Developing Process Safety Performance Indicators and Metrics in Chemical Industry

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Developing Process Safety Performance Indicators and Process Safety Metrics in Chemical Industry

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Turvallisuuden ja riskienhallinnan koulutus

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Prosessiturvallisuuden indikaattorien ja mittarien kehittäminen kemianteollisuudessa

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Prosessiturvallisuus on osa kemianteollisuuden riskienhallintaa ja tapahtuneiden onnettomuuksien vuoksi riskienhallinnan tärkeys on tunnistettu alalla. Ensimmäiset prosessiturvallisuusstandardit on julkaistu 1990-luvulla ja standardien kehitys on ollut nopeaa. Huomionarvoista on, että työturvallisuus ja prosessiturvallisuus ovat eri asioita. Esimerkiksi työturvallisuuden poissaoloon johtaneet tapaturmat eivät välttämättä mittaa prosessiturvallisuuden tasoa.

Kohdeorganisaatiolla on oma prosessiturvallisuusohjeistuksensa, mutta sen käyttöönotto ja soveltaminen vaihtelee eri toimipaikoilla. Tämän opinnäytetyön tavoitteena on tunnistaa soveltuvat prosessiturvallisuusindikaattorit, sekä luoda mittariston laatimisen ohjekirja kohdeorganisaatiolle. Tutkimuskysymykset liittyvät prosessiturvallisuuden kehittämiseen, sekä prosessiturvallisuuden mittareiden luomisprosessiin.

Tiedonkeruumenetelminä on käytetty kirjallisuuskatsausta sekä prosessiturvallisuusasiantuntijoiden haastatteluja. Kirjallisuudesta ilmenee, että organisaation aloittaessa prosessiturvallisuusmittariston luomisen on hyvä muodostaa ryhmä, jossa on eri osa-alueiden asiantuntijoita. Turvallisuus- sekä suunnitteluorganisaation edustajien tulee kuulua ryhmään samoin kuin prosessioperaattorienkin. Prosessiturvallisuutta voidaan mitata monelle tavalla, mutta vain parhaiten soveltuvimmat mittarit tulee ottaa käyttöön, jotta vältytään mittaristoa seuraavien henkilöiden ylikuormitukselta.

Opinnäytetyön tuloksena esitetään erilaisia prosessiturvallisuuden mittareita, joista kohdeorganisaatio valitsee soveltuvimmat, sekä luo järjestelmän, jolla mittaristoa seurataan. Jokainen kemianteollisuuden laitos- ja organisaatio on erilainen, joten toimivan prosessiturvallisuuden mittarin aikaansaamiseksi tarvitaan osaava suunnitteluryhmä. Mittaristo on turha, jos kukaan ei seuraa sitä eikä reagoi tarvittaessa poikkeamiin. Henkilöiden käyttäytymiseen liittyvät mittarit ovat myös tärkeitä, koska valtaosa onnettomuuksista Suomessa johtuu ihmisen toiminnasta, eikä niinkään vaarallisista olosuhteista.

Avainsanat: prosessiturvallisuus, prosessiturvallisuuden mittaaminen, riskienhallinta

Laurea University of Applied Sciences **Abstract**

Degree Programme in Safety, Security, and Risk Management

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Developing Process Safety Performance Indicators and Metrics in Chemical Industry

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Process safety is a crucial element in risk management of chemical industry organizations. The need to develop process safety has become more important after devastating accidents within said industry. The first process safety standards were published in 1990´s and after that they have evolved to their present state. Personal safety and process safety overlap but personal safety metrics, like loss time incidents, do not always indicate flaws in process safety.

The commissioner has process safety standards in use, but the implementation of the standards varies on different sites. The objective of the thesis is to develop a process safety indicators and metrics handbook to the commissioner. Research questions are tied to the process safety improvements and metrics creation process.

The used research methods are a literature review of different standards, publications and books and interviews with process safety experts in the industry. The literature review shows that when an organization starts to implement process safety metrics, it´s good to form a team with different experts. Safety and engineering should be part of the team and process operators should also be involved in the metrics creation process. There are multiple possibilities for process safety metrics but only most relevant and applicable should be chosen to prevent information flood to the leadership team, who is following results and making corrective actions.

As a result of thesis, a set of process safety metrics is presented to the commissioner and organization will develop a system to follow up and improve the selected process safety performance indicators and metrics. Every chemical industry organization and especially site is different, so implementing of the process safety metrics can be difficult or impossible if a competent team is not involved in the process. Process safety metrics are useless if no-one follows them and reacts to the deviations from approved safe limits. As a measure, behavior-based safety observations are important because it can be assumed that majority of all incidents is caused by hazardous activity, not hazardous condition.

Keywords: measuring process safety, process safety, risk management

Contents

1 Introduction

The topic of this thesis is a workplace development made for the commissioner in chemical industry. Thesis will be divided into two parts: public and confidential. Confidential part will only be available for use of the commissioner due to trade secrets.

According to HSE & Fire protection (2021) the first Process safety Standard was created by Occupational Safety and Health Administration (OSHA) in the USA in 1992. Even the standard has been published 30 years ago, major accidents occur around the world from time to time. After the process safety standard was released, some engineer associations have published guidebooks of their own for process safety.

Process safety is an interesting area to study because it´s implementation level varies at different chemical plants. The commissioner has got internal standards and procedures for process safety Management (PSM), but the implementation of these standards is ongoing at the thesis target site.

2 Aim of the Thesis, study questions, concept of process safety and commissioner presentation

Thesis aim is to answer needs for developing process safety metrics to a specific chemical plant. Study questions will be formed before data collection will begin. This chapter also describes shortly the commissioner and it´s 100-year history at the industry. Concept of process safety is also described in this chapter.

2.1 Study Questions

Efron & Ravid (2019, 51-52) describes that good research question is personal and meaningful for the researcher, and practical, and significant in the field of study. Study questions should be formed so that it is clear for readers and researcher. The question should also be manageable, but not too narrow or too broad because otherwise study will be too limited and lack depth. When selecting the research questions, it should be noted that those should also guide literature search. This can be achieved by framing questions so that the questions guide the search process. Questions shouldn’t be formed so, that those can be answered simply yes or no.

Study questions of the thesis are following:

1. How to manage process safety risks?
2. How to develop process safety performance indicators and process safety metrics?
3. How to integrate the behavior-based safety process with the process safety?
4. How to present leading and lagging process safety and personal safety indicators visually?

2.2 Concepts of process safety

Concepts that are closely related to this thesis are behavior-based safety, incident, indicator, metric, process safety, risk, and risk management.

Behavior-based safety process aims to reduce significant accidents by affecting people's behavior (Wever 2022, personal communication). It´s key elements are regular employee observations which include employee involvement, performance feedback and reinforcement of safe behavior. (McSween 2003, 157).

Incident is a safety endangering event that doesn´t led to injury or illness. If event has got potential to cause injury or illness, it can be called as a near-miss. If incident causes harm, it can sometimes be called as an accident. (Standard ISO 45001 2018, 15.)

Indicator can be a trend or fact of state of something that can be measurable (Process Safety Metrics Guide for Leading and Lagging Indicators 2022, 51).

Metric is a quantitative method to measure something. It can also be a result of measurements (Process Safety Metrics Guide for Leading and Lagging Indicators 2022, 52).

Process safety is a framework with which the integrity of hazardous operating systems and processes are managed. The aim is to prevent and control unwanted events leading to serious accidents such as fire, explosion, or toxic effects. The managing methods used are a good design principle, engineering, as well as operating and maintenance practices. (API recommended practice 754 2017, 8, 18.)

Process safety metric is a measure of analysis results either from a performance indicator or a process safety program. (Process Safety Metrics Guide for Leading and Lagging Indicators 2022, 53).

Risk is defined as a consequence times likelihood of an expected or unexpected event. Risk can be positive or negative and possible consequence is either risk or opportunity (Standard ISO 31000 2018, 6).

Risk management is activity that coordinates organization to control risk (Standard ISO 31000 2018, 6).

2.3 Presentation of the commissioner

The commissioner was founded over 100 years ago, in 1920. First, it started to produce sulfuric acid and superphosphates for the mining and fertilizer business. The company survived World War II by importing fertilizers to Finland. In 1957 the company decided to expand its products to titanium dioxide. This was the first step away from the fertilizer business. In 1960 the company started to produce aluminum sulphate for the pulp and paper industry. In 1972 company expanded production again and bought the paint production plant, which made a foundation for the business of the company for many years.

The company became international in 1980s by buying plants from the UK, Belgium, France, the Netherlands, and Denmark. In the 1990s the company was listed on the stock market. In 2004 the company decided to separate itself from the fertilizer business. In 2005 the company bought chemical plants in Finland and Germany. This made the company a leading pulp and paper chemical producer in the world. In 2008 the decision to concentrate on the water-intensive production business was made, which led to the situation in which the paint business was sold in 2010.

In 2014, the company started to grow in the Asian and South American markets. 2015 company expanded by the demand of the customers in European markets. 2018 company invested heavily in different continents. 2019 was the time to expand coagulant production and polymer product capacity in UK and USA. 2020 company published its target to be carbon neutral until the year 2045. In 2021 company had revenue of 2,7 billion and 5000 employees in 100 countries.

3 Theories of the thesis

Literature review and semi-structured interviews form the core of the thesis. An integrative literature review was chosen to be the main method and semi-structured interviews are the second method. The results of both methods will be evaluated against studied standards and other publications.

3.1 Integrative literature review

The purpose of the literature review is that the writer familiarizes himself with the topic and it´s context and develops the framework for research and position the work in the relation to other theorists (Sribbr 2022). Different types of literature (e.g., course books, standards, engineering association´s publications etc.) reviews were evaluated at the beginning of the thesis process and an integrative literature review was conducted. The reason for that is that an integrative literature review can be used to assess mature or new topics . This thesis assesses mature topics like process safety and process safety management and overviews the knowledge base of these topics. The purpose of the thesis is not to cover all publications or articles related to process safety, but its aim is to combine different insights and perspectives from different articles, publications, and books. (Snyder 2019, 335-336.) An integrative literature review gives a possibility for analyzing and examining critically and carefully a topic and deconstructing it to the basic elements. Usually, there are two topics in the integrative literature review: empirical, mature topics and literature that contains new topics. The integrative literature review writer tries to offer new topics such as preliminary conceptualization or new models of perspective on the issue. (Efron & Ravid 2019, 34.) This method was selected because information in the literature, which was reviewed at the pre-planning stage, was scattered among many publications, papers, and books. The aim of the thesis is to combine the industry's best practices and incident learnings into one document.

After the topic has been selected and the research question has been formed it is notable that it may be evolved or changed during the reading process. Articles, books, reports, and other sources will be the basis of the literature review and the search for these should be a systematic and thoughtful process. The beginning of process can start with a general idea of the topic that the writer is interested in, and it can be continued when the topic of the study is focused. The process of searching information can be linear of sequential. The topic that has been chosen at the beginning of the work can be modified, refined, or even changed during the investigation process for the literature review. (Efron & Ravid 2019, 57.) The process for library search process is described in figure 1.

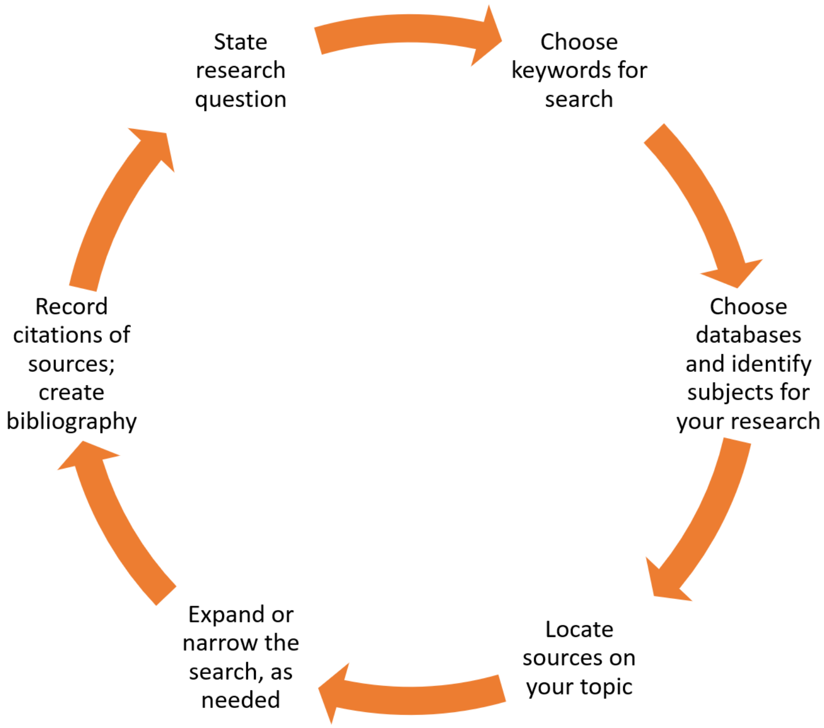

Figure 1: A diagram of the library search process (Efron & Ravid 2019, 58)

Thesis is also a workplace development work. Purpose of the thesis is to develop organization´s process safety metrics at a specific site but also at corporate level. Literature is published by different organizations that are specialized on process safety. Literature includes standards, publications, and webpages.

3.2 Semi-structured interviews and analysis

Research methods of the thesis will also include questionnaires with open-ended questions and semi-structured phone interviews. The questions for both data collection approaches are pre-selected and presented in same order to all participants (Saaranen-Kauppinen & Puusniekka 2006). Semi-structured interviews are selected as one data collection method because the thesis commissioner´s safety standards and instructions are available but are lacking explanations of some critical terms and abbreviations. Interviewees will be selected from different organizations by their expertise to the process safety and behavior-based safety. Collected data and interview results will be also analyzed by comparing these to other publications, standards, and other relevant material.

4 Process safety and risk management

Finnish safety and chemical authority TUKES (2016, 3) defines process safety as a risk management of the hazardous chemicals handling and storage. Process safety can be improved with actions such as facility siting and chemical leak controls systems. Chemical processes include hazardous chemicals and process parameters such as pH, pressure, temperature, and flow rate. Also, human factors are part of the process safety management. Process safety programs are designed to lower the process safety risk. With lowered process safety risks likelihood of severe accidents, like explosions, fires, fatalities, injuries, and property damages is decreased. (Guide for selecting leading and lagging indicators 2019, 30.) Process safety improves reliability, quality, and productivity of company (IOGP report 456 v.2 2018, 9).

4.1 Regulatory requirements of process safety in Europe

A serious major accident faced Italian town Seveso in 1976. This created situation, where European commission had to create a legislation for controlling major accident hazards in Europe. This is called Seveso-directive. Directive has been updated during years and latest version Seveso III directive has been taken into use in 2012. Seveso-directive applies to over 12 000 industrial establishments. (European Commission 2022.)

Seveso directive (2012/18/EU) creates rules for preventing major accidents, which involve consequence for human health and the environment and are caused by hazardous substances (Article 1). In article 3 there are definitions for 3 different category establishments: lower and upper tier from which upper tier establishment has got more regulations. Seveso directive also considers neighboring establishments which is located so close to another establishment that it has got increased risk for the major accidents.

Seveso directive defines that operator is a natural person who has got decision making power of the technical installations inside establishment (2012/18/EU, article 3, §9). Seveso directive sets that operators’ responsibility is to inform responsible authority of the changes in the dangerous substances inventory, significant changes of process and such modifications that could increase chance of major accident. Also, permanent closure of the site shall be reported to authority. (2012/18/EU, article 7, §4.)

Operator shall have Major Accident Prevention Policy (MAPP) in written format. Design basis of MAPP is to ensure that humans and environment are highly protected. It shall include management’s role, responsibilities, and actions to ensure that major accident hazards are controlled. MAPP shall be sent to authorities in case local legislation requires it. MAPP shall be updated if needed and reviewed periodically, at least every five years and sent to the authorities without delay. (2012/18/EU, article 7, §2, §4.)

Safety report is required from the upper tier establishment. Its purpose is to demonstrate that safety management system and MAPP has been implemented. Safety report also demonstrates that major-accident hazards and scenarios are under control by preventive measures. Safety, operation, construction, and maintenance of installations shall be adequately demonstrated. Internal emergency response plan shall be created on such detail, that creation of external emergency response plan can be drawn up. (2012/18/EU, article 10.)

Operator shall include following objects to emergency response plans: description of accident mitigation controls to minimize consequences to people, environment and property and measures to protect against major accident effects. Necessary information shall be communicated to the public and relevant authorities of the area. Plans shall also contain measures to clean up and restoration of the environment after major accident. Internal and external emergency response plans shall be reviewed, tested, and updated by authorities and operator on regular basis of no longer than three years. Changes of the establishment and emergency services shall be considered and development of the technical knowledge to major accident response should also be considered. (2012/18/EU, article 12.)

Upper tier establishments shall share all relevant information of the major accident risks, safety measures against those and requisite behavior in the event of a major accident to all persons who are likely to be impacted. The safety report and inventory of dangerous substances must be made available to the public upon request. Safety report that is public, shall include at least description of major accident hazards and its potential effects to humans and environment. (2012/18/EU, article 14.)

Competent authorities shall create a system, where they shall organize inspections on regular basis to establishments. Inspections shall be systematic examinations of technical, organizational, or managerial so the operator can demonstrate their appropriate measures to prevent, mitigate and limit consequences of major accidents. Period between site visits should be one year for upper-tier establishment and three years for lower-tier establishment. Authorities have possibility to change visiting periods based on a risk assessment of the establishment. Authorities will deliver written report of the inspection in four months period. This report includes required actions that were identified. Authorities shall ensure that all necessary actions are taken care by the operator in reasonable period. (2012/18/EU, article 20.)

4.2 Risk assessment

Standard ISO 31000 (2018, 15-17) describes risk assessment as a process of identification, evaluation, and analyzation of risks. Risks should be identified to recognize either their help or prevention of the organization to achieve its objectives. There are several methods to identify risks and opportunities. Risks should be identified even they are not in control. It should be considered there can be more than one type of outcome which results into consequences. Risks should be analyzed to identify likelihood and severity of the risk, magnitude of consequences and their complexity. At risk assessment existing controls effectiveness should also be evaluated. Quality of information, assumptions and exclusions can affect to the quality of risk assessment. When risk is evaluated, it must be decided that does it require further actions or controls or are the existing controls good enough. Risk evaluation should be communicated through the organization´s appropriate levels. Risks can be treated differently. Options are to avoid risk, taking risk, removing the risk source, changing likelihood, changing consequences, or sharing risk with e.g., insurance company. It must be remembered that new risks can be introduced while risks are treated (Standard ISO31000:2018, 15-17.)

4.3 Risk management

The purpose of risk management is to create added value. Effective risk management principles that are the foundation of risk management~~.~~ Risk controls should be connected to organizations risk management processes. There are nine elements, that risk management requires: it should be integrated as a part of all organizational activities, approach should be comprehensive to risk management, framework should be customized and related to organization´s identified context, stakeholders should be involved timely, and it should be dynamic because organizations external and internal context can change and risks can either change, emerge or disappear. Risk management should be based on historical, current, and future expectations and the information should be available to stakeholders. It should also be noted that human factors influence each level of risk management. Risk management should be continually improved through learning and experience. (Standard ISO 31000:2018, 7-9.)

Standard ISO 31000 (2018, 9) describes risk management framework as an organizations assistant for integrating risk management into their functions. Framework has got five components: leadership and commitment, integration, design, implementation, evaluation, and improvement. Risk management should be integrated to all levels of organization, and it is at the responsibility of the highest management. The highest management must ensure that there are all needed resources available for allocating risks and they should assign authority and responsibility to all necessary levels of organization to help it to ensure that risk management framework is considered as a part of the organization’s context. Organizational structures and context are part of the integrated risk management. Risk management is everybody’s responsibility and integration of the risk management into the organization’s context is dynamic process. (Standard ISO 31000:2018, 9-10.)

Organization should understand it´s context when risk management framework is designed. Context of organization is divided to external and internal, which can include complex networks and dependencies. Top management should create policy or statement to articulate their commitment to risk management. This should be communicated throughout whole organization and relevant stakeholders. Top management should also assign roles and responsibilities and allocate appropriate resources. Part of the effective risk management is communication and consultation, where risks are communicated to relevant stakeholders and feedback is received from them as a consultation. Successful implementation of the risk management framework requires engagement of the stakeholders. If risk management process is properly designed, the process is part of all activities, and it is included in all decision making. Organizations should review framework periodically against its purpose. During the evaluation it should be determined does framework support organizations objectives. During monitoring of the risk management process, it should be analyzed for possible improvements. These improvements should be planned after identification so that they can be assigned to be implemented. After implementation, changes should contribute risk management. (Standard ISO 31000:2018, 9-13.)

4.4 Elements of process safety management

Process safety management can be divided to 14 different elements. Under knowledge and control segment there are process safety Information, Operating procedures, hot work permit and other safe practices, contractor management and training. Hazard identification segment includes process hazard analysis, management of change, pre-startup safety review and mechanical integrity. Participation and management cover employee participation, compliance audits and trade secrets. Incident learning and response covers incident Investigation and emergency planning and response. (HSE and fire protection web page 2021.) 14 elements of process safety management are described in the figure 2.

Figure 2: 14 Elements of Process Safety Management (HSE and fire protection web page 2021)

4.4.1 Knowledge and operational control

Process Safety Information (PSI) includes e.g., reactivity of chemicals, safe process parameters and limits, and flow diagrams. Material Safety Data Sheets (MSDS) can be used to identify e.g., toxicity and the reactivity of chemicals. (Process safety management (PSM) 2021.) PSI should also include technology information like block flow diagram, process chemistry, safe upper and lower limits for temperatures, pressures, flows or compositions. Deviation consequences should also be evaluated, especially those which are affecting safety and health of the employees. Process equipment information such as construction materials, Piping, and Instrument Diagrams (P&ID´s), electrical classification, pressure relief system design basis, design of the ventilation, design codes and standards, material and energy balances and safety systems like interlocks and detectors should also be included in PSI. (Process safety management OSHA 3132, 7.)

Operation procedures are documents which give clear instructions to perform activities safely. They shall be developed for operation phases. These should include elements such as operating phase, operating limits and safety, health, and environment controls. (Process safety management (PSM) 2021.) Operating procedures should be kept up-to-date and accessible to all employees who work at the process. It is mandatory to review operating procedures as often as necessary in case process or operations change. Tasks and procedures should be communicated well to employees. (Process safety management OSHA 3132, 12-13.)

Permit to Work (PTW) is a system that is used to control maintenance works. It is a formal way to document and share information of the tasks that are ongoing. With properly filled PTW it can be ensured that the process equipment's are properly isolated and safe to work with. Work permit also ensures that the work has been checked before equipment is returned to service. (Kletz 2001, chapter 17.) Hot Work permit and safe practices are meant to prevent fires, explosions, and toxic releases. Especially hydrocarbon processing is vulnerable for these kinds of accidents. Site should have robust PTW system to mitigate hazards from maintenance activities. (Process safety management (PSM) 2021.) Hot work permit must be issued when operations are conducted near a covered process. Permit must be issued before beginning of the hot work. Hot work permit must indicate date(s) and object which hot work is to be performed. Hot Work Permit must be kept in a file until work has been completed. (Process safety management OSHA 3132, 21.) Also, other non-routine work such as line breaking, and confined space entry must have a work permit (Process safety management guidelines for compliance OSHA 3133, 15).

All maintenance and specialized work performing contractors should be managed by evaluating their safety performance. All contractor employees should be also informed of the major risks of the site and site emergency plans should also be explained. (Process safety management (PSM) 2021.) All relevant Process safety risks like fire, explosion, or toxic releases must be informed to contractors (Process safety management OSHA 3132, 16).

All employees shall be trained properly before they are involved in process (Process safety management (PSM) 2021). Prior the training, employer must develop a training plan which identifies employees to be trained and the subjects that training should cover (Process safety management guidelines for compliance OSHA 3133, 10). Training shall cover overview of the process and operating procedures. Re-trainings shall be organized at least every three years or more frequently and trainings should be documented (Process safety management (PSM) 2021.), to each employees' training records of the PSM. A record must contain a verification that employee understood the training. (Process safety management OSHA 3132, 15.) Training of the existing staff during their time as a student and when being staff of the plant creates culture. Culture is difficult to change but it can be done even it takes time. (Kletz 2001, chapter 30.6.) Also training of the top management is important because the rest of the staff will follow if top management has the right approach. (Kletz 2001, chapter 30.8). British cognitive psychologist Lisanne Bainbridge has developed a theory called "ironies of automation", where it can make the difficult parts of the job even more difficult by taking away easy parts of a human operator´s tasks. Many system designers think that human beings are inefficient and unreliable, but they still design systems for human interaction in case they don´t know how to automate system to return to a safe state after failure. Operator´s task is to monitor highly automated system even it is known that even best motivated people cannot maintain vigilance for a long period of time. This creates situation where it is very difficult to react to very rare abnormal conditions. Operators should practice their skills, but automation system fails only very occasionally. This denies the possibility to maintain skills that are needed in case of emergency. This means that highly automated systems can deskill operators. Automation systems that are successful require rarely needs for operator intervention. This creates need to the greater investment of operator training. (Bainbridge 1983, 775-777.)

4.4.2 Hazard identification and control

It is employers' responsibility to complete written process safety Information before Process Hazard Analysis (PHA) is done (Process safety management OSHA 3132, 7). PHA is systematic and orderly approach to identify, evaluate, and control hazards. There are many methods for PHA: What-if, checklist, What-if/checklist, Hazard, and Operability Study (HAZOP), Failure mode and effect analysis (FMEA), fault tree analysis or equivalent appropriate methodology. (Process safety management OSHA 3132, 9.) The focus of the PHA is on equipment, instrument-tation, utilities, human actions, and other factors that affect process (OSHA standard 1994, 6). PHA´s purpose is to mitigate risks of the process. During PHA, risks are identified, and likelihood of the event is minimized. In PHA the hazards of the process and previous incidents and accidents should be considered as a potential major accident precursor. Resulting recommendations of the PHA should have tracking system to verify that recommendations will be resolved in timely manner. (Process safety management (PSM) 2021.)

Management of Change (MOC) is a system to manage all kind of changes like equipment, technology, and processing conditions. Employer shall have MOC process, that describes what kind of changes should be analyzed. These changes can affect e.g., technically to the plant equipment and they can also impact safety and health and operating procedures. All other changes must be reviewed through MOC process, except "replacement in kind", where equipment is replaced with similar one. (Process safety management guidelines for compliance OSHA 3133, 13.) McSween has stated that majority of workplaces keep changing all the time (2003, 162). Number of catastrophes has been caused by temporary changes. Employer must develop a system to detect both, temporary and permanent changes. If temporary changes are not in control, those can become permanent. (Process safety management guidelines for compliance OSHA 3133, 16.) Changes shall be trained to all employees who are involved in the changing process. (Process safety management (PSM) 2021 2021.) If changes modify results in the process safety Information, operating procedures, or practices, those must be updated (Process safety management OSHA 3132, 22).

One of the most common causes of the incident is a failure in MOC. Sometimes change has been implemented many years ago but documentation and communication has not been done. This can cause incident to occur years later. (European Commission Joint Research Centre – Institute for the Protection and Security of the Citizen 2014, 9.) Modification and changes in plants should always be reviewed by competent professional engineer who makes sure that change is according to the design standard and there are no side-effects. After the modification engineer who approved the change should check that modification looks right and is according to the plans. (Kletz 2001, chapter 12.)

HAZOP should be used in substantial changes. Smaller changes can be approved by completing a checklist which is designed to help to identify modification and its consequences. (Kletz 2001, chapter 7.1.) To keep any protective system in working order, those should be checked regularly. (Kletz 2001, chapter 6). Equipment or procedures should not be removed or changed unless their function is known (Kletz 2001, chapter 26.6). Kletz (1993, 21) suggests that every instruction or code should have a description of the reason why it has been made for the reader to better understand why it must be followed. Most of the plant staff changes in ten years, so no-one remembers why e.g., procedure or equipment was originally installed. this can lead to the situation that equipment can be removed or procedures can be abandoned. (Kletz 1993, 4.) Organizational changes should be examined the same way that technical changes (Kletz 2001, chapter 24.3).

Pre-startup safety review (PSSR) is a method to ensure that new or modified plant is safe to start. In PSSR process there are things that must be confirmed. These can be e.g., that equipment meets design specifications, new procedures are present, MOC process has been followed and training of the employees has been completed. (Process safety management (PSM) 2021.) PSSR should be done if change is significant and requires change to the process safety Information. In case highly hazardous chemical is introduced, PSSR should be done prior startup. (Process safety management OSHA 3132, 18.)

Mechanical integrity´s purpose is to verify that pressure vessels, piping, safety devices, emergency shut down systems, critical control systems, sensors, alarms, interlocks, pumps, and compressors are functioning as designed. Equipment should be installed and inspected regularly according to manufacturer’s specification. All equipment materials should be suitable for application. (Process safety management (PSM) 2021.) Employers’ responsibility is to create and maintain written procedures to maintain the integrity of process equipment. Good engineering practices should be followed when inspection and testing is performed to the process equipment. If equipment deficiencies and values are outside acceptable limits of process safety Information, these must be corrected before system is taken into use. In some cases, it may be possible that deficiencies are not corrected prior use, but in this case, if necessary, steps must be taken to ensure safe operation. (Process safety management OSHA

3132, 19.). Scaffolding, hoses, and other temporary equipment should be inspected regularly to prevent them to become hazardous in case those are left in use for long period of time. Same principal applies to temporary procedures which should be reviewed from time to time. (Kletz 2001, chapter 27.3.) Reliability should not be confused with safety. An equipment reliability can be high, but it can still be unsafe. Even failures have not been reported, it doesn´t mean that equipment or software is safe. (Kletz 2001, chapter 29.4.)

4.4.3 Participation and management

Employees should be involved in processes where process safety Information is shared. Also, information of process changes, process technology and highly hazardous chemicals should be communicated with employees. All relevant documents should be available for all employees. (Process safety management (PSM) 2021.) Employer must provide employees and their representatives possibility to consult in Process Hazard Analysis (PHA). Employees must have access to PHA´s. (Process safety management OSHA 3132, 14.)

Compliance audits shall be conducted by competent person, who has also knowledge of the process (Process safety management (PSM) 2021). Employer must evaluate compliance to process safety management every three years to verify that procedures and practices are adequate and followed (Process safety management OSHA 3132, 25). Purpose of the compliance audits are to ensure top management, that systems, practices, and standards are under control. Written audit report should be developed and responses for the audit findings should be corrected and documented. Management should regularly have management reviews, where they follow up actions of previous management reviews, process safety leading and lagging indicators, PSM audit findings and actions and PSM element gap analysis and action plan. (Process safety management (PSM) 2021.) Line management is responsible for safety, not safety department. Safety department supports and advice line management. Auditing of safety management system is vital to make sure that the procedures and decisions are carried out as it has been planned. (Kletz 2001, chapter 17.7.)

Trade secrets, like all relevant information such as process safety Information should be shared to employees by employers (Process safety management (PSM) 2021). These employees include PHA and operating procedures developers, people responsible of incident investigations, emergency response planners and emergency responders, and people who are performing compliance audits (Process safety management OSHA 3132, 26). If needed, non-disclosure agreement can be made with employee. (Process safety management (PSM) 2021.)

4.4.4 Incident learning and response

Kletz (2001, Introduction) describes, that accident investigation is like peeling an onion or dismantling Russian doll. Outer layers are causes and recommendations and inner layers are way to avoiding the hazards. Only outer layers are often considered but, in this case, investigation fails to consider all information available. Incident investigation aims to identify the root causes of the incidents and to implement corrective actions to prevent similar incident in the future (Process safety management guidelines for compliance OSHA 3133, 17.) Every hazardous condition of the process such as near miss or incident, should be investigated as promptly as possible but investigation should not begin later than 48 hours from the incident (Process safety management OSHA 3132, 23). Investigation team should include at least one person, who is familiar with the process. Other team members should have experience of the incident investigations. Investigation report should be written, and it should contain incident date, time, detailed description, root causes and recommendations to prevent incident in the future. These recommendations should be tracked, and resolutions and corrective actions shall be documented. Report should be reviewed and evaluated by all relevant persons including employees. (Process safety management (PSM) 2021.) Incident site should always be seen before closing the report (Kletz 2001, chapter 15.1). Incident reports should include all the facts even in case some would not have conclusions. This helps different background readers to draw additional conclusions which might not have been obvious for investigators. (Kletz 2001, chapter 14.) After incident investigation it must be remembered that incident lessons are learnt after an incident but also forgotten in a few years due to staff changes (Kletz 2001, chapter 19.5.). Kletz (1993, 21-22) recommends, that important incidents of the past should be trained to all employees and undergraduates. To prevent incidents happening again, incident report should be shared to people who use similar equipment or work at similar department. (Kletz 2001, chapter 9.)

Emergency response plan must cover the whole plant (Process safety management OSHA 3132, 24). Emergency response should be planned against major fires, explosions, toxic emissions, oil spills, etc. Emergency response plans should be trained to all employees and exercises should be organized to verify effectiveness of the plans. Emergency response plan should be reviewed every time plant is modified. (Process safety management (PSM) 2021.) Employer needs to make decision, if they want employees to handle and stop small releases or do employees need to evacuate to safe area and alarm emergency responders to handle the release (Process safety management guidelines for compliance OSHA 3133, 24).

4.5 Process safety and occupational safety

Process safety and occupational safety overlaps each other but it must be remembered that measuring only process safety events or occupational safety events don´t give necessary information of both areas. Process safety relies more on the technical systems and occupational safety to the individual person´s risk profile. Overlapping areas include e.g. metrics, training and incident investigation. API recommended practice 2017 describes differences and similarities of process safety as a figure 3.

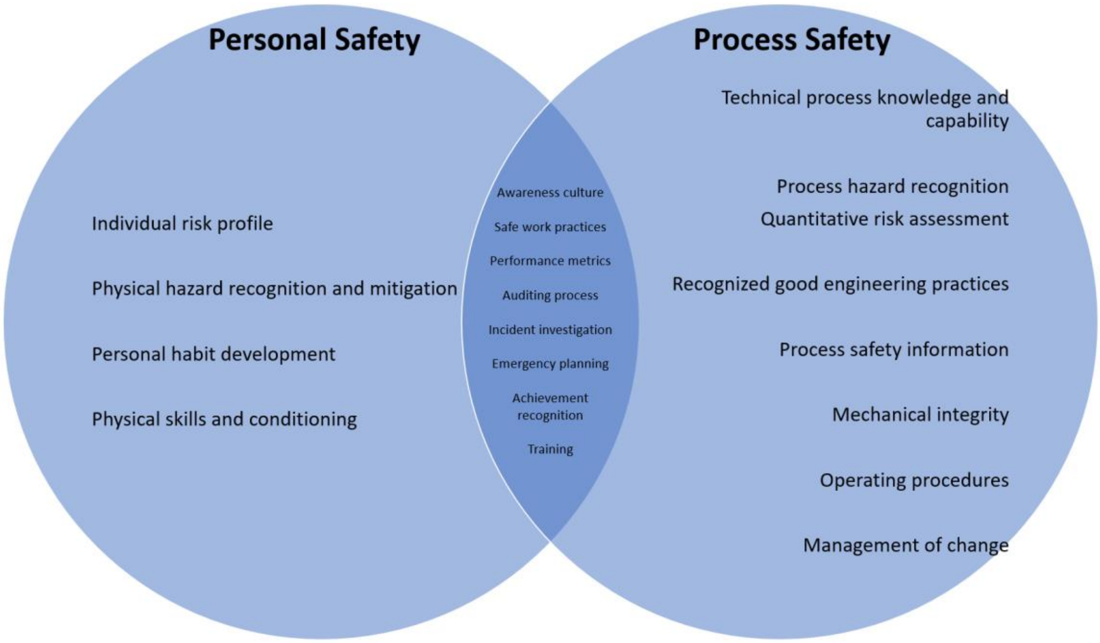

Figure 3: Personal safety/process safety graphic (API recommended practice 2017, 77)

Personal or occupational Safety accidents occurs mostly to one individual. Accidents can be slip, trip, falls or similar, which are not chemical process related. Process safety incidents can cause catastrophic events which can result in multiple injuries or even fatalities. Major accidents can also cause substantial damages to environment, property, and economics. Process safety events can affect workers inside plant area and nearby members of public. (Baker report 2007, X.) Process safety incident probability is small, but consequences are serious. These events often include release of hazardous energy or chemical. Occupational safety incident hazards are more visible and concrete than process safety Hazards. Probability for occupational safety incident is high but consequences are limited to small group. (Prosessiturvallisuus ja sen mittaaminen 2016, 4.). Many of the injuries and fatalities are caused by personal safety accidents rather than process safety accidents. As a result, these statistics reflect how company is handling personal safety hazards rather than process safety hazards. Companies, that rely on these statistics, must develop process safety data related indicators that relate specific process safety hazards. (Hopkins 2007, 3.) Sometimes companies rely, that injury related statistics give information also of the status of their process safety. Injury reports don´t necessarily include information of the process safety but site should consider that injury reporting includes process safety if injuries are process related. (Hopkins 2014, 54-55.) It must be remembered that Lost-time accident rate does not measure process safety (Kletz 2001, chapter 24.4).

Typical injury triangle model is a way to make statistics of occupational safety related events. Triangle model is based on empirical study by Bird and Heinrich. In the study they found that there was certain ratio between precursor events and serious injuries. This triangle does not consider major accidents as a top tier event. Some studies have assumed that there are certain numbers of serious injuries for every major accident. This thinking assumes that serious injuries are precursors for major accidents. (Hopkins 2014, 56-57.) Typical injury triangle model is described on figure 4.

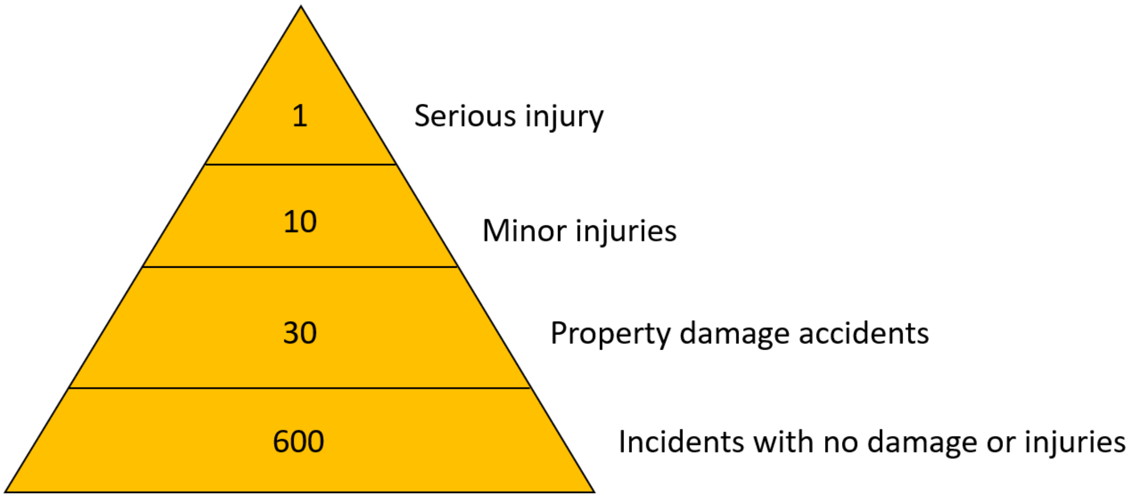

Figure 4: Typical injury triangle (Hopkins 2014, 56)

Thesis commissioner has got a visualization of the personal injury pyramid. In the visualization all reported dangerous situations are formed as Heinrich´s triangle. Personal injury pyramid's purpose is to visualize status of the personal safety level of company. (Wever 2022, personal communication.) Thesis commissioner defines in their injury pyramid different kind of KPI´s on personal injuries in figure 6.

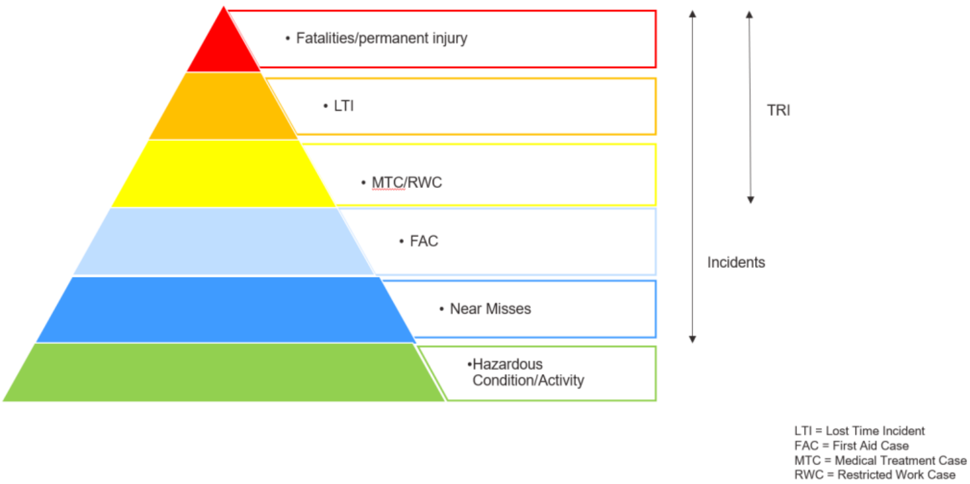

Figure 5: Personal injury triangle (thesis commissioner 2021)

Thesis commissioners (2021) definition of permanent injury is an event, that leads to injury that will indefinitely restrict the employment or other normal activities of an individual. Organization keeps record of Total Recordable Injury Frequency (TRIF), which includes Fatalities, permanent injuries, LTI´s, RWC´s and MTC´s. TRIF is reported globally and normalized to 1 000 000 work hours. This key performance indicator also includes fatalities.

Lost Time Incident (LTI) is a work-related injury or illness that results at least one day away from work (this doesn´t include day of the injury). Injury or illness must be determined by physician or other health care professional. Restricted Work Case (RWC) is a work-related injury or illness that requires to have restricted work or transferred to another job for at least for one day. Injury or illness must be determined by physician or other health care professional. Medical Treatment Case (MTC) is any work-related injury that requires medical treatment or prescription medication. Medical treatment means beyond first aid level of medical attention. MTC requires at least visit to doctor and an injury or illness that requires reporting to governing agency or body. First Aid Case (FAC) is a work-related injury or illness, that requires treatment by first responder or equivalent and does not require treatment of physician or paramedic attention. Near Miss is an undesired event in the work environment that could have led in different circumstances to harm to people, property, equipment, environment, or loss of business. Hazardous condition or hazardous activity (HC/HA) is shared between two different conditions: HC is a condition that has potential to cause physical or environmental harm and it has got possibilities to cause significant injury, property damage, chemical release, or process related incident. HA is defined as human behavior or action at work environment that jeopardizes safety and has potential to cause injury, property damage, incident, chemical release, or process related incident. (Wever 2022, personal communication)

Thesis commissioner defines the reportable process safety Incident (RPSI), which are incidents in production, distribution, storage, utilities, or pilot plants within organizations facility, directly involving a chemical substance or a chemical process unit, and causing release of material, fire, explosion/implosion, and results in TRI, over 2500 EUR/USD damages in direct costs or evacuation or shelter in place. Release thresholds for hazardous chemicals are 1 kg (acute toxicity cat 1 & 2, GHS-statement H300, H310, H330), 10kg (for acute toxicity cat 3 & 4, GHS-statements H310, H311, H312, H331, H332) or 100 kg for other H-statements. Any event that did not meet definition of a RPSI but could have become one, must be treated as a PS related near miss. These must be investigated, specially venting of a rupture disc or pressure relief valve activation of critical safety interlock (real or accidental), failure of critical safety interlock during scheduled testing, spill of Seveso, OSHA/PSM or United States Environmental Protection Agency or Risk Management rule listed hazardous chemicals below their threshold, fire, explosion, or implosion without significant consequences. (Wever 2022, personal communication.)

Thesis commissioner has created material release pyramid where different events are formed as a triangle form. Lowest at the pyramid are the foundations of the process safety metrics and highest are most significant process safety events. In figure 7 there is a visualization of the commissioner's material release pyramid.

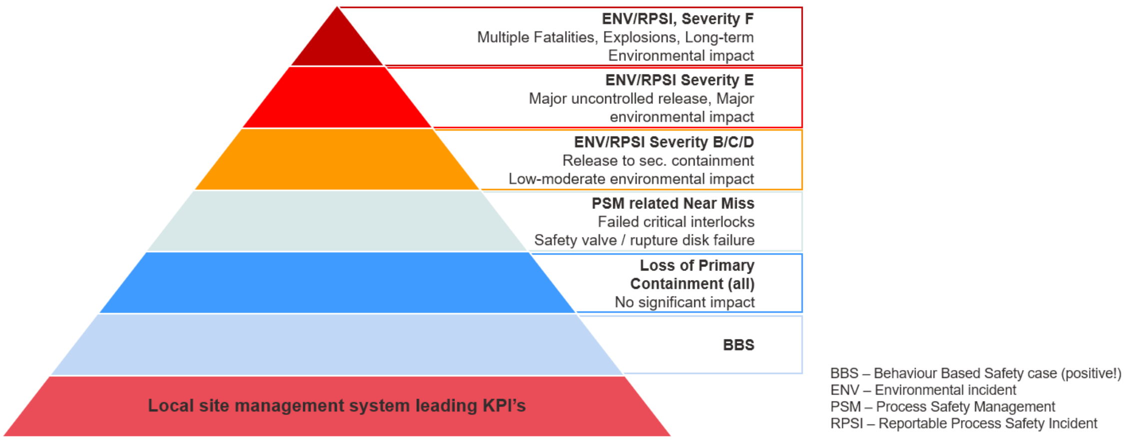

Figure 6: Material release pyramid (Thesis commissioner, 2021)

Environmental (ENV) incidents are unplanned releases of chemical, process material, waste, or pollutant more than 1 kg to the air, soil, or water (including ground water), or 3rd party offsite wastewater treatment plant. Releases which are contained in secondary containment are not considered as environmental incidents. (Wever 2022, personal communication.)

Loss Of Primary Containment (LOPC) is a leak outside e.g., pipeline valves, pipe fittings, storage tank, process vessel, hose, container, rail car, tank wagon etc. that is intended to fully contain the material and is not part of a planned maintenance activity like line breaking. LOPC is a spill or leak that exceeds 1 kg. LOPC does not include equipment that is designed to release material when opened like filter presses which remove solids from the system. LOPC includes any device or piece of equipment that is designed with the intention of containing materials to prevent the release to the environment. Pure water is exempt from this requirement. These rules apply also to company owned equipment that are located at the customer location. (Wever 2022, personal communication.)

BBS is a Behavior Based Safety observation of employee that is done by trained and competent person. (Wever 2022, personal communication.)

According to Hopkins (2014, 57-58), all accidents have a precursor event, and they should have their own triangle. In this theory typical injury triangle and major accident triangle overlaps each other at the precursor events. Occupational health and safety events like near misses or hazardous conditions and actions and process safety events such as leaks, and exceedances can be warning signs for both type of events. This is described as a two-triangle model on figure 5.

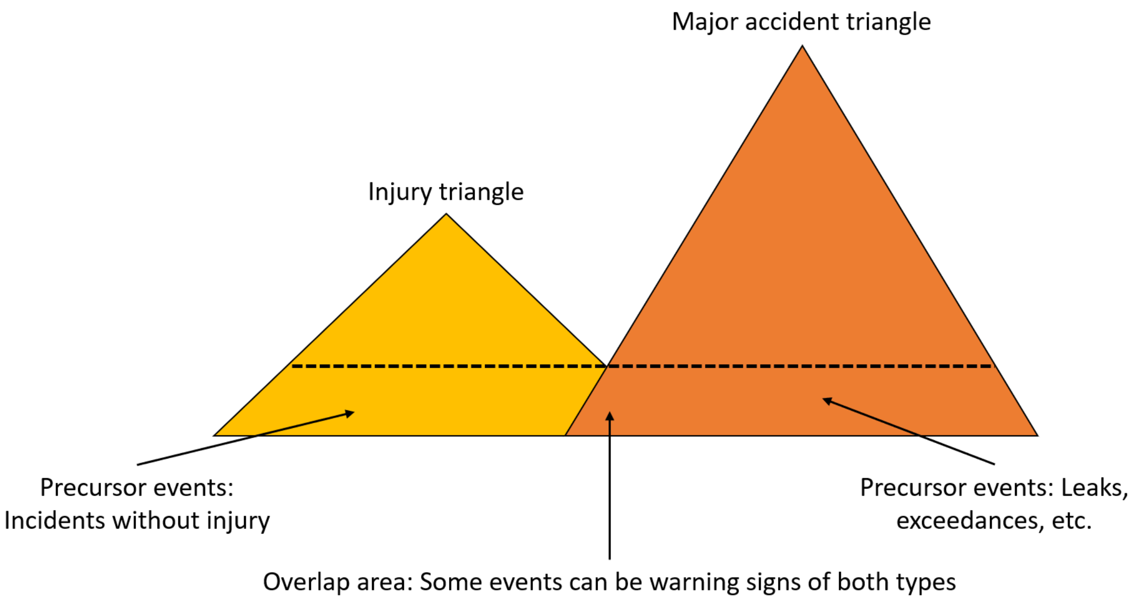

Figure 7: A two-triangle model (Hopkins 2014, 57)

The airline industry has recognized two-triangle thinking where flight safety and occupational safety are separated to two different triangles. Many airlines have two databases: one for flight safety near miss incidents and another for occupational safety incidents. They understand that incident such as slip of a flight personnel doesn´t tell anything about the risk of an aircraft crash. Sometimes companies mix up occupational health and safety metrics and process safety metrics. This was a situation at the BP Texas City refinery before devastating explosion in 2005. BP Texas City had a triangle model in use but the model didn´t consider Process safety events as a precursor of the major accidents. This led to the situation where process safety precursor events were not identified as a major accident hazard. (Hopkins 2014, 58-60.)

4.6 Incident prevention

System designers have defined 80:20 problem, where around 80 percent of accident are caused by human and only 20 percent are caused by technical failures. This has led to the situation where automation level has rapidly increased. Using of the high-tech computing power offers commercial advantages. (Reason 1997, 42.) According to Kletz, many accidents are blamed on human error. Usually this someone is at the bottom of the pile, and he cannot blame anyone below him. It seems that designers and managers don´t make errors at all or they are not humans. People make mistakes when they think that they are doing right thing, or they don't know what to do. In this, best thing is to simplify the job or make better instructions and training. In case someone violates the rules and decides to not to do task as it has been planned, correct way of working should be explained because the society we live does not make people do things as instructed even they are told to do so. Checks should be made to see if correct methods are in use because incorrect methods can be seen many months or years before accident occurs. It´s always good to consider if the job could be simplified in case safe way to perform it is difficult. People can also do mismatches on work in case the task is beyond his or anyone's mental ability. Usually, it is better to change work situation, not person. Slips and lapses of attention also occur in a situation where worker knew what to do, was able to do it but still either did it incorrectly or failed to do the task. This is common to human nature because humans are what they are, and they make mistakes from time to time. This kind of situations are almost impossible to prevent. Changing work situation to situation where are fewer opportunities for errors and less serious consequences is more effective way of preventing errors. (Kletz 2001, chapter 30.8.)

Everyone at the plant should always keep in mind that dangerous chemicals and processes are always present. The people should not only be trained to normal running of the plant, but they also should be capable to respond emergencies. This requires adequate knowledge and experience. Every operation of the safety trip or interlock should be reported and investigated. Also lessons from other plants and from similar industry should be followed up to keep incident awareness up to date. Past incidents should be regularly reminded. (Kletz 2001, appendix 2). Defenses that are designed to reduce human error can be relocated which can create more costly errors to other part of the system. Defenses can also be converted from protective to productive which can render system into a less safe state. Latent conditions can build up insidiously in case defenses are based on redundancy and diversity. Excess number of alarms that are meaningless cause situation where alarms of the true emergency are less likely reacted. Measures that are designed to mitigate previous, conspicuous incident can contribute to the next one. Defenses, barriers, and safeguards do not only increase safety, but these also make system more complex and can fail catastrophically in their own right. (Reason 1997, 58-59.) If unsafe operation is more practical than safe operation, people will follow unsafe method. System design basis should be, that it is not difficult to operate safely. (Kletz 2001, chapter 6.6.)

API recommended practice 754 (2017,8) defines that process safety event (PSE) is a material release that is uncontrolled and unplanned. This includes non-toxic and non-flammable materials like steam, hot water, nitrogen, compressed air, and compressed CO_2. To be defined as PSE, release must come from the process in undesired event or condition. Cases like office building fires or injury of employee, which is not caused directly from process, does not meet PSE criteria. (Guide for selecting leading and lagging indicators 2019, 10.)

Process incident indicates that the prevention of an incident or process controls are not effective. For this reason, it is very important to report and investigate all near misses and process incidents to prevent recurrence. The process incident must fulfill specified criteria to be classified as process safety incident. A fall from ladders which results LTI, is not a reportable process safety incident but in case if the fall is caused by chemical release, incident is reported as a PS-incident. (HSE and fire protection web page 2021.) It must be ensured that employees recognize, and report also Tier 3 & Tier 4 incidents, which are precursors and leading indicators to upper Tier incidents. These lower Tier incidents can be small leaks, safety interlock activations, or deviations of critical procedures. (Process safety fundamentals 2021, 34.)

Process safety management (PSM) (2021) describes that reporting threshold is a release of energy or chemical from the process which leads to one of the three situations: LTI, fatality or hospital admission. This applies to all employees, contractors, and third-party operators. Fire or explosion which has direct costs to the company or acute releases of hazardous chemicals from primary containment such as pipeline or vessel that exceed chemical release threshold. Incident location criteria has also been fulfilled: Incident must occur at production, storage, distribution, or pilot plants of a facility. Also, tank farms and distribution pipelines at the control of the site are included in this criterion. One hour rule is applied to the acute release. One hour rule describes that release reaches reporting threshold level in one hour or less. In case release threshold is not reached in one hour, incident is not treated as a Process Incident. In case duration of the leak cannot be determined, it should be assumed to be one hour. (Process safety management (PSM) 2021.)

4.7 The protection layer approach

The idea of layers of protection is a system where one barrier guards each other against possible threats. These barriers include alarms and warnings which alert potential victims of imminent danger. If automated system features can´t restore system to a safe state, physical barriers stand between hazards and potential losses. If all defenses fail, emergency response layer is the last defense against hazard. (Reason 1997, 7.) Large chemical inventories should be avoided to reach inherently safe design of the plant. All constructions should be inspected thoroughly during and after construction. If hazard is a gas, gas detectors should be installed to detect leaks. In case of a leak people should be warned and those who are not dealing with the leak, should be evacuated via safe route. Best way to isolate a leak is to shut down remote controlled emergency isolation valves. If gas is toxic, leak should be dispersed with water curtain or steam before it reaches people that are not trained to deal with them. If gas is combustible, ignition sources should be removed even this is one of the weakest safety measures. Flammable gas does not require much energy to ignite so even it has been tried to isolate all ignition sources a source of ignition can turn up. (Kletz 2001, chapter 30.1.)

Protection layers of the management systems can be illustrated like an onion, where inner layers are the preventive controls and outer layers are mitigating controls. If the design of the system is weak and doesn´t properly consider the safety of the process, loss of primary containment can occur. This activates mitigating layers, but if there are deficiencies like broken safety pool, incident can escalate and activate emergency response layer. Example of protection layer hierarchy is described in the figure 8.

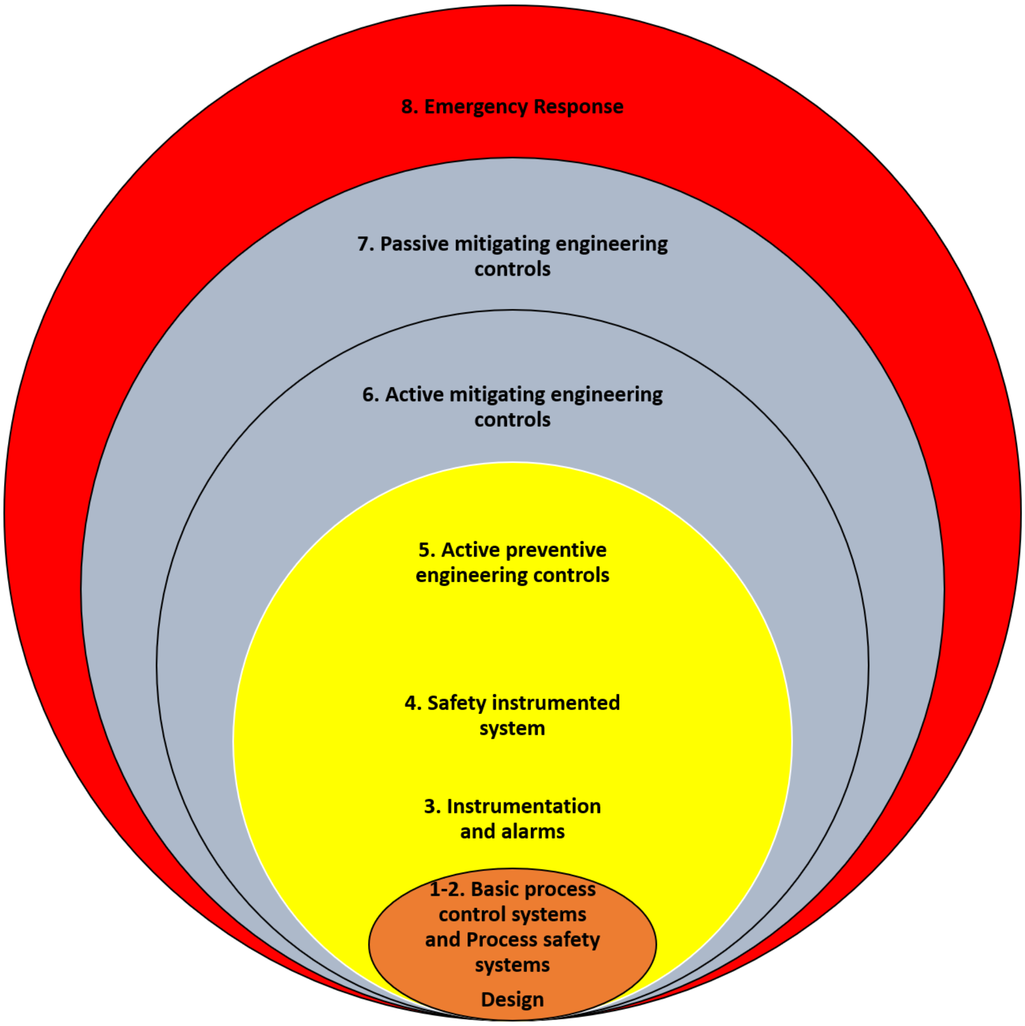

Figure 8: An example of Protection Layer Hierarchy (Guide for selecting leading and lagging indicators 2019, 35)

The core of the protection layers is Inherent safe process design, which is planned according to process chemistry. Design considers process safety information and process control instrumentation which monitors and controls process. Process safety systems include different kind of management systems, like administrative controls and risk management systems. Basic Process control systems are engineering controls that ensure that process is operated safely. Instrumentation and alarms are designed to be triggered when operation parameters deviate outside designed safe limits of the process. Safety Instrumented System´s (SIS) purpose is to be the last barrier between process, which is under control, and hazardous release. SIS can shut process down safely or generate emergency shut off. (Guide for selecting leading and lagging indicators, 34.)

Active Mitigative Engineering Controls includes safety devices such as flares, pressure relief devices and gas scrubbers. Passive mitigative engineering controls are designed to mitigate consequences of the accident. These include dikes and safety pools. Emergency response layers are combination of engineering and administrative controls. Engineering controls can include fire suppression systems such as sprinkler or foam systems. Administrative controls can include employees that are trained for emergency response and other emergency responders such as professional fire fighters. (Guide for selecting leading and lagging indicators 2019, 35-36.)

If these process safety risk mitigation barriers are weak, LOPC can occur if the detective protection layers (yellow in the Figure 8) fail. This results to activation of the mitigative layers (light blue in the Figure 8). If these layers fail, can it lead to the worst-case scenario, where emergency response is needed because of fatalities, injuries, environmental harm, or property damage (red in the Figure 8). (Guide for selecting leading and lagging indicators 2019, 35-36.)

4.8 Swiss Cheese and Spinning Disk theories

In James Reason´s Swiss cheese theory, there are protective barriers like cheese slices. Every barrier has got weaknesses which are described as holes in cheese. When holes align, hazard is released which results in consequence, in this figure harm. The process safety barriers can be independent protective layers such as mechanical engineered devices or behavioral controls of people. The holes can be latent or those can be opened actively by people. (API recommended practice 2017, 12-13.) Swiss cheese theory is described on figure 9.

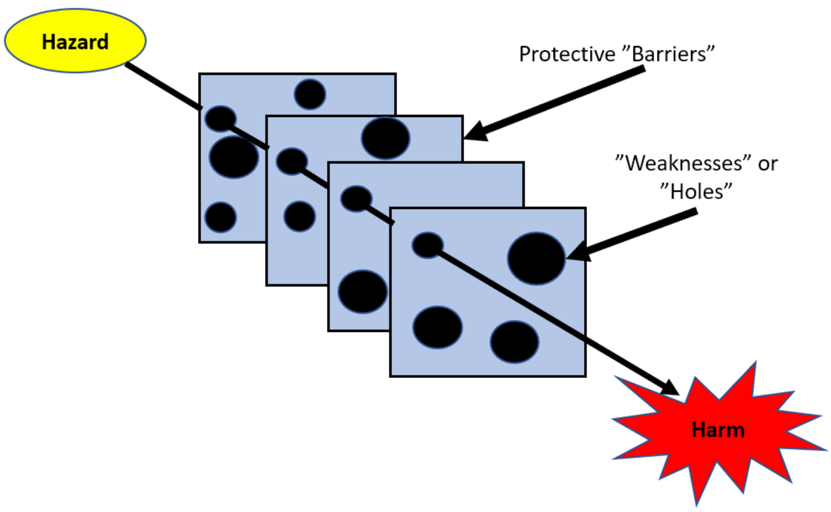

Figure 9: James Reason´s Swiss Cheese Theory (API recommended practice 2017, 13)

Holes in the Swiss cheese slices have probability to failure on demand and those failures are represented as holes. If cheeses slices are mitigating barriers, they always have some sort of consequences in case hazard passes the hole. (Guide for selecting leading and lagging indicators, 31.) Active and passive latent failures can create the holes (Reason 1997, 12).

Spinning Disk model is a modification of Reason´s Swiss cheese theory. In this theory protective barriers are spinning continuously and when the holes align, hazard is released. (API recommended practice 2017, 12.) In the spinning disc theory, protective barriers can be procedures, Personal Protective Equipment (PPE) or systems or devices, which are also called layers of protection. Layers of protection block the hazard beam from reaching consequence, in this case harm. Layers of protection do not always function 100 percent. This is called Probability of Failure on Demand (PFD). Holes in the disc are failures of the protective layer. Number or size of the holes increase if the reliability of the protective layer decreases. Failure of the protective layer is random, which is illustrated by spinning the disc. Also initiating event can be random. If all deficiencies of the protective layers align, these holes allow the hazard beam to pass through to the consequence, in this figure harm. (Spinning Disc Model. Center for Chemical Process safety Process incidents 2021.)

5 Process safety performance indicators and metrics

It is important to identify most critical hazard scenarios and their key risk control systems. Questions like what can go wrong and what risk control systems have we got in place should be asked. It is useful to search data of the previous incidents, audits, and inspections. From this data it is recommended to try to identify the factors which challenge integrity of the plant or equipment. Outcome of this should provide data what should be considered as critical indicators. (Developing process safety indicators 2006, 17.)

5.1 Process safety performance indicators

According to Reason (1997, 38-39) it is almost always possible to see warning signs before accidents happen. After accident, question “how could these warning signs have been missed or ignored at the time” arises often. With “20/20” hindsight after the fact, observer’s views events different compared to participants who had only limited foresight. Psychologist sometimes have called this “outcome knowledge”. The fact that some prior indications of accidents are true warnings only if you know what kind of disaster you will suffer. From the point of view of the involved persons, many of the accidents are “impossible accidents”. Only such safety indicators are worth developing that are used to drive improvement. This requires organization to focus attention on these. (Hopkins 2007, 12.)

Beale (2011, 217) has identified three main types of PSPI´s which are operational control indicators that are based on plant specific risks. These are defined to be in safe limits, general site indicators that are linked to safety systems like PTW, MOC and site risk assessments. Also, program indicators like measurement of percentage of completed scheduled maintenance and planned audit and percentage of procedures which are up to date are part of the main type of PSPIs.

PSPI´s should be easy to implement and understand by all stakeholders like employees. Employees should be explained what´s the difference between personal safety and process safety because they are normally very familiar with personal safety expectations and goals, but process safety requirements may be unclear. Employees should be shown that they also have connection to the process safety by pointing to them how many ways they can impact process safety. It is good to highlight process safety with past incidents and investigation results to show how they have impacted facility. (API recommended practice 2017, 77.) Unless safety indicators are not driving improvement, those are useless to be developed. Improvement needs organization´s focus and attention to them. (Hopkins 2007, 12).

5.2 Leading and Lagging PSPIs

API recommended practice 754 (2017, 11-22) defines PSPIs to 4 tiers, which are formed as Heinrichs incident pyramid. Tiers 1 and 2 are lagging indicators such as events that have lesser or greater consequences and Tiers 3 and 4 are leading indicators such as management system performance indicators and challenges to the safety system. These are described below in figure 10.

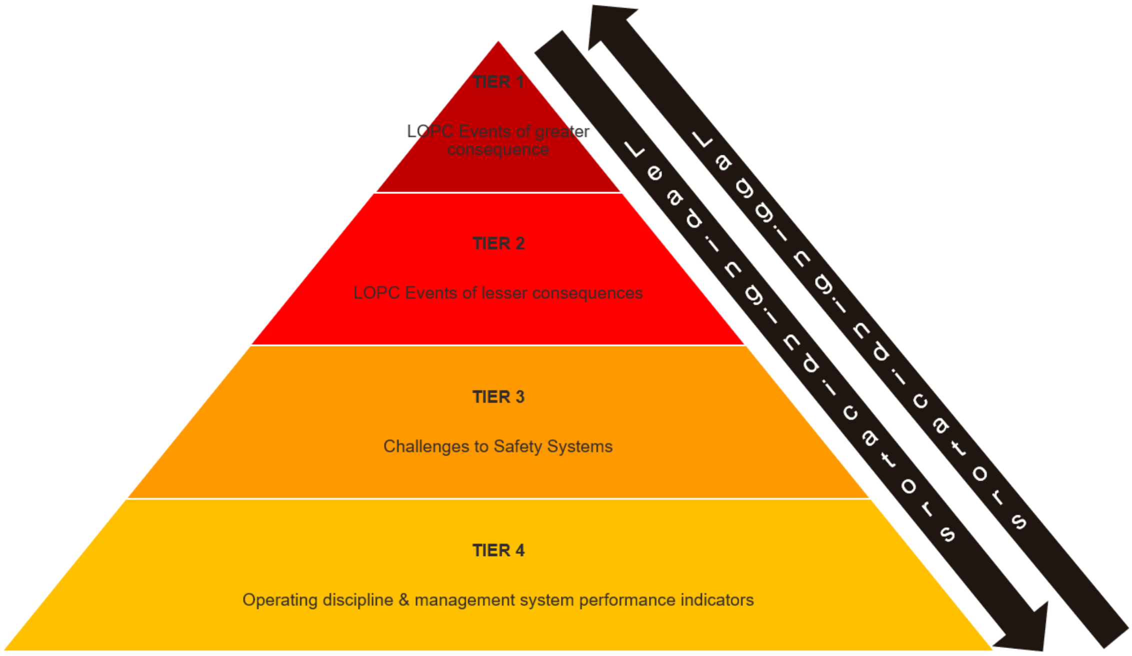

Figure 10: Process safety Indicator Pyramid (API 2017, 12)

Tier 1 is a LOPC and most lagging PSPI. Its purpose is to represent greater consequence LOPC´s that are barrier system weaknesses. Tier 2 is a LOPC with lesser consequence. These events indicate weaknesses that may have potential for more significant events in the future. Tier 2 is a leading indicator for Tier 1 events. Tier 3 event is precursor for Tier 1 and Tier 2 events. These events represent challenges to barriers that are between hazard and harm and provide opportunity to identify weaknesses within the barrier system. Tier 3 indicators are so facility specific, that it is not possible to develop industry applicable criteria. Tier 3 events are intended for company´s internal use. Tier 4 PSPIs are facility specific barrier systems and performance objectives. Indicators at this level provide information of the process safety system weaknesses that can lead to the Tier 1 or Tier 2 events. Tier 4 indicators are intended for company´s internal use. (API recommended practice 754 2017, 11-22.)

Leading indicators are measures of controls before incident has happened (Beale 2011, 468). These indicators can be described as protective barriers in a swiss cheese theory by James Reason (1997, 12). HSE publication 2006 (8) describes that leading indicator can be engineering, and maintenance related such as plant MOC, and inspection and maintenance. Administrative leading indicators can be qualified personnel and PTW system. Leading indicators look at the safety systems that are proactive and prevent a loss of control of the process (Beale 2009, 271). Leading indicators can be considered as process measures that are essential to deliver desired safety outcome. Leading PSPIs should be checked systematically to ensure that key actions are undertaken as intended. (Developing process safety indicators 2006, 7.)

Lagging indicators measure failures like incidents (Beale 2011, 468). Lagging indicators are holes in a Swiss cheese theory (Reason 1997, 12). Otherwise said lagging indicators are reactive measures of recorded failures in control. Lagging indicators do not only measure leaks but also safety critical system failures and operations outside safe limits. (Beale 2009, 271.) Figure 11 illustrates accident trajectory model, where hazard passes all holes in the protective barriers, which results in accident.

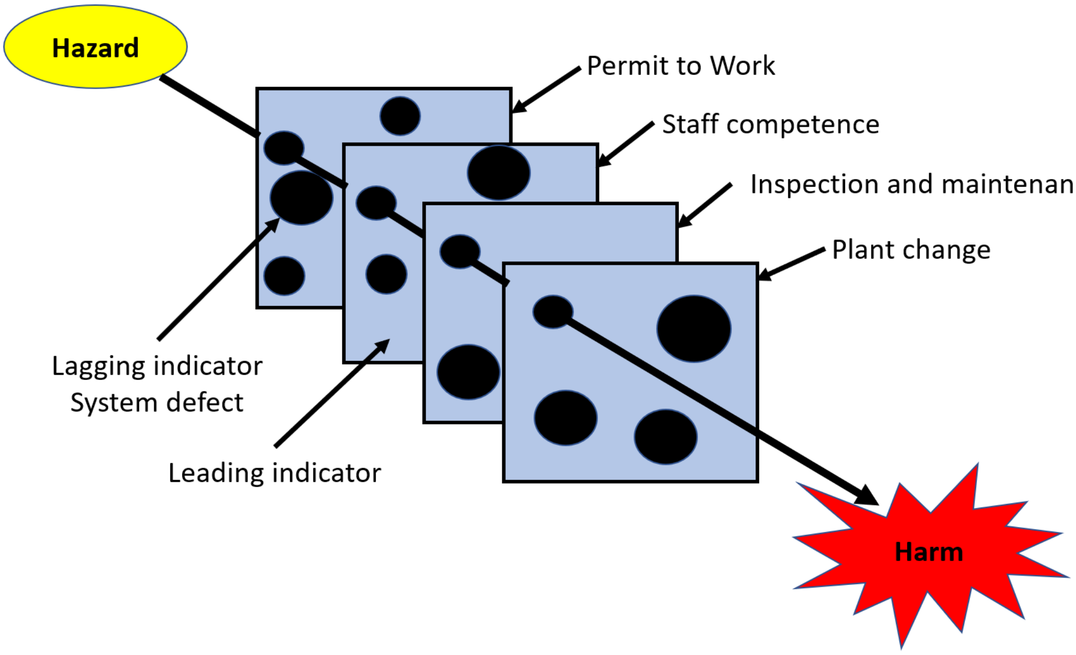

Figure 11: Leading and Lagging indicators set to detect defects in important risk control systems (Developing Process safety Indicators 2006, 8)

These protective barriers can be administrative like PTW and staff competence. Also, operative barriers like inspection and maintenance and plant change can be other protective barriers. These barriers are considered as leading indicators and holes in these barriers are lagging indicators. (Developing process safety indicators 2006, 7-8.) If these barriers, Risk Control Systems (RCS), are unchecked, they will deteriorate over time and may cause major incident when RCS fail one after other. By setting leading and lagging indicators should prevent failing of all barriers and before they all are defeated. (Developing process safety indicators 2006, 8.)

PSPIs should supplement existing safety management systems, not replace them. EHS audits should be carried out and audit findings should be closed. Incidents should be reported, and trends should be analyzed to detect weak controls and to identify problem areas. MOC system should be implemented, and actions should be closed out correctly. Risk assessments should be done to mitigate major accident scenarios. PSPI´s should be communicated to all levels of organization from front line staff to senior managers. Safety reports provide demonstration of the system effectiveness and that the process safety continuous improvement system is in place. (Beale 2011, 469.)

PSPI´s should be reliable, repeatable, consistent, independent of outside influences, relevant, comparable, meaningful, appropriate for intended audience, timely, easy to use and auditable. When selecting indicators, those should be selected so they drive process safety performance improvements. On selection process, hazard evaluation and risk assessment should be used to identify critical events with high impact and barriers against them. During the process, questions like what can go wrong, what are the consequences, what is the likelihood, which are the most critical barriers and how vulnerable are the barriers to rapid deterioration should be asked. It is recommended to use internal incident investigation results and external learnings to identify potential barrier failures. When doing analysis, employees, process safety professionals and engineers should be involved. (API recommended practice 754, 24-25.) PSPI´s should be decided and reviewed every few years to ensure that those reflect main process risks. In case new process is introduced, plant design has been changed or staff or competence has been lost in certain areas, PSPIs should also be reviewed. If review is not done, indicators may become meaningless, and they don´t give assurance anymore to senior management that the hazards and risks are under control. (Developing process safety indicators 2006, 27.)

PSPI program can be designed with various approaches. These can be high level, where companies benchmark against each other's or lower level where PSPI´s are defined for specific risks that plant operations face. Beale (2011, 471-472) has identified six different models that organizations have implemented. The insurance model is focused on Top 10 risks that are insurance company's concerns based on historical experience of large industrial accidents. This approach measures site performance level compared to company sector level, but the disadvantage is that site specific risks might not be identified. According to Beale, Taylor has developed the analytical model. In the model high consequence accidents has been analyzed to identify critical organizational vulnerabilities that are implicated to the events. This model should be used as a high level PSPI instead of plant specific PSPI. In the industry sector model group of similar type of companies co-operate and create a PSPI template to be used at all sites. These PSPIs are not fully suitable for every site and all operations but especially companies with low numbers of people and technical resources can save time and effort when they can select PSPI´s that suit their operations. The accident rate model is similar as traditional Occupational Health and Safety (OHS) model. In this model metrics are defined as a ratio of process safety incidents per million work hours. The plant specific model´s advantage is that it focuses on plant specific PSPIs. Disadvantage is that it requires resources and technical expertise to define PSPIs. This model can be linked to other models for more generic indicators. The LOPC model is based on collection of lagging PSPI data which is mostly from lower scale events such as small leaks that haven´t had significant impact to people, property, or environment. LOPC model data can be benchmarked between sites and even companies. When selecting performance indicators, it is recommended that decision of what should be on the scope; organization, site, plant, or installation, should be made. Indicators of plant level provide specific information of the activities selected. Site level indicators may provide summarized information of the whole site activities such as contractor management, emergency arrangements and staff competence. (Health and Safety Executive 2006, 14.)

Performance of the PSM system should be reviewed routinely to give assurance that critical systems are identified correctly, and them continue to operate as intended. There might be variation between performance of leading and lagging indicators. If performance of the leading indicators is poor but lagging indicators performance is satisfactory, it is possible that leading indicators are too far from critical control measure. If leading indicators are on target but lagging indicators show poor performance, it shows that risk control system is not functioning as intended. Indicators should be reviewed every few years to ensure they reflect main process risks. If new processes are introduced, existing plant design has been changed or there has been changes in the organization that has led to the loss of competency, review should be done immediately. Also, tolerances, that has been set, should be reviewed, because those might not be right at the first time. (Developing process safety indicators 2006, 26-27.) If there are no actions based on deviations of indicators, there is no point to implement safety performance indicator system (Guidance on developing safety performance indicators related to Chemical Accident Prevention, Preparedness and Response Guidance for Industry Second edition 2008, 26).

5.3 Process safety metrics

There is a need for both, leading and lagging metrics. Most process safety metrics are based on lagging metrics, but because of the nature of the PSE, which probability is low, and consequences are high, it might be possible that there is not enough PSI available to get long enough trend of the events. Leading metrics may indicate better the process safety level of the organization. Most important is to define correct measures for the process safety control and incident response. It is recommended that both leading and lagging metrics data should be used when developing process safety. Selection of the process safety metrics shall be based to the risk assessment of the site. (Prosessiturvallisuus ja sen mittaaminen 2016, 9-10.) At small sites, where harmful process safety events are rare, metrics should be concentrated to more often occurring precursor events (Hopkins 2007, 6). Data related to process safety metrics is commonly available but there is a possibility that organization does not utilize it. Process safety metrics should be integrated to already available metrics such as financial metrics. (Prosessiturvallisuus ja sen mittaaminen 2016, 11.)

Centre for chemical process safety CCPS recommends that companies should implement leading process safety metrics that also measure process safety culture. It is important to identify components that are most important for the safety of the facilities. Leading metrics should be meaningful, which have most significant potential for performance improvements. (Process safety Leading and Lagging Metrics. You don´t Improve what you Measure 2011, 29.) Proactive metrics show needs for actions in case of deviations outside defined limits. They also show why safety target was not achieved. These metrics also are measures of the process integrity, and they reflect latent conditions of the incidents, like safety culture and leadership. (Prosessiturvallisuus ja sen mittaaminen 2016, 9.) A near miss is described by Guide for selecting leading and lagging indicators (2019, 25) that it has got three essential elements: an unexpected event occurs, or a potentially unsafe situation is discovered, the event or unsafe situation had reasonable potential to escalate, and the potential escalation would have led to significant adverse consequences. Other way described near miss is a situation where incident causing fatality or permanent injury, significant property damage, or significant environmental harm could almost have happened (Guide for selecting leading and lagging indicators 2019, 25).

Examples of process safety Near Misses are e.g., safety relief device activations like pressure relief valve or rupture disc opening to atmosphere or failure of the rupture disc or pressure relief valve. Activation of the Safety Instrumented System (SIS) when process runs “out of acceptable range” like in case where process shuts down when interlock of high pressure of reactor reaches its limit. Also, failures of SIS are reportable near misses. Process deviations such as critical process parameter like pressure, temperature, or flow outside work window, but within design limits, activation of the emergency stop, using the equipment outside of the design parameters and unusual or uncontrolled response are considered as process safety near misses. Management system failures can also be process safety near misses. These should be understood to see opportunities for improvement. Failures of a safety systems, like interlocks, gas detectors and emergency shutdown systems are also process safety near misses. Process control system´s interlocks can be bypassed and left bypassed by accident or process control engineer can accidentally download incorrect configuration to the process control system unit. Equipment can also be in unexpected state due to damage or unexpected deterioration. (Process safety management (PSM) 2021.)

Lagging metric can be described as e.g., challenges to protective layers which include near miss incidents (Center for chemical process safety 2019, 7). Lagging metrics doesn´t give information of the actions which could improve safety, but they help to evaluate the quality of the leading metrics. They also give a possibility to identify system weaknesses after process safety events. (Prosessiturvallisuus ja sen mittaaminen 2016, 9.)

6 Safety improvement programs

Goal of the process safety metrics program is to provide organization insight of the systems like policies, programs, procedures etc. are not functioning as intended or have deteriorated over time. Program also identifies actions that might be needed for correction. (Guidance on developing safety performance indicators related to Chemical Accident Prevention, Preparedness and Response Guidance for Industry Second edition 2008, 9.) Risk assessments of the site are the basis of the metrics. When developing metrics, relevant question is how incident prevention plans and equipment function as intended. (Prosessiturvallisuus ja sen mittaaminen 2016, 12.) Behavior based safety program is also important to reduce number of incidents (McSween 2003, 4).

6.1 Implementation of the process safety metrics

Decision of the scope of the indicators should be made in the whole organization, an individual site or an individual installation or plant. Organizational level indicators are more generic, and plant or site level will be more focused on key activities. When selecting indicators, it should be remembered that quality is more important than quantity. Management teams lose interest of KPI´s if they are overloaded with information. When selecting leading and lagging indicators, those should be linked to each other for dual assurance that risk is being managed. It´s important to identify hazard scenarios that can go wrong. These differ from site to site: bigger Control of Major Accident Hazard (COMAH) or Seveso sites have got detailed reports of the hazard scenarios, but smaller sites might have to first identify how major accidents can occur. (Developing process safety indicators 2006, 13-17.) Beale (2009, 216) suggests that at this stage any chemicals or plant areas that have not major accident hazard should be screened out. Indicators should be based to the plant risk assessments and plans of incident prevention. Simplified risk assessment asks questions like what can go wrong and what are the consequences. During the assessment it is good to think about e.g., storing and using of hazardous chemicals. (Prosessiturvallisuus ja sen mittaaminen 2016, 12.)

Decision of the scope of PSPI program should be made based on the identified issues of concern. After this, there might be a need to limit amount of performance indicators to focus on most important ones. At the beginning it is advised to start with few prioritized indicators and increase amount after more experience has been gained. Pitfall of this process is that organization ask questions what they can measure instead of question what they should measure. Result of this might be that organization finds indicators that are most obvious but not most valuable for safety purposes. At this stage of the process question what to monitor should be asked instead of question how to monitor. (Guidance on developing safety performance indicators related to Chemical Accident Prevention, Preparedness and Response Guidance for Industry Second edition 2008, 14.)

It is suggested to set lagging indicator to see if outcome is achieved. If desired safety income is not clearly identified, identifying of the indicators that show the desired outcome, will be impossible. Mitigation for each risk should be in place to prevent consequences of these events. After hazard scenarios have been decided, and risk control systems, that are mitigating consequences, are decided, desired safety outcome should be expressed. If a risk control system has been on a place for a long time, it might be difficult to describe the outcome of it. Questions like why we have this risk control in place, what does it deliver in terms of safety and what would be the consequence if we didn´t have this system in place, can be helpful. Lagging indicator should be set to show is desired outcome achieved. It should be possible to use just one indicator if desired outcome has been clearly described. Even indicators are set up, they will not lead improved performance if they are not followed. Lagging indicator failure needs to be investigated to see why system failed. This helps to make decisions for needed improvements. Lessons of these incidents should be shared across the whole organization. (Developing process safety indicators 2006, 18-21.)

After indicators have been selected, data collection and reporting system should be established. Usually, companies have data already available, but it is used for different purpose like quality control or business efficiency. Ideally data should be compiled by one person who is also responsible for reporting it to management team. Presented data should be kept as simple as possible. Systems like graphs, charts and dashboards are good way to do presentation. Also smile faces and traffic lights can be used to show is process safety doing well or not. It´s good to remember that data is useless unless it is used to improve health and safety. (Developing process safety indicators 2006, 25.) If threshold metrics are used, there should be procedures that describe which is the point when deviations need some actions to change them to correct level (Guidance on developing safety performance indicators related to Chemical Accident Prevention, Preparedness and Response Guidance for Industry Second edition 2008, 24). Beale (2011, 470) suggests that reporting systems for SLT meeting structures, site initiatives and existing management systems should be complemented. Process safety should be considered at key business decisions and key process safety issues should have right degree of focus. Reporting system should be integrated to all site levels and SLT attention should be drawn to the most critical risk control systems. SLT´s should understand the intent of indicators to learn from events and to drive performance improvement actions in process safety performance. Process safety presentations held face to face with examples of past incidents establishes improvement need in process safety performance (API recommended practice 2017, 79).

Each risk control system critical elements should be identified that are vital to deliver the outcome. The leading indicators should be set for monitoring effectiveness of the risk control systems. Monitoring of every part of the risk control system is not necessary. Questions like “which activities or operations must be undertaken correctly on each occasion, which aspects of the system are liable to deterioration over time and which activities are undertaken most frequently?" will help to identify critical in delivered outcome. Leading indicators should have tolerances that will be set by management team, not the person responsible for the activity. Tolerance can be zero, which means that 100% of actions must be made by the schedule. Tolerances should be set because then the performance can be evaluated, and intervention is possible if deviation has gone outside accepted limits. (Developing process safety indicators 2006, 22-23.) Metrics for each indicator can be helped to be developed by asking questions like "who will use the indicator to make decisions, how will the indicator be used to make decisions and how can the activity be measured?". Using of existing data is recommended but if such data is not available, it should be considered that what are the methods for data collection, that are consistent with organizations measurement culture. (Guidance on developing safety performance indicators related to Chemical Accident Prevention, Preparedness and Response Guidance for Industry Second edition 2008, 22.)

Once indicators have been identified, it is needed to decide what are the appropriate metrics. Raw material of the PSPI´s is safety data and data are used the way metrics define. It should be considered what metric is appropriate for PSPIs in program, who will use PSPI and how to highlight metric that is useful for end user. Different type of metrics is useful for all kind of indicators. Descriptive metrics are basis for threshold or trended metrics. Descriptive metrics include simple sums, which describe e.g., how many people have participated in preparedness planning or how many safety reports have been submitted of installations. Percentage metrics describe sums divided by totals e.g., how many percentages of employees have participated on emergency response training and how their performance has been. Composite metrics are more complex, and they describe e.g., percentage ratio between inspected installations and non-inspected installations. Threshold metrics like single threshold or multiple thresholds compare either single metric to single tolerance level or multiple different types of metrics to multiple tolerance levels. (Guidance on developing safety performance indicators related to Chemical Accident Prevention, Preparedness and Response Guidance for Industry Second edition 2008, 20.) Trended metrics are metrics which describe metric value over time. These metrics can describe e.g., reported incidents, difference between annual reports of incidents or percentages of reported incidents of previous year. Trended metrics can be simple trends, which can show e.g., safety change results over time or indexed on variable metrics which can describe e.g., ratio between production amount and incidents. Indexed on data set, metrics can be e.g., long term monitoring of employees. Nested metrics use above-described metrics to safety related data for e.g., senior managers to show deviations within time. (Guidance on developing safety performance indicators related to Chemical Accident Prevention, Preparedness and Response Guidance for Industry Second edition 2008, 20.)

Usually, a project for developing process safety metrics, starts by selecting the project group and responsible champion. A champion is usually organizations safety professional who is familiar with the risks of the site. The champion is needed to promote new concept and system. He or she also links process safety to other Health, Safety, Environment and Quality (HSEQ) system as well as quality management system. He or she should gather information and communicate the results with others working in this area. Project implementation team is important because workload may be too high for one person. Larger group has benefits such as more collective ideas. Involving employees increases ownership of the risks and control. Senior management should be involved because they are the main customers for risk assurance information. Senior management also should participate process so they can understand the process safety benefits for successful business. Senior managers should give appropriate resources and support for the implementation of process safety indicators. (Developing process safety indicators 2006, 11-12.) It is also important that the senior management understands the meaning and importance of the process safety (Prosessiturvallisuus ja sen mittaaminen 2016, 12). Senior management should show example on paying attention to the process safety. By emphasizing process safety, knowledge is increased at the employee level. (Prosessiturvallisuus ja sen mittaaminen 2016, 5.) Senior managers have specific need for the PSPI´s that are not too detailed. Site Leadership Team (SLT) has got multiple tasks to manage, and process safety is only one of them (Beale 2011, 469). It´s essential to get senior leadership support for the indicator program (API recommended practice 2017, 76). It is not reasonable to overload SLT with huge amount of PSPI´s. (Beale 2011, 469.) Meaningless indicators or too many indicators may result situation where senior leaders are not capable to understand presented information. This creates a situation where they also are not able to respond presented information. (API recommended practice 2017, 76.)

Experts and employees should be involved to get a detailed understanding of the relevant policies, programs, procedures, and practices. It might be reasonable to analyze costs and benefits of the project as part of the budgeting process to reserve sufficient resources. Team should develop reasonable timetable with milestones of the program. Test period might be useful before full implementation of the metrics. (Guidance on developing safety performance indicators related to Chemical Accident Prevention, Preparedness and Response Guidance for Industry Second edition 2008, 12.)

6.2 Behavior Based Safety (BBS) observation program

Du Pont is an old chemical company that has been focusing on their personnel safety for a long time. They found out 1929 that 88 percent of their injuries were result of an unsafe action, not unsafe conditions. DuPont has got Safety Training Observation Program (STOP) that it also promotes it outside company. STOP program involves trained observers to perform formal, regular safety audits of all employees including supervisor and manager level. Observations are collected on STOP cards, where safe and unsafe acts are marked. After the observation the observer approaches the employee who has been under observation and asks two questions:

“What could happen?” to help employee to identify if there is a risk for incident. Second question “How could [the employee] do the job safer?” helps the employee to pinpoint how to do that. (McSween 2003, 4-5.)

Burns has described in the McSween´s book Values-based safety process second edition (2003, 157-162) how performance management of the employees prevent also serious accidents. This includes involvement of the employees and measuring of their safety performance. Feedback and reinforcing of the safe behavior are also important during the process. Burns also gives examples of the serious incident prevention process, where volumes of the leaks and spills have been reduced from 50 to 1 in three years after the implementation of the BBS process. Effective serious incident prevention process is heavily linked to organizations capability to identify their critical tasks and managing these tasks complex details. Keys to the successful process is management commitment and raising this to the top priority of the organization. Employees expertise and knowledge should be harnessed to the process is essential to get most out of the limited resources of the organization. The organization must understand and manage risks before incidents happen at the location. It is recommended that organization looks into the future and considers that what can happen instead of looking into the past and think what has happened. Identifying critical tasks and work is essential to control risks. These tasks include employee training preventive maintenance, equipment testing and inspection, emergency response drills and observations that include feedback to employees. Safe behavior reinforcement sustains people´s safe activities and shapes the organization to achieve safer workplace. Outstanding safe performance should be recognized, and unsafe behavior should be interrupted as early as possible to prevent incidents. Workplaces change all the time so change management for organizational changes is important to maintain incident free operations.

The commissioner of this thesis has implemented STOP program with a name Behavior Based Safety (BBS) observation program few years ago. BBS observations are one indicator of their process safety material release pyramid. Research question for the process safety specialists of the different organizations was “how to integrate BBS-program with process safety?”.

Björkhem (2021, personal communication) says that identifying unsafe behavior and reasons behind it is a possibility to improve e.g., is the unsafe behavior related to inadequate tools, knowledge, or training etc. He mentions that when behavior is digged deeper, reasons are often human factors related the way or other. He believes that BBS observer should have a clear topic when he goes to the observation tour. Observer could use specific checklist like Lock Out, Tag Out (LOTO) to help the process. BBS observation tours should also be separated of the regular safety walks, which purpose are sometimes mixed. Björkhem also pinpoints that safety walks should focus mainly to housekeeping, installations, equipment, pathways etc.

Takala (2021, personal communications) mentions that PHA, Job Safety Analysis (JSA) and Standard Operating Procedures (SOPs) are excellent tools when they are used correctly and discussed with the employees. He also proposes that BBS discussions should be guided towards process safety instead discussing e.g., Personal Protective Equipment (PPE). Also, discussion, that is operator aware of the safe operating limits of the process, what kind of limits there are and are there safety interlocks, could be reviewed. Discussion of the bypassing of the interlocks should also be done with the focus that those should not be bypassed in any case, instead interlock is broken and interferes process.

Wever (2021, personal communication) suggests that BBS questionnaires should be short and concentrate on hazardous activities like practical use of PTW and LOTO. This would shift focus from the quantity of the BBS observations towards quality. Juanmarti (2021, personal communication) gives examples of the elements of process safety that could be checked during BBS-observation. These include checks of contractors and how they follow safety rules and procedures at their tasks to minimize process safety risks. During BBS-observation it could also be checked that how contractor has understood and follow existing operational procedures. Training needs can also be identified during BBS-observation. Work permits are important for process safety and written permits can be checked to see are risks under control and are the permits approved as instructed. Observing conditions of workplace, like leaks or spills and housekeeping gives perception of the asset integrity and helps to identify gaps on preventative maintenance plans.

Bonaldo (2021, personal communication) has been considering that it is important to connect consequences and root causes to behaviors. The way those can be connected can be via engineering and process, like lack of process, inadequate process to address the task observed, failure to maintain the process and process upgrades that were not properly trained or communicated to employees.

7 Thesis process

Thesis process description has been divided to four different phases which were pre-planning, data collection and analysis, recommendations and conclusion and thesis publishing. The Process started in January year 2021 and was finished in November 2022. Originally thesis was supposed to be finalized during the year 2021, but writer´s balance between personal life, work and studies forced to have breaks at writing the thesis during years 2021 and 2022. Thesis process has been described in the figure 12.

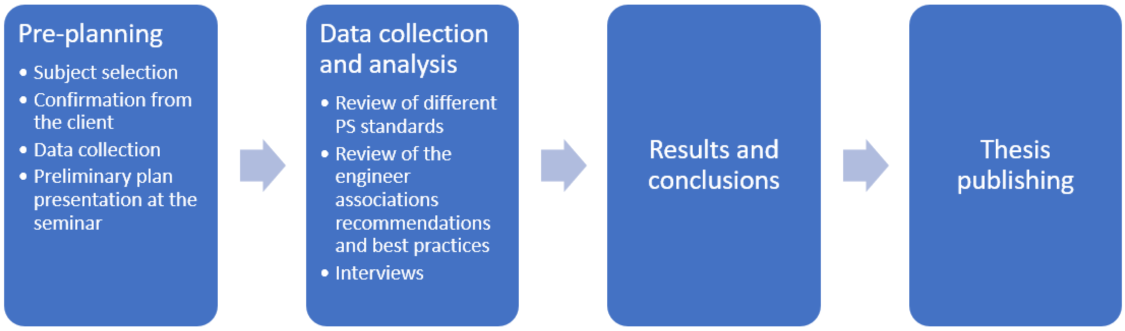

Figure 12: Thesis process

Thesis process started from the needs of the commissioner site, that had planned to introduce process safety indicators and metrics to their daily operations. Thesis process planning started earlier that 2021 when process safety was defined partially as thesis writer´s responsibility. The focus of the of the literature review was to familiarize thesis writer to the topic. Thesis was planned to be a development work for the commissioner, which included integrative literature review and structured interviews.

Pre-planning phase included subject selection and approval from the thesis commissioner and school representative, preliminary planning, and presentation of the thesis plan at the seminar. Implementation of the study questions, topic delimitation and data collection analysis method selection were also important part of the process. During the planning process literature review and interviews were selected. Aim of the data collection was to gather information of the past incidents, incident learnings, leading and lagging process safety Indicators and how to convert indicators into metrics. The core of the collected data was engineering associations publications and different process safety related standards.

When thesis knowledge base was almost ready, commissioners' material release pyramid was inspected more detailed, and it was noted that BBS-observations were at the foundation of it instead of personal injury pyramid, which would have been more logical, because BBS-program´s intention is mainly to prevent personal injuries. This was interesting so research question "how to integrate BBS program with process safety?" was formed.

Literature review is a method to study existing studies and to transfer these into new studies. In this thesis integrative literature review was selected as a study method. Literature review´s purpose is to create basic knowledge of the topic and to increase process safety knowledge of the writer. Good integrative literature review creates foundation for interviews. During the literature review it was noted that there were multiple sources of risk management, incident learnings, process safety standards and process safety key performance indicators. One problem that writer faced, was that there was so much literature available, that only most relevant had to be chosen.

Integrative literature review was done by first reviewing API recommended practice 754 (2017), which is foundation for many other engineering associations process safety publications. API recommended practice 754 is mainly concentrated on refinery industry, so it´s content did not straight fit to the scope of the study because thesis commissioner site produces inorganic chemicals. After API recommended practice 754 was studied, it was time for reviewing different engineering association process safety publications and OSHA standards. This review showed that there are different kind of themes like process safety fundamentals and incident prevention guidelines. Literature reviews intention was to get tools to present process safety as a subject that also non-engineers, like environment, health, safety, and quality specialists can understand and implement it to their workplace in case needed. Different themes are separated on own themes in this thesis. Purpose of the thesis process was also to do wider interview for process safety specialists, but during the literature review, only open questions appeared to be that how commissioner could better implement behavior-based safety program to the process safety. There was also need for detailed explanation for the commissioners personal and material release pyramids abbreviations, which were explained by specialist in an interview.

Literature review was conducted both years, 2021 and 2022. Part of the Interviews were carried out during the literature review in 2021 by e-mail and one interview was carried out by phone because the interviewee was in different country than interviewer in 2022. Thesis development versions were discussed with commissioner´s contact person and thesis supervisor. Work was modified according to comments and improvement proposals during the process. Interview questions can be found from appendix 1.

8 Results

Process safety risk management requires lots of systematic work e.g., risk analysis and assessments, PHA´s, MOC´s, equipment inspection and maintenance, and incident investigation. Developing process safety performance indicators and metrics is a teamwork of competent persons. Usually there is a need for responsible person, who is steering the development team. Steering team defines PSPI´s which are the foundations for metrics. Behavior-based safety program is important because most of the incidents and accidents are caused by hazardous actions, not hazardous conditions. Thesis commissioner presents their leading and lagging safety KPI´s as two separated pyramids, but those could be combined like Hopkins has presented in his two-triangle model.

8.1 How to manage process safety risks?

Managing process safety risks is quite complex and it requires program that includes different elements. These elements are divided to four categories which are knowledge and operational control, hazard identification and controls, participation and management and incident learning and response. These all include subcategories that are related to knowledge and skills of employees. (HSE and fire protection 2021.) Employer is responsible that all process relevant risks are written in process safety information before PHA is done (OSHA standard 2000, 7). McSween (2003, 162) has stated that most workplaces change all the time, so managing technological changes with MOC-system is important to keep process equipment in safe state (OSHA standard 1994, 13). Temporary changes have caused many accidents during years so managing them is important to keep risks under control before temporary changes become permanent (OSHA standard 1994, 16). All plant modifications should be checked by competent person. When doing check, it should be remembered that everything that seems not to be right, usually are not right. (Kletz 2001, chapter 7.1). Process equipment should be inspected and maintained according to manufacturer's specification, and it should be verified that all materials are suitable for application (HSE and fire protection 2021). Equipment can be highly reliable, but they can still be unsafe. Even no-one has reported failures, it does not guarantee that equipment is safe. (Kletz 2001, chapter 29.4.) Learning from accidents is important for all organization so they can prevent similar accidents in the future. These investigations should go deep to find out real root causes. (Kletz 2001, introduction.) Also, near misses of incidents should be investigated similar way as accidents (OSHA standard 2000, 23). Last barrier of the process safety management is emergency response, that should be planned and coordinated. Emergency response plans should be made against major fires, explosions, toxic emissions, oil spills etc. These plans should be reviewed so they comply with plant changes. (HSE and fire protection 2021.) All process safety related information should be shared with all employees (HSE and fire protection 2021).

According to all interviewees and e.g., ISO standard (31000:2018) process safety risk management needs commitment to process safety and process safety culture. Site must be following process safety standards and responsible persons should be competent to process safety. Employees should also be involved in design and decisions. Hazard and risk identification and analysis is important for understanding risks of the site.

Up to date operating procedures and safe work practices are part of the risk management. Equipment integrity should be analyzed, and reliability should be evaluated on regular basis. If reliability analysis indicates that integrity is going to be threatened, decision for next steps like replacing the equipment or increasing the preventative maintenance must be made before equipment break down when in use. Contractors should be managed, and all employees should be trained to site hazards, process safety and emergency response. Robust management of change program should be developed and followed to verify that plant will not have temporary changes that are note documented.

Learning of incidents is important to prevent similar incident in the future. This should include competent incident investigation before corrective actions are defined. Safety measurement and metrics describe the safety level of the plant and should be followed on regular basis by management.

Management review should be conducted on regular basis and plant and site risks should be evaluated with the team. Auditing of the site against corporate and e.g., ISO standards will show strengths and weaknesses of the site processes. Management should remember that continuous improvement drives whole organization towards safety.

8.2 How to develop process safety performance indicators and process safety metrics?

During the study it was noted that process safety metrics development is teamwork, which requires competent people across the organization. Different sources define that when selecting PSPI´s, risks should be evaluated and PSPI´s should be linked to existing KPI´s. Quality of the PSPI´s should be on scope, not the quantity. (Developing process safety indicators 2006, 13-17.)

PSPI´s are the foundation of the metrics, which results should be evaluated from time to time. Reporting of the results for senior management is important to keep them updated of the current process safety status of the plant. Data should be followed up and corrective actions should be made according to the results. It should be noted that metrics are not static, and they can evolve. Process to develop process safety metrics is described in the figure 13.

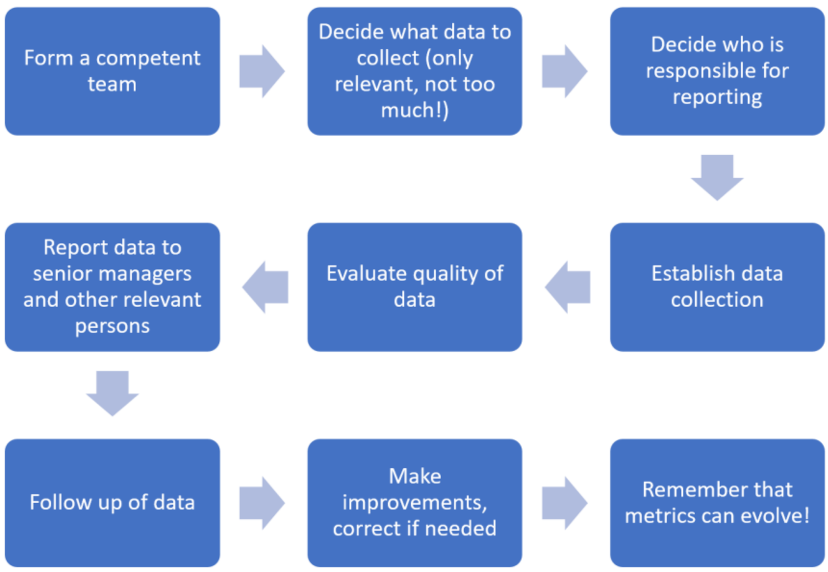

Figure 13: Process to develop process safety metrics (Laine 2022)

When project to select process safety metric begins, it´s good to form a team with competent persons to start with identifying plant specific PSPI´s which are reliable, and which results are always measurable After that metrics can be defined. Important is, that there are not too many metrics, just enough to follow up process safety of the plant. Follow up frequency can be e.g., from once in a week to once in a month depending on the size of the organization. Toleration level should always be defined for metrics to follow up and mitigate the cases where metric is out of desired level. It can be noted that metric that has been selected, can evolve, and improve.

Metric should always have a person, who follows up and reports it to higher management. Follow up of metrics can require data collection before it can be measured so company may have to start project for implementation if they choose to measure these as their key performance indicators. Results of process safety metric analysis should be reviewed regularly with all employees, including blue-collar workers, white-collar workers, and higher management. To make things easier to understand, it´s good to make results visually easy to read with graphics like smile faces, charts, gauges, or traffic lights. (Developing process safety indicators 2006, 25.) If no-one follows metrics or if actions are not made in case of deviation, it is useless to implement process safety metric system to the organization (Guidance on developing safety performance indicators related to Chemical Accident Prevention, Preparedness and Response Guidance for Industry Second edition 2008, 26).

Senior management has got also other tasks to manage, so they need only PSPI´s that are not too detailed (Beale 2012, 469). If meaningless or too many indicators are presented, it is possible that senior management are not capable to understand information that is presented (API recommended practice 2017, 76).

Process safety is risk management to prevent significant incidents. It should be extended from analyzing process hazards to people behaviors because most of the incidents are caused by hazardous activities of humans. Changes of process equipment can cause risk in case those are not well assessed before implementation. This requires robust management of change program. In this risk assessment it´s important to analyze what are the consequences if the change causes severe problems. Process equipment should always be in good condition and their integrity should be followed with regular inspections and maintenance. If incident happens at location, it is important to do investigation immediately to find root causes and corrective actions to prevent similar incident in the future. If all protective layers fail, emergency response should be planned to prevent escalation of the accident.

Process safety metrics are different at the different levels of organization. Some of the corporate, and bigger site level metrics can be calculated e.g., against of work hours and site-specific metrics at smaller sites can be calculated as safety event amount per week or month.

8.3 How to integrate the behavior-based safety program with the process safety?

Du Pont STOP-program is formal way to audit employees on their duty. This program is concentrating on people behavior and risks that they may be taking on their tasks (McSween 2003, 4-5). Purpose if the BBS-program is to change everyone´s thinking towards safety. If BBS-program is a success, it results in less injuries and other incidents like LOPC´s. BBS-program can also fail if workers are not committed to the system.

STOP program is called BBS at the commissioner. BBS is part of their material release pyramid, not personal injuries pyramid. This created interesting question of the BBS program integration to process safety. Question was asked from five specialists. Björkhem and Wever (2021, personal communication) propose that practical use of LOTO and PTW should be reviewed on observation tours to see are hazardous works under control. Takala (2021, personal communication) proposes that more proactive tools, like JSA, PHA and SOP´s could be reviewed with employees under observation. Also, operator awareness of risks control methods like safe operating limits and safety interlocks could be reviewed during discussion. Juanmarti (2021, personal communication) would follow contractors to get understanding how they follow safety rules and procedures like PTW. Bonalbo (2021, personal communication) would follow that are process upgrades communicated and trained properly to employees.

During the BBS-observation, verification that operating procedures and safe practices are followed, operators have been involved in process design, and they are trained to process operations and emergency response plans could be made. Operators should also be aware of other process safety information such as process hazard analysis, safe operation limits and protective layers of the process. Hot works are obvious reason for fires, so follow up of the hot work permit conditions should be made.

8.4 How to present leading and lagging process safety and personal safety indicators visually?

Commissioner has a system to analyze both personal and process safety events as a leading and lagging metrics at corporate level. Foundation of the material release pyramid is local management KPI´s. For personal safety pyramid foundation and most leading metrics are hazardous conditions and activities and foundation for material release pyramid is BBS-observations. (Wever 2022, personal communication.) This thesis proposes that these two triangles can be combined as a one common two-triangle model described originally by Hopkins (2014, 57). Proposal is seen in figure 14 below.

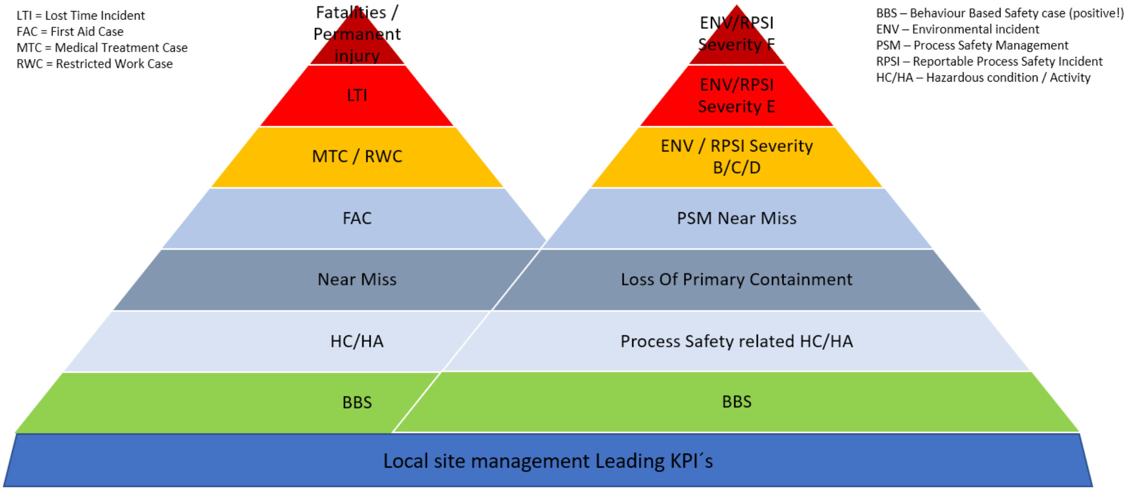

Figure 14: Hopkins Two-triangle Model customized to thesis commissioner's incident pyramids (Laine 2022)

Modified Hopkins two triangle model shows on one page the status of all relevant indicators that are selected by organization. This proposal changes the current situation, where there are two different triangles. This is because proposed foundation and most leading metrics in the pyramids are local site management KPI´s and BBS discussions with both have proactive effect to the personal and process safety. Change for the original triangles is that in the proposed two triangle model personal injuries pyramid and material release pyramids have overlapping areas (Local site management leading KPI´s, BBS´s and HC/HA reports).

8.5 Evaluation of own work

Thesis aim was to create process safety metrics to specific site, but during the process, aim was transformed to be more general guidance to the corporate level. Process safety KPI´s and metrics for this specific site were also defined but this information is not public due to included trade secrets. During the thesis process, study methods seemed to give enough information to quality research and at the end all the study questions had got detailed answers.

Thesis literature review was comprehensive and included many relevant standards and engineering associations publications. First problem of the thesis was a student's missing engineering training, but in the end, conclusion is that it was not needed. Challenge was also sources that were mostly in English. Decision to write study in English was made for two reasons. First reason was a need for translations of sources in Finnish, which would have required lots of time and work and translations had also possibility for errors. Other reason was that English is commissioner business language.

Interviewees were selected across and outside of commissioner organization by their expertise and interview results were good quality even there was only two questions. Validity of the literature can be considered as reliable due that most of the literature are published by credible engineering associations. After the interviews BBS process was studied closer, and it was noted that robust program can be effective to prevent all kind of personal injuries and process safety incidents like LOPC´s. Due to the lack of more detailed literature of BBS and it´s relation to the process safety created development need for BBS-program. To improve safety, BBS program integration to process safety needs further investigation across all organizations.

When thesis is evaluated, reliability is one topic. References are up to date, and they are collected from trusted sources like standards and professional process safety related publications and books. Even the oldest reviewed standards are from 90´s, it must be noted that process safety management has still the same difficulties as 30 years ago: devastating process safety incidents happen from time to time. Interviewees were professionals on process safety and behavior-based safety, so their reliability can also be considered as very high. To get more data from the interviews, there could have been more process safety related questions but in the other hand there was so much useful data in the literature, so expanding thesis work was not considered as reasonable. Study questions, which were selected in the beginning, got answers during the thesis process. Results of the study were partially expected and partially new, like two triangle model for the commissioner safety pyramids. Long thesis process created possibility to analyze literature and other sources more detailed and to find more sources during the process. This thesis can help the commissioner but also other chemical manufacturers in their way towards better process safety.

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Figures

Appendices

Appendix 1: Interview questions

1. How to integrate BBS program to process safety
2. Elaborate organizations definitions for personal injury and material release pyramids