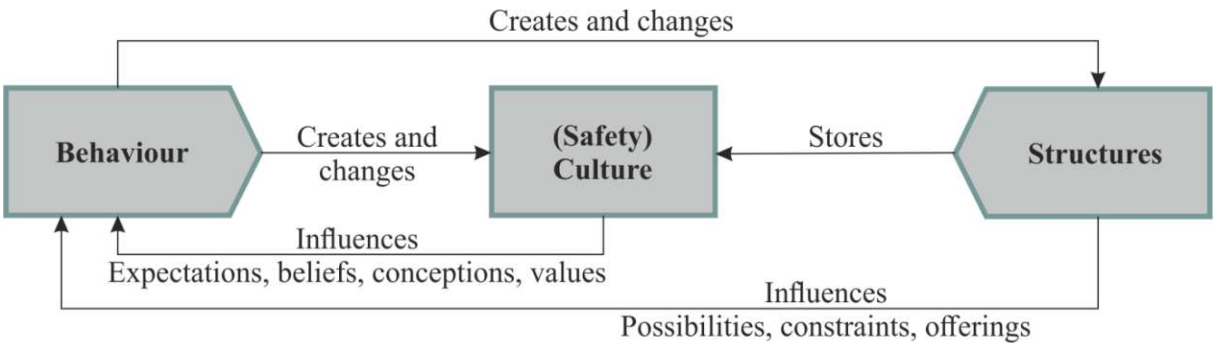

Figure 16: Overview on the nature of safety culture. Modified from Möller, et al. [105]

Safety culture must be an iterative process. It must not hinder work, but feedback must flow in regularly. Rigid guidelines that only prescribe and "allow nothing" quickly lead to intentional deviations in execution. In other words, deliberate violations, which imperatively must be avoided.

As part of the safety culture, it is also important to create practicable work instructions. Many SOPs in companies are created at the desk to fulfill a quality management measure, but are not or only partially used in reality due to non-feasibility. [106]–[109]

Targeted training and feedback helps to identify and improve this problem in SOPs. It creates more acceptance and safety culture and thus safety. [106]

4.4 Some triggers of process safety

Accidents in the workplace have resulted in many losses, damages, injuries, deaths and suffering. Therefore, continuous work has been done to improve safety. In its initial stage for loss prevention, then for the protection of assets, the protection of people and the environment. While this process logically contributes to improvement, there were many accidents that have contributed to a more crucial improvement or a change in thinking. This rethinking was usually accompanied by regulatory requirements.

Accidents happen! But why do accidents happen? Accidents happen due to a multitude of influences. In the following, a few accidents with triggers and consequences will be presented, which have a lasting influence on the landscape of process safety.

But even accident research and process safety thinking often reach their limits. Many accidents, some with catastrophic consequences, turn out to be a series of highly improbable correlations. There are the "black swans". The black swan theory is a metaphor that describes an event that occurs unexpectedly, has major consequences, and is often inappropriately rationalized after the fact. No one expected anything like this, it was unpredictable.
Examples would be the nuclear accident in Fukushima or the airplane attacks on the World Trade Centre on September 11, 2001 known as "9/11" in New York. [110]–[112]

The Dragon King (DK) theory is a dual metaphor for an event that is both extremely large or powerful ("king") and has a unique origin ("dragon"). A Dragon King is triggered by an unique event and amplified by a variety of random independent influences. It is not predictable. The magnitude can be described as catastrophic.
Examples of Dragon kings would be asteroid impacts leading to extinction. Some sources also describe the Chernobyl nuclear power plant accident in 1986 as a Dragon King. [111]–[113]

Many reasons led to countless accidents. From neglected work procedures, missing permits, incomprehensible communication, design flaws, material defects to human error, many reasons have led to serious accidents. In the following, a few excerpts will be presented.

<u>Blind operation: The Tenerife accident in 1977.</u>

Fog and miscommunication claimed a total of 583 lives in 1977. An airplane in the regular take-off procedure in Tenerife and an airplane, which wanted to take-off accidentally, collided. The accident was caused by faulty or misunderstood communication between the tower and the pilots. The "ready for take-off" and the "clearance for take-off" were misunderstood. A clarifying radio message was not understood due to interferences. The aircraft took off and collided with another. Due to the fog they couldn't see each other. This incident was a significant one for the introduction of controlled language in air traffic. [9], [18]

Figure 17: The wreckage of Pan Am flight 1736 burns at Tenerife Airport

Source: Bureau of Aircraft Accidents Archives

https://admiralcloudberg.medium.com/apocalypse-on-the-runway-revisiting-the-tenerife-airport-disaster-1c8148

Design problem: The Bhopal methyl isocyanate release in 1984

The Bhopal disaster occurred on December 3, 1984, in Bhopal, India. Maintenance work was taking place at the time of the accident. In the course of cleaning work, through an unfortunate chain of events as well as failures in the maintenance of the plant, water was filled into a tank with methyl isocyanate (MIC). An exothermic reaction occurred, increasing the pressure inside the tank and causing between 25 and 40 tons of methyl isocyanate and other reaction products to escape into the atmosphere through the pressure relief valves. A separate cooling system had been installed to safeguard the storage of the MIC, but this had been switched off unknowingly about five months before the accident. Gas washers were not functional, but even if they had been functional, they would not have been able to prevent the accident due to faulty sizing. Maintenance was neglected and stainless steel parts were replaced with ordinary steel. Disaster plans did not exist.

Estimates of casualties range from 3,800 to 25,000 dead from direct contact with the gas cloud and up to 500,000 people injured, some of whom are still suffering from the consequences of the accident today. [61], [114]–[116]

In the wake of the Bhopal and Seveso accidents, safety standards were tightened internationally.

Figure 18: Tank at Bhopal

Source: https://www.thewhatis.org/what-was-bhopal-gas-tragedy-in-1984-worst-industrial-disaster/

Maintenance and management of change problems: Flixborough explosion in 1974.

The Flixborough explosion impacted the chemical plant in Flixborough, England, on June 1, 1974, killing 28 people and seriously injuring 36.

The reason for the disaster was a hasty change in equipment. A bypass line was installed for a repair. However, this was not calculated and dimensioned according to design standards and was not made out of the correct material. The managers who approved the change overlooked the technical problems, and the severity of the potential consequences of failure were not considered. The bypass line ruptured and released 40 tons of cyclohexane, which ignited as it escaped, causing a huge explosion. [18], [114], [117], [118]

The Flixborough case led to a widespread public outcry about industrial safety of plants.

In Europe, the Flixborough disaster and the Seveso disaster in 1976 led to the development of the Seveso Directive in 1982 (current: Seveso-III 2012 Directive 2012/18/EU). [119]

Figure 19: Flixborough explosion

Source: https://www.scunthorpetelegraph.co.uk/news/flixborough-disaster-anniversary-new-pictures-85880

Figure 20: Flixborough explosion - aerial view

Source: https://www.sheilds.org/flixborough-40th-anniversary/

The series of accidents can be extended to the most diverse areas. It is important to clarify and reappraise these incidents and learn from them. This knowledge should predominantly also flow into the area of education. Every chemist, process technician, mechanical engineer, but also the executing companies must be aware of the mistakes of the accident and must know them to be able to avoid them in the future. [18], [92], [115], [120]–[125]

4.5 Ageing, Inspection, Management of Change and Maintenance

The degradation of systems and processes is a topic of great concern to the author. It has a major influence on process safety during normal operations. No distinction is made here between technical or organizational systems.

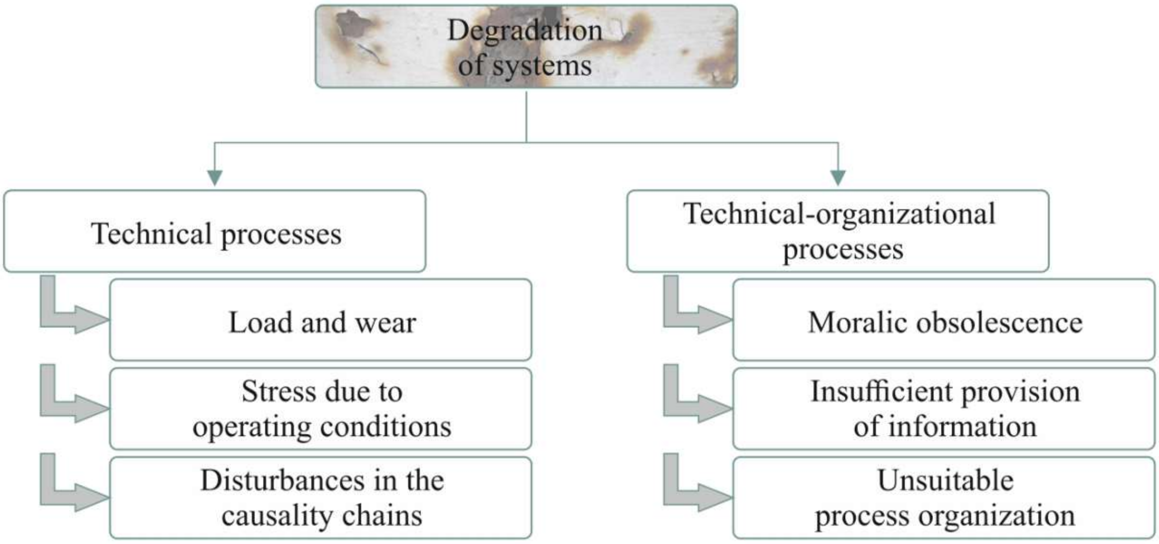

Figure 21: Degradation of systems

Degradation as shown in Figure 21 occurs in systems and technical equipment due to simple aging, wear, changes in process parameters, repairs, modifications and many other factors. [2], [126], [127]

But organizational systems also degrade. Standard operation procedures are written at a point in time. From this point on, they are subject to change management, which, for example in a QM-certified (quality management system certified) company, should detect and improve deviations through immediate changes in case of adaptations or when noticed at regular Plan-Do-Check-Act checks. Often, instructions are written redundantly and changes are not adopted in the redundant documents. The state of the art and standards can change, as can task assignments, last-minute changes in shift schedules, and even workflow improvements can lead to organizational deterioration if not properly represented or communicated. The creeping onset of operational blindness among employees can also be mentioned here.

All this leads to aging or deterioration in systems and to degradation of performance and safety.

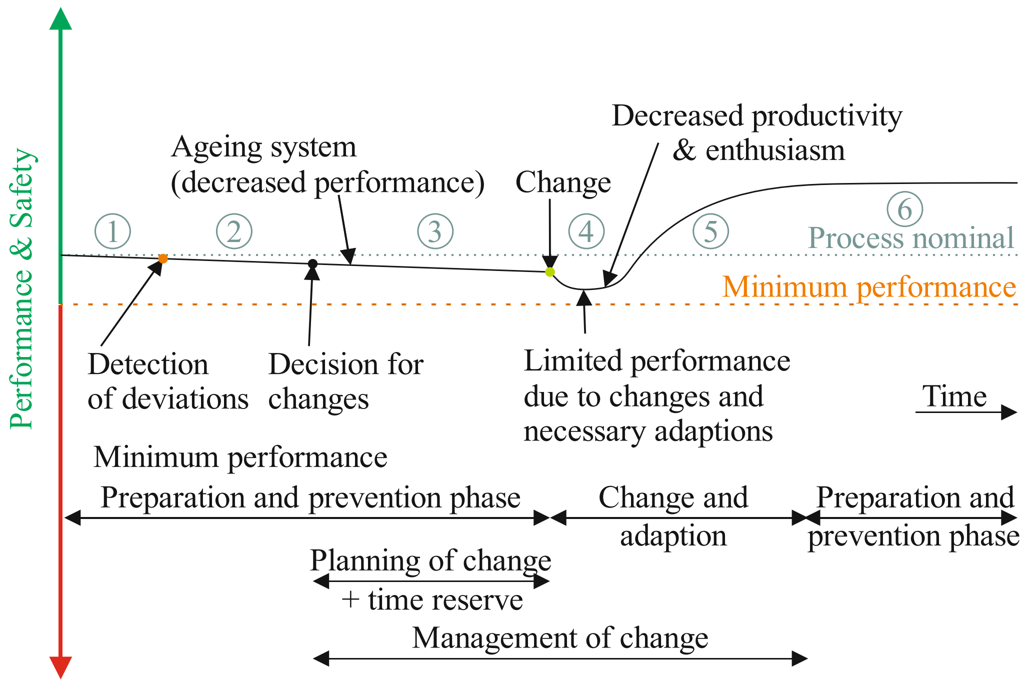

Figure 22: Performance degradations and changes in systems

Figure 22 describes an exemplary change to a system in terms of performance and safety. In time period 1, an unnoticed degradation of the system occurs. In time period 2, a deviation is detected and observed. Time period 3 describes the planning of the change. Here, the deviations are reacted to proactively. An adaptation and improvement is prepared. Beginning with the change in time period 4 a deterioration of the performance can occur. Systems must first start up again. This can be caused by running-in of components but also by interaction with other components or changes. The system must first settle in. In time period 5, the most difficult hurdles in the start-up process have been overcome and the control recovery to a process nominal value works well. In period 6, the system has been run in and has also improved its performance compared to period 1.

The statements of deviations or deteriorations described in this chapter are mainly related to the "operational period" of a system as shown in
Figure 23.

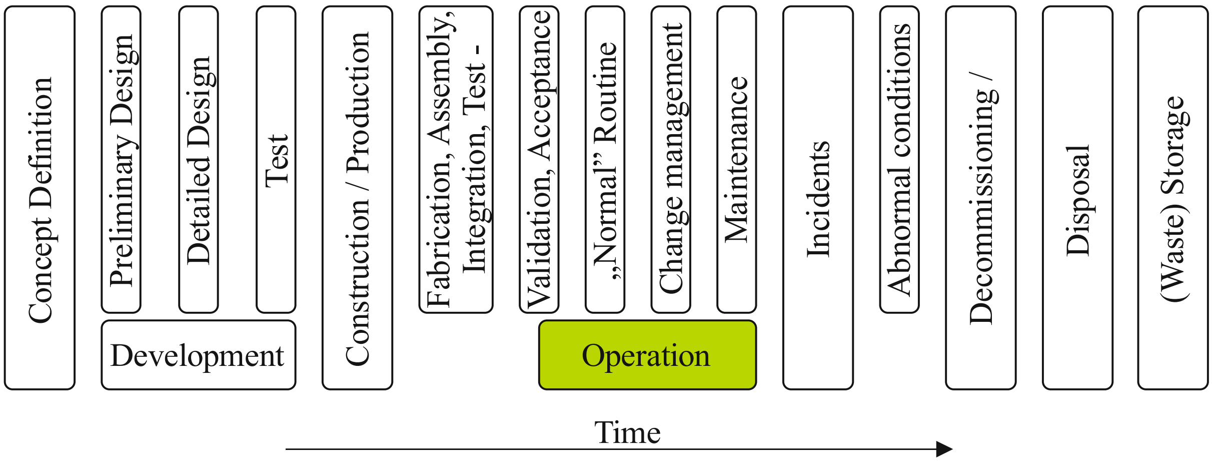

Figure 23: Life cycle periods of a system. Adapted from Stolar, Friedl [2]

Assets and equipment are subject to varying extents of regulated maintenance and inspection intervals. These can be of a legal regulatory nature, such as those imposed by government agencies or laws. But maintenance requirements from manufacturers are also possible. The portfolio ranges from regular maintenance to predictive maintenance or risk-based inspection. [17], [128]–[132]

Companies and organizations are well served if they not only maintain and inspect their machines and systems correctly, but also regularly check their documents such as work instructions or checklists. It happened to many companies or organizations that instructions that are rarely used lead to deviations from the nominal when they are applied. Both on the plant side and in the area of deviations, for example, from well-intentioned, wilful, unacceptable improvements. That is why instructions must be tested. [106]

A good equipment example that is often used to illustrate unrecognized deterioration is the classic hard hat like in Figure 25 in companies. In some companies, it is only very rarely needed for certain tasks, such as crane work, and is always hanging in the wardrobe. It is "unused and like new" for many years.

However, UV radiation, temperature influences, possible cleaning agents and aging also affect the plastic. Therefore, this helmet must also be replaced regularly when not in use. A help about the production date gives the so-called casting clock.

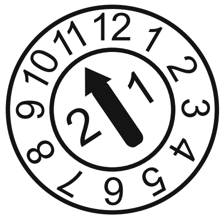

Figure 24: Casting clock

Figure 25: Hard hat

The casting clock in Figure 24 or other markings indicate the date of manufacture or the period of use. In this case it indicates a production in November 2021. In addition, the operating instructions apply as an aid to control.

Vaughen & Klein [133] aptly described this matter of fact with the title of the paper, "*What you don't manage will leak ...*"

5 Publications summary

The publications range over the field of process safety, the application of process safety techniques and influences such as controlled language or training of personnel in various industries, as well as green chemistry, sustainability and resilience.

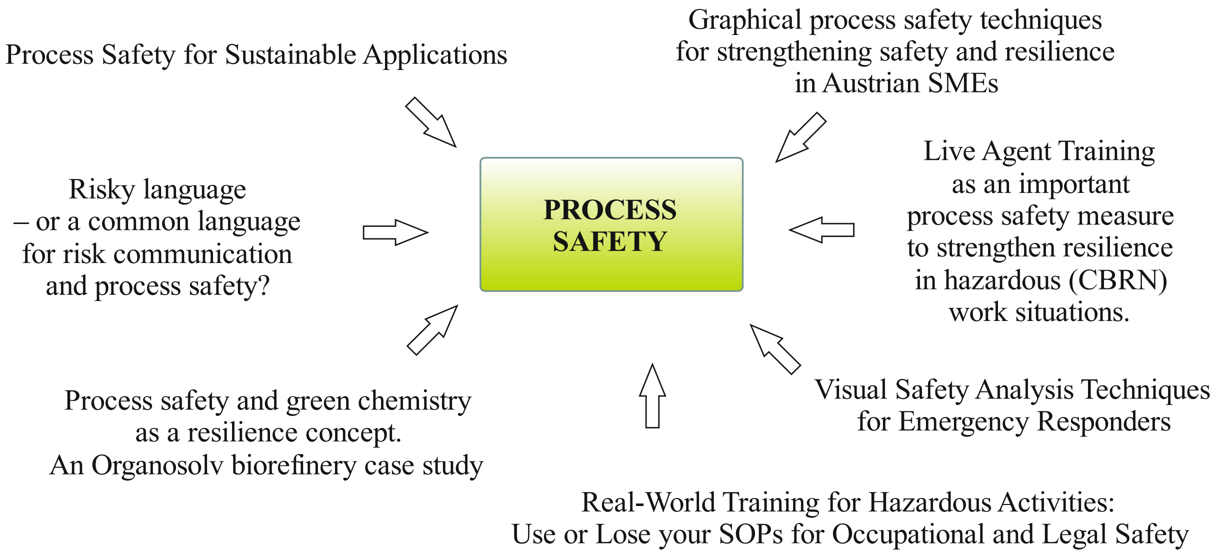

Figure 26: Overview over the publications

The following objectives resulted for the publications:

[Paper 1]: *Process Safety for Sustainable Applications.* [2]

This paper provides a literature review where process safety techniques are suitable for application outside of the process industry. One focus is on the broad applicability in a wide range of business areas without much implementation effort in terms of personnel or software resources. The techniques should be applicable in different life cycle phases of systems and applications and include an additional focus on sustainability with respective applications to existing techniques.

[Paper 2]: *Graphical process safety techniques for strengthening safety and resilience in Austrian SMEs.* [4]

Small- and medium-sized enterprises (SMEs) are the backbone of economic achievement in Europe and Austria. However, they represent a small minority in the field of users of process safety techniques. Whereas large industries have been hiring people and equipment for decades to improve their process safety with techniques and risk management, the main activity of SMEs is to "do their job". Simple, mainly graphical techniques allow creating targeted help on a simple basis, which could make their work safer and more efficient. Within the framework of the study, a survey was conducted in Austrian companies with the support of the Chamber of Commerce on the acceptance of those techniques. A corresponding mood picture was obtained for a possible future of this techniques.

[Paper 3]: *Live Agent Training as an important process safety measure to strengthen resilience in hazardous (CBRN) work situations.* [3]

Emergency responders or incident response personnel often have to deal with stressful and dangerous situations, especially when CBRN (chemical, biological, radioactive & nuclear) hazardous materials are involved. Live agent training can help these persons to be prepared for the mission at a better level than others. The physiological as well as psychological stresses of training under real-life conditions with hazardous substances ensure better confidence in the equipment used as well as in the individual's own skills and the team's resilience. To support the study, a literature review combined with field reports and the results of a survey are included.

[Paper 4]: *Process safety and green chemistry as a resilience concept - An Organosolv biorefinery case study.* [134]

The approaches of green chemistry as well as green engineering have become increasingly established in the chemical industry in recent years. Various origins, such as the responsible care initiative and inherent safety, seek to make plants and processes safer and to protect people as well as the environment. The application in the field of bio-based resources can help to strengthen sustainability but also the resilience in production. But an equivalent replacement of conventional processes and solvents is not always possible. A case study of a lignocellulosic biorefinery was performed as an example to highlight the difficulties and the opportunities of substitutions. Process safety techniques will help to evaluate deviations and to make improvements in terms of sustainability and resilience.

[Conference Paper 5 & Presentation]: *Visual Safety Analysis Techniques for Emergency Responders.* [65]

Not only in the field of classical industries, but also in the field of emergency planning or training of emergency response teams, simple graphical process safety techniques can help to design a safer and more efficient workflow. Barrier diagrams, bow-tie diagrams and service blueprints make it possible to understand the interrelationships and limitations of sometimes dangerous activities better with visual assistance than with checklists and to achieve better mission planning and mission readiness accordingly.

[Conference Paper 6, Presentation & Poster]: *Risky language – or a common language for risk communication and process safety?* [34]

In the context of process safety and risk identification, but also of risk communication and operational safety, precise statements are required. Statements that are ambiguous or misleading have already led to severe accidents. The conference paper with the poster highlights the importance of the use of a so-called "controlled language" in risk management and process safety. Controlled language enables safer communication, easier understanding and better translatability.

[Conference Proceedings 7, Presentation & Poster]: *Real-World Training for Hazardous Activities: Use or Lose your SOPs for Occupational and Legal Safety.* [106]

To support activities, SOPs are required at the normative, qualitative and also legal level, which are intended to support the work and thus also ensure process safety. During the studies in the context of the dissertation it was noticed that many SOPs are made at the desk and have little to do with the real work situation. This can quickly lead to problems if work instructions have never been tested in training and then lead to deviations when their application is required. Regardless of the possible negative consequences in terms of impacts due to non-compliance. Training in real-world conditions helps build resilience and allows real-world SOPs to be tested and improved as necessary.

6 Conclusions

In order to bring process safety techniques into wider use, for example in SMEs, advance work is needed in the form of education and awareness-raising in the area of risk management. [4] People need a solid technical, social and personal competence, which requires training to be able to succeed in practice.

Process safety techniques can be used over a wide range for many applications. They are used to evaluate safety, but also to evaluate deviations in terms of sustainability. They can be used to evaluate conditions and, when applied in a correct manner, strengthen the resilience of systems and processes that are under attack in these times. [2], [106], [134] Simple graphical techniques can improve acceptance and understanding. [4]

Process safety in practice must be viewed holistically. Process safety in practice does not only consist of process safety techniques. It requires people who, with skill and a sense of risk perception, also communicate these and create a climate for safety and understanding. Process safety can be seen as a large puzzle. Elements such as process safety techniques, communication, language, risk perception, technical understanding, fears, hazards, risk, training, management of change, incident management, but also the adaptation to future requirements, processes and raw materials must be connected together with other elements in a complex interaction like individual well-formed puzzle pieces to produce a complete picture without flaws. The missing of a single piece already impairs the overall picture and thus the desired result of a perfection to be achieved is not reached.

7 Outlook and future works

One approach for future works and theses could be to consciously contact companies with the evaluated techniques via cooperation with the Chamber of Commerce in order to test the techniques on specific processes and applications in companies and to evaluate the acceptance in order to achieve best practice examples. [4]

The application of process safety techniques, but also of concepts such as inherent safety is to be incorporated into the training of, for example, chemists, mechanical and chemical engineers. Early awareness raising can help bridging the process safety approaches into companies via multiplier functions and introduce them there broadly for the areas of operability, safety and sustainability. [4], [134]

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II Scientific publications

1. Publication: Process Safety for Sustainable Applications [2]

Title: Process Safety for Sustainable Applications

Author(s): Alexander Stolar, Anton Friedl

Publication type: Paper in professional journal

Journal: International Journal of Reliability, Quality and Safety Engineering

Impact factor: 1,4 (academic-accelerator.com - real time)

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Formatting: Published original

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in the online version.

2. Publication: Graphical process safety techniques for strengthening safety and resilience in Austrian SMEs [4]

Title: Graphical process safety techniques for strengthening safety and resilience in Austrian SMEs

Author(s): Alexander Stolar, Anton Friedl

Publication type: Paper in professional journal

Journal: Int. J. of Business Continuity and Risk Management

Impact factor: 0,8 (CiteScore, 2021)

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Year: 2023

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in the online version.

3. Publication: Live Agent Training as an important process safety measure to strengthen resilience in hazardous (CBRN) work situations. [3]

Title: Live Agent Training as an important process safety measure to strengthen resilience in hazardous (CBRN) work situations

Author(s): Alexander Stolar, Anton Friedl

Publication type: Paper in professional journal

Journal: Journal of Emergency Management

Impact factor: 0,78 (Resurchify.com)

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Year: 2023

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Status: accepted

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4. Publication: Process safety and green chemistry as a resilience concept - An Organosolv biorefinery case study. [134]

Title: Process safety and green chemistry as a resilience concept - An Organosolv biorefinery case study.

Author(s): Alexander Stolar, Anton Friedl

Publication type: Paper in professional journal

Journal: International Journal of Sustainable Manufacturing

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5. Publication: Visual Safety Analysis Techniques for Emergency Responders. [65]

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Author(s): Alexander Stolar

Publication type: Conference paper

Journal: Conference Proceedings
of the ICRP International Conference on Recovery After Nuclear Accidents

Website: https://www.icrprecovery.org/post/cp-07, date accessed: Jan. 05th, 2023

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6. Publication: Risky language – or a common language for risk communication and process safety? [34]

Title: Risky language – or a common language for risk communication and process safety?

Author(s): Alexander Stolar

Publication type: Conference paper & poster

Journal: Proceedings of the 16. Minisymposium Verfahrenstechnik & 7. Partikelforum 2020

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Pages: 4

Year: 2020

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Status: Published

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7. Publication: Real-World Training for Hazardous Activities: Use or Lose your SOPs for Occupational and Legal Safety. [106]

Title: Real-World Training for Hazardous Activities: Use or Lose your SOPs for Occupational and Legal Safety.

Author(s):

Publication type: Conference abstract and poster;

Journal: Conference proceedings
of the 6th International Symposium on the System of Radiological Protection
(ICRP 2021+1)

Website (Program): https://icrp2021.com/wp-content/uploads/2022/10/ICRP2021-Digital-Program-Book-FINAL.pdf date accessed: 05.Jan 2023

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