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**HUMAN FACTOR AND SAFETY CULTURE IN SAFETY RESEARCH IN
THE PROCESS AND CHEMICAL INDUSTRIES**

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Abstract

Human factors and safety culture have become increasingly important in improving safety in the process and chemical industries. New methods and tools to improve human factor consideration and safety culture are constantly developed. However, organisations do not have time to follow the development and evaluate how the methods and tools would work. This thesis aims to find and evaluate new methods and tools and to improve organisations' ability utilise the latest safety research.

Current methods and tools published in safety research journals were obtained from a literature search. Nine methods and tools were chosen to be presented, and they were evaluated with an evaluation matrix created in this thesis. Based on this assessment, three methods were presented to twelve safety professionals from the process and chemical industries, insurance, and university in semi-structured interviews.

Overall, 66 articles matched the search criteria, and the Safety Science journal had the most articles regarding the criteria. The method of *the ranking of process safety cultures* by Zwetsloot et al (2020) was ranked highest based on the evaluation matrix. The interviewees deemed two of the three methods applicable to larger industrial use. Companies want useful methods that fulfil the organisation's needs and are easily implementable. Similarly, companies are more likely to implement methods modified to their specific needs, for example, in the language of the method. Safety professionals in companies and in insurance do not have time to follow new research. Instead, they obtain their knowledge of new methods and tools from seminars, associations, and online sources. In addition to providing more time for safety professionals to follow new research, collaboration among researchers and the industry is one of the best ways to improve the utilisation of recent safety research in organisations.

Keywords human factor, human error, safety culture, safety climate, safety research, process and chemical industries

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Tiivistelmä

Inhimilliset tekijät ja turvallisuuskulttuuri ovat yhä tärkeämpiä ratkaisuja turvallisuuden parantamiseen prosessi- ja kemianteollisuudessa. Uusia menetelmiä ja työkaluja kehitetään jatkuvasti inhimillisten tekijöiden huomioonottamiseksi sekä turvallisuuskulttuurin parantamiseksi. Kuitenkaan organisaatioilla ei ole loputtomasti aikaa arvioida miten nämä menetelmät ja työkalut toimisivat käytännössä. Tämän diplomityön tavoite on löytää ja arvioida uusia menetelmiä ja työkaluja sekä parantaa tuoreen turvallisuustutkimuksen hyödyntämistä organisaatioissa.

Kirjallisuuskatsauksessa etsittiin uusia menetelmiä ja työkaluja turvallisuusalan tieteellisistä julkaisuista. Yhdeksän menetelmää ja työkalua valittiin esitettäväksi laajemmin ja ne arvioitiin tässä työssä kehitetyllä arviointimatriisilla. Tämän luokittelun perusteella kolme menetelmää esitettiin kahdelletoista turvallisuusalan ammattilaiselle prosessi- ja kemianteollisuudesta, vakuutusosalta ja yliopistoista.

Kaiken kaikkiaan 66 hakukriteerit täyttänyttä artikkelia löytyi ja Safety Science tieteellisessä julkaisussa oli eniten hakukriteerit täyttäviä artikkeleita. Menetelmä nimeltään *the ranking of process safety cultures* kirjoittajina Zwetsloot et al (2020) luokiteltiin parhaaksi arviointimatriisin perusteella. Haastateltavat pitivät kahta kolmesta menetelmästä käyttökelpoisina teolliseen käyttöön. Yritykset haluavat hyödyllisiä menetelmiä, jotka täyttävät tarpeen organisaatiossa ja ovat helposti käyttöönotettavia. Samoin menetelmät, jotka on muokattu yrityksen tarpeisiin, esimerkiksi kielellisesti, otetaan todennäköisemmin käyttöön. Turvallisuusalan ammattilaiset yrityksissä ja vakuutusosalalla saavat tietoa uusista menetelmistä seminaareista, yhdistyksiltä sekä verkkolähteistä. Turvallisuusilmapiirin määritelmä on epäselvä turvallisuusalan ammattilaisten keskuudessa. Ajankäytön mahdollistaminen uuden turvallisuustutkimuksen seuraamisen lisäksi, yhteistyö yritysten ja tutkimuksen välillä on yksi parhaimmista tavoista lisätä tuoreen turvallisuustutkimuksen hyödyntämistä yrityksissä.

Avainsanat inhimillinen tekijä, inhimillinen virhe, turvallisuuskulttuuri, turvallisuusilmapiiri, turvallisuustutkimus, kemian- ja prosessiteollisuus

Preface

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Porvoo 12.5.2023

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Table of Contents

Preface	iv
Table of Contents.....	v
List of the abbreviations	1
1 Introduction	1
1.1 Aim of study	1
1.2 Focus	2
1.3 Structure of the thesis.....	3
Literature review.....	4
2 Definitions.....	4
2.1 Human factor	4
2.2 Human error.....	7
2.3 Safety culture	8
2.4 Safety climate.....	11
2.5 Safety management	12
3 Safety research	15
3.1 Results from the literature review	15
4 Methods and tools.....	18
4.1 Human factor-related items.....	18
4.1.1 Post-Incident Behaviour-Based Discussion.....	19
4.1.2 Human Factor Risk Management	23
4.1.3 Task Improvement Process.....	27
4.2 Human error-related items	30

4.2.1	A novel qualitative prospective methodology for analysing human error	31
4.2.2	Re-designed Just Culture process	34
4.3	Safety culture-related items	38
4.3.1	The Egg Aggregated Model.....	39
4.3.2	Ranking of process safety cultures	43
4.4	Safety climate-related items	47
4.4.1	Transformational and active transactional leadership behaviour intervention	48
4.4.2	Development of a safety climate tool	50
4.5	Conclusion on safety research and methods and tools	54
	Applied part	55
5	Methodology.....	55
5.1	Ranking of methods and tools	55
5.2	Interviews.....	59
5.2.1	Interviewees	59
5.2.2	Questions	60
5.2.3	Implementation of Interviews	63
6	Results and discussion	63
6.1	Results	63
6.1.1	Human factors, human error, safety culture, and safety climate	65
6.1.2	Methods and tools.....	71
6.1.3	Application of new research	85
6.1.4	Reliability of the results	87
6.2	Discussion.....	88

6.2.1	Examination of the ranking matrix for the methods and tools	88
6.2.2	The interviewees' views on the four main concepts	89
6.2.3	Application and requirements for new methods and tools	90
6.2.4	The presented methods and tools and their application	92
6.2.5	More efficient ways to utilise recent safety research	97
7	Conclusions	99
7.1	Key findings	99
7.2	Observations	101
7.3	Limitations and recommendations for further research	101
	References	103
	Appendix 1. List of articles found in literature research	
	Appendix 2. Re-designed Just Culture picture	
	Appendix 3. Questionnaires for companies	

List of the abbreviations

CMMS	Computerised maintenance management system
EI	Energy Institute
FMEA	Failure Modes and Effects Analysis
HFRM	Human Factor Risk Management
HSC	Health and Safety Commission (the UK)
IAEA	International Atomic Energy Agency
ISO	International Organisation for Standardization
OHS	Occupational Health and Safety
PDCA	Plan-Do-Check-Act
PIBB	Post-incident behaviour based
PSF	Performance Shaping Factors
SCTA	Safety Critical Task Analysis
SMS	Safety Management System
SQE	safety, quality, and environment (management system)
TEAM	the Egg Aggregated Model
TIP	Task Improvement Process
TRL	Technology readiness level
Tukes	Finnish Safety and Chemicals Agency

1 Introduction

In a perfect world, problems would be solved before they materialise; it would be proactive. This is apparent in various fields, but none more than in safety. In recent years, the process and chemical industries have highlighted safety as a number one priority. Different safety practices, from technical to management to culture, have been developed to minimise the risks. The first solutions were technical safety practices introduced in the 1960s (Lindhout and Reniers, 2017). As the technical solutions did not achieve zero accidents, the attention shifted towards the nontechnical safety aspects, such as safety management, human factor, human error, and safety culture. Many practices used to improve the nontechnical aspects that are now widely known are the same models as when the discussion around the topics was raised in the 1980s.

Improving safety is a continuous process that openly welcomes innovations. New methods and tools to improve human factor consideration and safety culture are constantly developed. However, organisations in the process and chemical industries need more time to follow the development and evaluate how the methods and tools would work in practice. To bridge this gap, this thesis reviews new methods and tools recently published in safety journals that could be implemented in practice to improve human factor consideration and safety culture.

1.1 Aim of study

The thesis aims to find and evaluate new methods and tools from recent safety research to improve human factor consideration and safety culture. An integral part of the thesis is finding practical ways to apply the research to minimise accidents and property losses in the process and chemical industries. Significant safety research journals from recent years are systematically reviewed to find methods and tools related to human factors and safety culture. These methods and tools are presented,

and their applicability to the process and chemical industries is evaluated. Safety professionals are interviewed to assess the possibilities to utilise the methods and tools in practice. These professionals include risk engineers, safety managers, and university lecturers. Based on this study, the ability of organisations to utilise the latest safety research can be improved.

Thus, the following research questions are prepared.

- What are the definitions of human factors, human error, safety culture, and safety climate, and what tools or methods have been introduced in recent safety research to improve them?
- What is the best way to deploy the tools or methods to organisations so that they can be utilised in safety management system and in organisation, team, and personal levels?
- What is the interviewees' perception (risk engineers, safety managers, and university lecturers) of these tools or methods and their usability in day-to-day actions?
- How could organisations utilise recent safety research more efficiently?

1.2 Focus

This thesis focuses on methods and tools published in safety journals and excludes the possible methods and tools published in chemical industry journals to narrow the search. The ten best safety journals were selected based on an article by Reniers and Anthone (2012). The best safety research journals were listed based on rankings from safety researchers and citations. The selected journals included the Journal of Loss Prevention in the Process Industries, Journal of Hazardous Materials, Reliability Engineering and System Safety, Safety Science, Risk Analysis, Accident Analysis and Prevention, Journal of Safety Research, Process Safety and Environmental Protection, Process Safety Progress, and Fire Safety Journal. To obtain recent research and limit the results to a reasonable amount, the timeframe was set from January 2018 to June 2021. The systematic search through the journals was done with "human factor", "human error", "safety culture", and "safety climate" as search terms to filter the

results. At least one of the terms needed to be on the title, in the abstract, or among the keywords to be considered in this thesis. Only articles related to process and chemical industries were included. Therefore, articles addressing construction, aviation, healthcare, transportation, shipping, or nuclear industry are not part of this study.

1.3 Structure of the thesis

The thesis includes a literature review, applied study, results, discussion, and conclusions. The literature review defines human factors, human error, safety culture, and safety climate and explains their relations. The methods and tools from the safety journals are presented and evaluated.

The applied part consists of the methodology of the study. This part introduces the research process, methods and the questionnaire used to conduct the interviews. The interview results are collected, presented, and discussed in the results and discussion part of the thesis.

The last part concludes the critical findings of the thesis. Additionally, it provides observations of the methods used and suggests further research.

Literature review

2 Definitions

The definitions for the four main concepts of this thesis: human factor, human error, safety culture, and safety climate vary among different articles. There are no specific definitions that are universally used. Hence, this chapter of the thesis specifies the use of the terms in this thesis. Safety management is also explained here to provide an understanding of the concept for part 4, which presents the methods and tools found in the literature review.

2.1 Human factor

The human factor has been defined as the interaction between a human and a machine (Gordon, 1998). Over time, it has evolved to a more comprehensive concept of interactions within a work environment: the tasks performed, the equipment used, the workspace, and the organisation's influence (Attwood *et al.*, 2006; Edmonds, 2016). In some contexts, the human factor is a synonym for ergonomics, but this thesis will not address this definition.

There are multiple different definitions from different sources. The most well-known is the one from The UK Health and Safety Executive (1999): "Human factors refer to environmental, organisational and job factors, and human and individual characteristics which influence behaviour at work in a way which can affect health and safety". The definition also describes human factors through the *job*, the *individual*, and the *organisation*. The *job* includes the aspects of the work, the tasks, the workload, the procedure, and the decision-making requirements. The *individual* part describes the individual's personal properties, their competence, skills, and attitudes. The *organisation* part consists of the specific aspects of the organisation: the culture, leadership, values, and communication. Figure 1 presents this division of human factors.

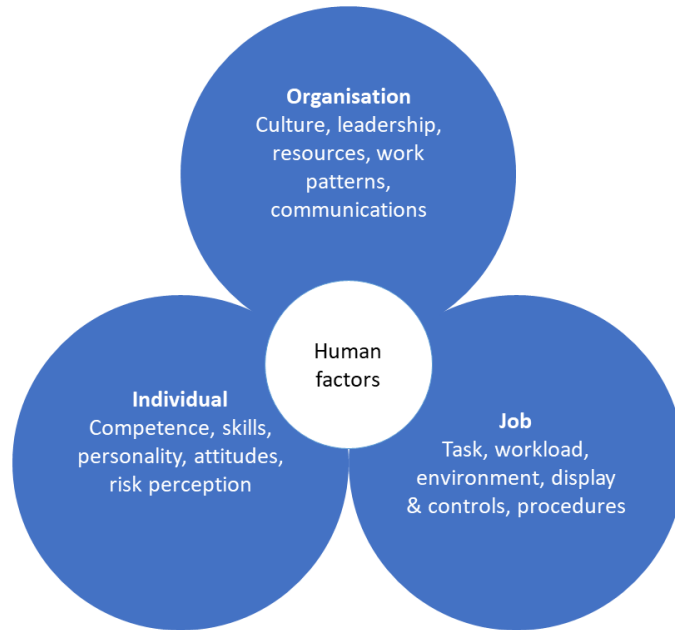


Figure 1. The portrayal of human factors in organisational safety (reproduced from Health and Safety Executive, 1999).

The UK Health and Safety Executive definition was made for occupational safety, and it applies to most situations. However, a more specific definition of the human factor concept in process safety considers the uniqueness of work systems in process and chemical industries (Edmonds, 2016). Firstly, the work systems include large-scale processes that contain vast amounts of chemicals and materials. These substances can be toxic, unstable, or flammable. Secondly, humans are an intrinsic part of the processes as they design, install, commission, operate, maintain, and support them. Figure 2 presents the different aspects of human interactions in process and chemical industries by Edmonds (2016).

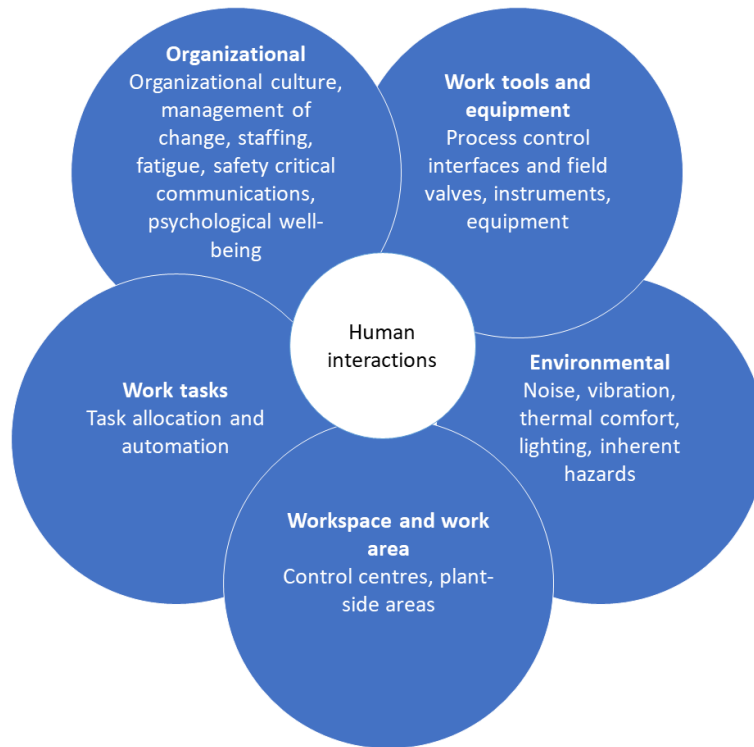


Figure 2. Human interactions in industrial work systems by (reproduced from Edmonds, 2016).

The main difference between the models of the UK Health and Safety Executive (1999) and Edmonds (2016) is that Edmonds has emphasised the significance of the *job* factors in the model and has divided the job category of the earlier model into multiple different entities, *work tools and equipment*, *environment*, *workspace and work area*, and *work tasks*. Edmonds (2016) has not included a category similar to the *individual* category in the earlier model because the factors are seen as human interactions within the work system.

2.2 Human error

Reason (1990) defines human error as “the failure of planned actions to achieve their desired ends – without the intervention of some unforeseeable event”. It consists of three elements: a plan or intention that includes the goal and the means to achieve it, a chain of actions started by the plan, and the result of these actions and their success in achieving the plan (Reason, 1997). This leads to two possible outcomes for the failure of the task: unintended or intended actions. With unintended actions, the plan is sufficient, but the actions fail due to slips, lapses, trips, or fumbles. In the case of intended actions, the actions go according to the plan, but the plan is insufficient to achieve the desired result. These are referred to as mistakes. Rule-based mistakes are due to the misapplication of commonly good rules or the application of bad rules. Knowledge-based mistakes are due to a lack of proper instructions resulting in solving the problems immediately without adequate knowledge. Additionally, intended actions include violations that are deviations from rules, standards, and safe operating practices. These are visualised in Figure 3.

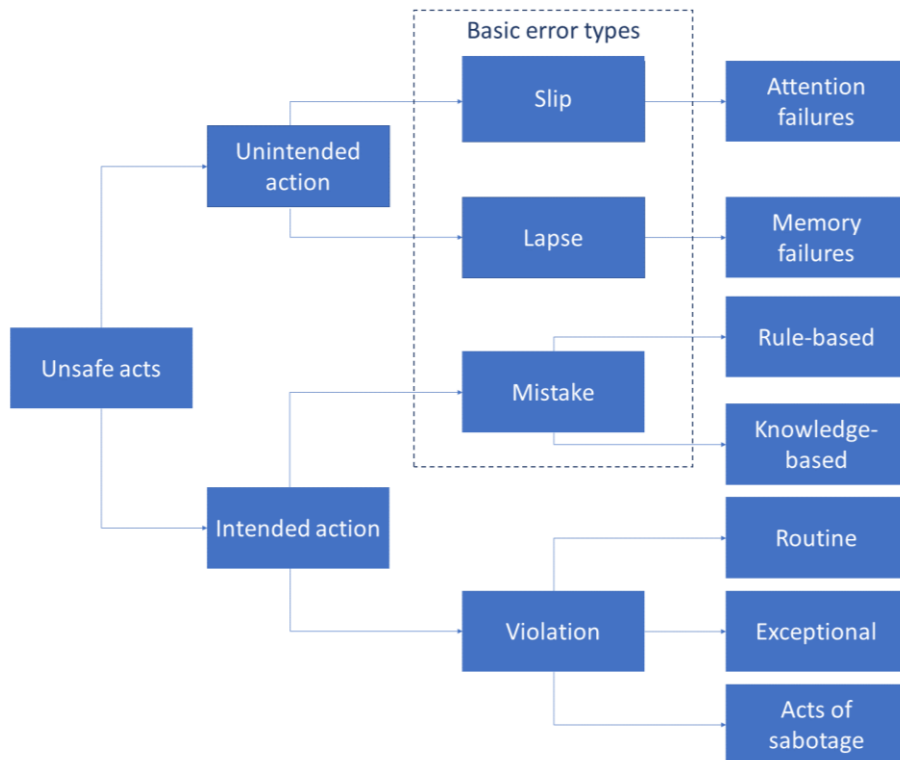


Figure 3. Types of human error according to (reproduced from Reason, 1997)

2.3 Safety culture

Safety culture was first defined after the Chernobyl accident by the International Atomic Energy Agency (IAEA) (1991) as: “...the assembly of characteristics and attitudes in organisations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance” (Booth and Lee, 1995). A widely used definition of safety culture is by the UK Health and Safety Commission (HSC) (1993) that defines it as: “product of individual and group values, attitudes, perceptions, competencies, and patterns of behaviour that determine the commitment to, and the style and proficiency of, an organisation’s health and safety management”(Human Engineering, 2005). The definition by Center for Chemical Process Safety (2016) states safety culture as: “the combination of group values and behaviours that determine the manner in which process safety is managed”, which is very similar definition to the UK HSC (1993) definition. Similarly, Levä (2003) from the Finnish Safety and Chemicals Agency (Tukes) defines safety culture as: “to consist of the conscious and unconscious basic beliefs, values, attitudes, and practices of safety in an organisation.” Overall, safety culture describes the way things are done in organisations, what is expected, and how employees behave when nobody is watching (Center for Chemical Process Safety, 2016)

Safety culture frameworks are used to target safety, leadership maturity, and business management systems (Behari, 2019). The DuPont Bradley curve, newly branded as the dss⁺ Bradley curve¹, and the evolution of safety culture by Hudson (2001) are two well-known examples of safety culture frameworks, that describe different behaviours of a workforce as a function of safety performance. The dss⁺ Bradley curve framework is in Figure 4, and the framework by Hudson (2001) is in Figure 5.

¹ The Dupont Bradley curve was rebranded in 2019 when DuPont Sustainable Solutions separated from DuPont and became dss⁺, an independent global operations management consulting firm (Dupont, 2019).

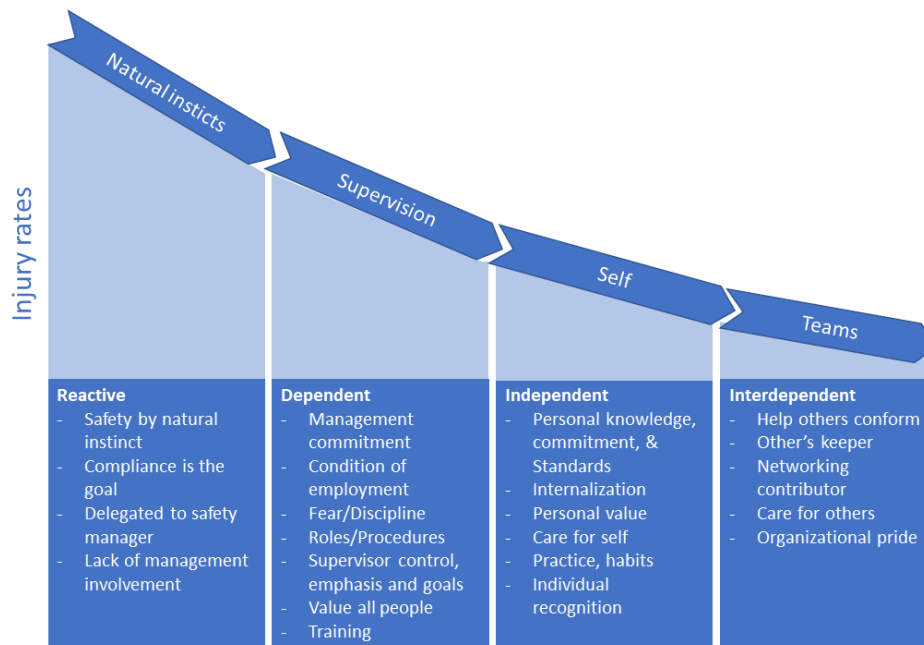


Figure 4. The dss+ Bradley curve (reproduced from dss+, 2022; Branchini, 2020)

The dss+ Bradley curve has been used since 1995, and it describes cultural maturity as a correlation to the number of injuries or accidents (Branchini, 2020; dss+, 2022). The model states that cultural maturity is divided into four stages: *reactive*, *dependent*, *independent*, and *interdependent*. The *Reactive* stage is seen as the stage where safety comes from natural instincts and injury rates are high. On the other end is the *interdependent* stage, where the care for others is the main driving force, and the injuries move toward zero.

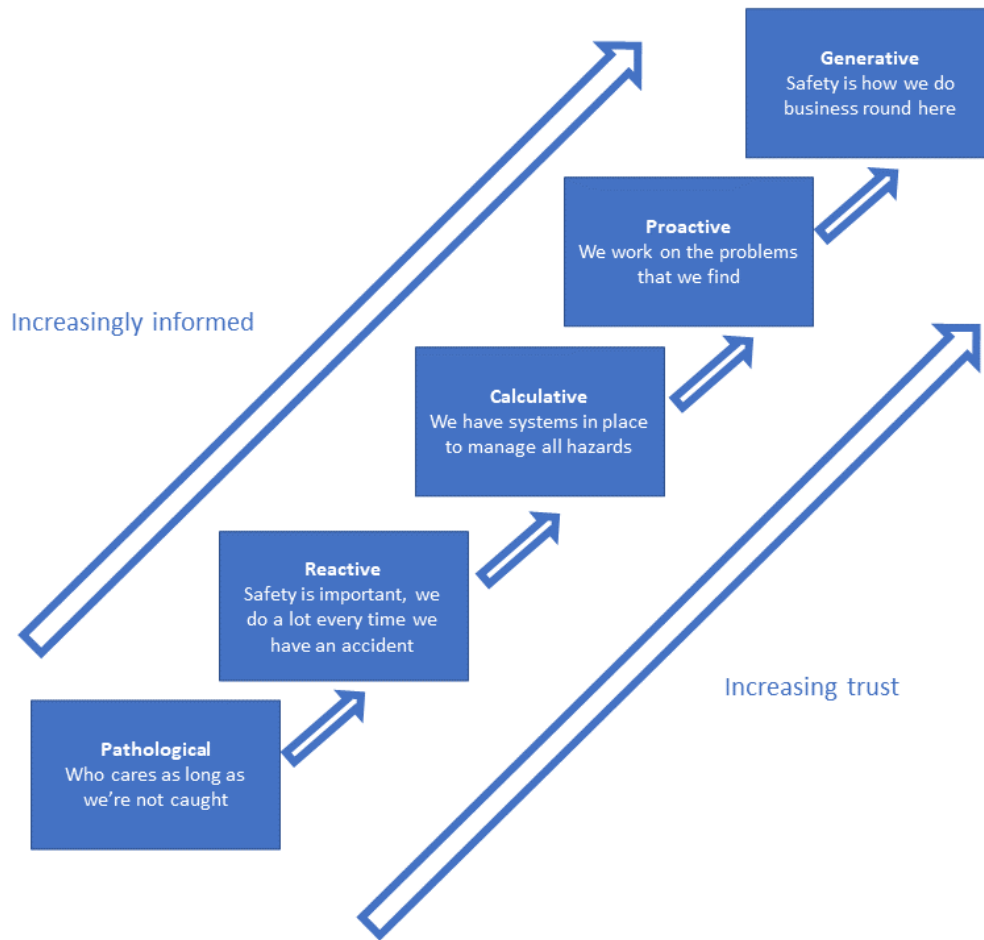


Figure 5. The evolution of safety culture (reproduced from Hudson, 2001)

The evolution of safety culture by Hudson (2001) in Figure 5 shows different types of safety cultures, from *pathological*, where the main concern is not getting caught to, *generative*, where safety is part of everything. Of the two frameworks, the dss⁺ Bradley curve generates more hits in online searches like google scholar, and it is the go-to framework regarding safety culture. The dss⁺ Bradley curve is more people-oriented, while the Hudson (2001) framework seems more comprehensive and represents the organisational side more (Parker *et al.*, 2006). The dss⁺ Bradley curve is a commercial product, while the other framework is presented very comprehensively in an article by Parker *et al.* (2006).

2.4 Safety climate

The definition of safety climate is often discussed in relation to safety culture. The most common way to view the difference between safety culture and safety climate is to define safety climate as an organisation's safety perception at a given time (Goncalves Filho and Waterson, 2018). Safety climate is seen as a reflection of the organisation's culture, visible and measurable, and it describes the current state of the organisation and its internal environment. Climate is seen as short-term and tactical. In contrast, culture is long-term and strategic (Glendon and Clarke, 2018). Hudson (2001) remarked that it was a missed opportunity not to name safety culture as climate and the safety climate as weather because the relation is similar to the weather-related terminology of weather and climate, where the weather is a specific point in time and climate is the long-term situation.

The term safety climate was first used in the 1980s by Zohar, who defined it based on the human perception of risk and its influence (Luo, 2020). The study by Zohar in 1980 also established the practice of using safety questionnaires to study an organisation's safety climate (Hecker and Goldenhar, 2014). According to Luo (2020), safety climate has four characteristics. Firstly, safety climate refers to the perception of an organisation's safety and is a psychological phenomenon. Secondly, it is connected to intangible things like situational and environmental factors. Thirdly, it is a temporary state that describes an occasion of safety culture, and lastly, it includes the cognitive traits of the work environment.

The correlative relationship between safety climate, safety performance, and safety behaviour is essential. Safety climate can be a leading indicator of safety performance, while most traditional tools to measure safety performance are lagging indicators (Luo, 2020). Safety performance is defined as result-oriented when safety work indicators like economic loss, loss of working hours, and accident rates are used (Luo, 2020). Safety behaviour also affects safety performance. A good safety climate can endorse individual safety behaviour and improve safety performance by reducing accidents and injuries (Luo, 2020). The relational model of the effects of the safety

climate of an enterprise and individual safety cognition on individual safety performance by Luo (2020) is presented in Figure 6.

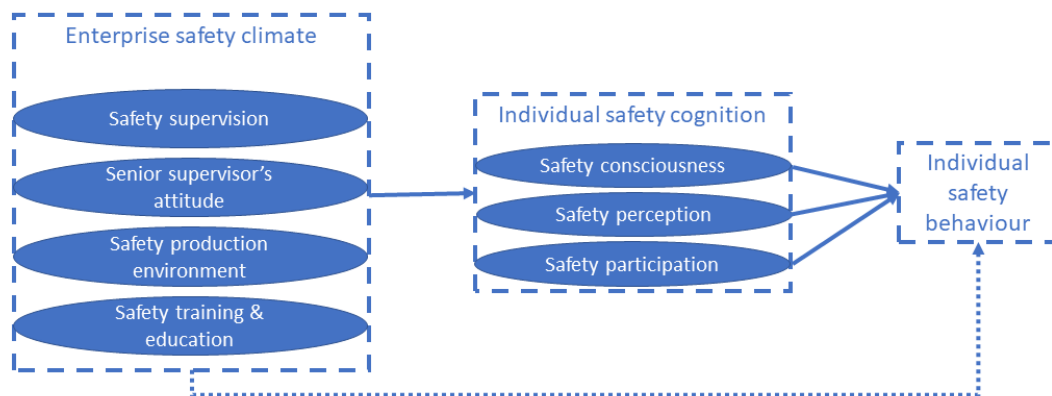


Figure 6. The relational model diagram of enterprise safety climate and individual safety cognition to individual safety behaviour (reproduced from Luo, 2020).

A safety performance model by Neal et al. (2000) defines the two dimensions of safety performance: compliance and participation. Safety compliance includes following safety protocols and working safely. Safety participation includes supporting other employees, encouraging the application of the safety program within the work environment, showing initiative, and striving toward improving safety in the work environment (Neal *et al.*, 2000). These dimensions can be used to find better measures to replace traditional safety measures like accident reporting and injury data that are not responsive nor reflective of dangerous behaviour (Luo, 2020).

2.5 Safety management

Safety management includes ensuring the safety of humans, the environment, and property, as well as improving the safety goals of organisations (Booth and Lee, 1995; Levä, 2003). The critical elements incorporated with safety management are policy and planning, organisation and communication, hazard management, and monitoring and review (Booth and Lee, 1995). Firstly, policy and planning are used to set safety targets, quantifiable objectives and priorities, and a plan to achieve these. Secondly, clear lines of responsibility and two-way communication are established

with organisation and communication. Thirdly, hazard management includes identifying hazards, assessing risks, and determining control measures. Finally, monitoring and review are used to ensure that all the stages above are implemented, used, and work in practice. Safety management is included in organisational management and so falls under the responsibility of the leadership (Levä, 2003).

Safety management systems (SMSs) are a way for leaders to implement safety management in organisations (Levä, 2003). SMS is a systematic and documented approach to controlling the safety of an organisation (Reiman, 2008). It recognises the risks and their probability in an organisation and evaluates the consequences (Reiman, 2008) to ensure that safety measures exist and work in the organisation (Levä, 2003).

Organisations can build their SMSs based on standardised SMSs, like the International Standard ISO 45001:2018, "Occupational health and safety management systems. Requirements with guidance for use" by International Organization for Standardization (ISO) (2018). The standard defines a management system as a "set of interrelated or interacting elements of an organisation to establish policies and objectives and processes to achieve those objectives" and occupational health and safety (OHS) management system as a "management system or part of a management system used to achieve the OHS policy" (International Organisation for Standardization (ISO), 2018). The standard sets guidelines for leadership and worker participation, planning, support, operation, performance evaluation, and improvement and expects organisations to use a Plan-Do-Check-Act (PDCA) concept for continual improvement (International Organisation for Standardization (ISO), 2018). The PDCA concept and its relation to the OHS management system are visualised in Figure 7.

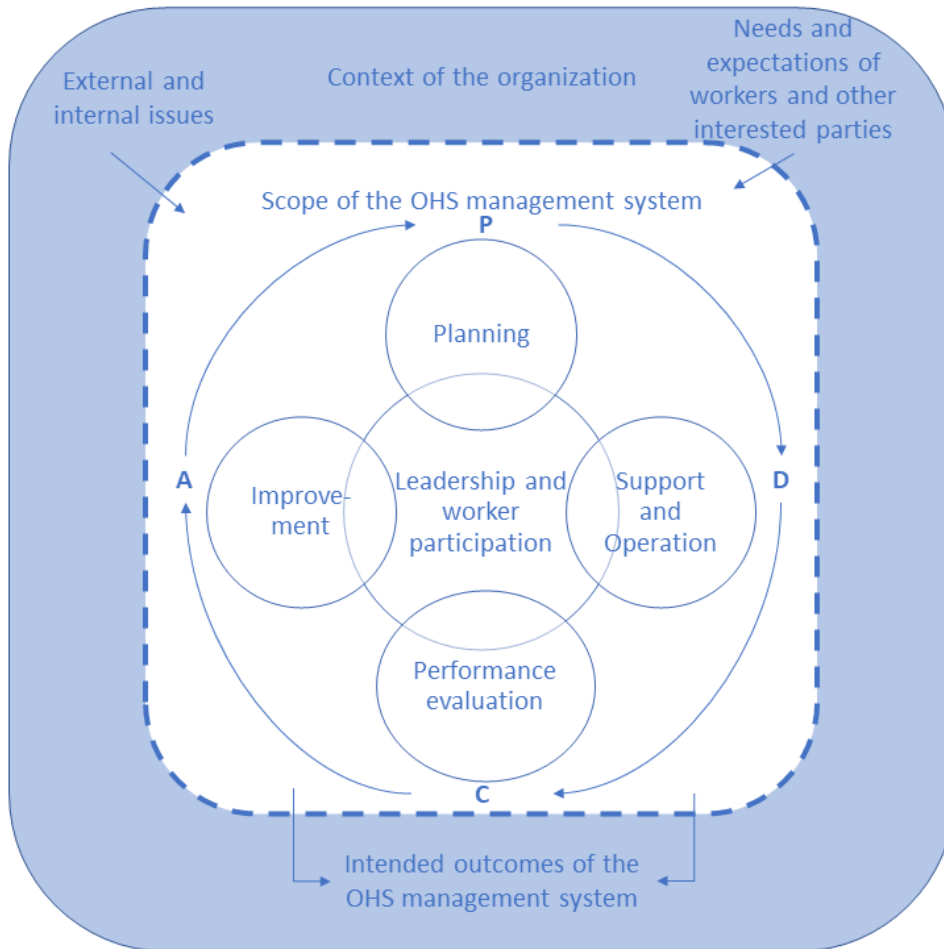


Figure 7. Visualisation of the relationship between the PDCA concept and the OSH management system (reproduced from International Organisation for Standardization (ISO), 2018).

3 Safety research

The top 10 safety journals, according to Reniers and Anthone (2012), were gone through from January 2018 to June 2021. Articles including human factor, human error, safety culture, and safety climate in their abstract, keywords or title were collected. Additionally, the articles were chosen if they were in the field of process and chemical industries or if the field was not specified. This part introduces the number of articles matching the search criteria.

3.1 Results from the literature review

To obtain a systematic review of the current safety literature, the top 10 safety journals were gone through. The articles were searched methodically by going through every issue of each journal, searching articles with the selected terms in their title, keywords or abstract. The ten journals, their rankings, and the number of articles found in each are shown in Table 1.

Table 1. Ranking of the best ten safety journals according to Reniers and Anthone (2012) and the total number of articles matching the search criteria.

Ranking	Journal	Total
1	Journal of Loss Prevention in the Process Industries	12
2	Journal of Hazardous Materials	0
3	Reliability Engineering and System Safety	3
4	Safety Science	26
5	Risk Analysis	0
6	Accident Analysis and Prevention	2
7	Journal of Safety Research	7
8	Process Safety and Environmental Protection	5
9	Process Safety Progress	11
10	Fire Safety Journal	0

The total number of articles found was 66, and Safety Science contained the most articles meeting the search criteria. Three of the ten journals had no articles matching the search criteria. Figure 8 shows the distribution of the articles to the search terms. Safety culture was the most researched, then safety climate, human factor, and human error.

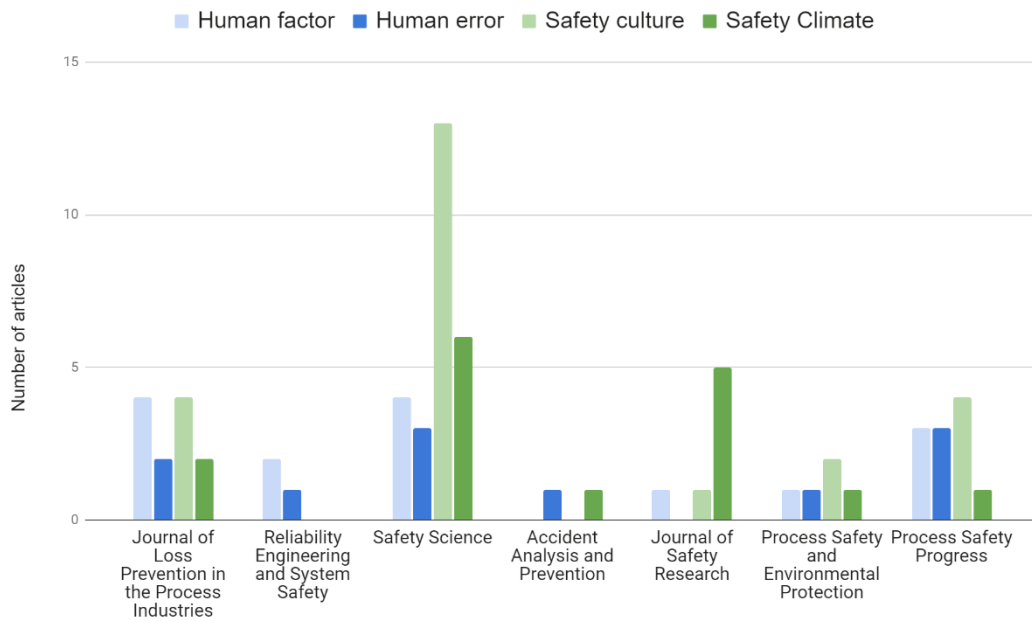


Figure 8. The number of articles per journal and search term.

Only some articles were about new methods or tools to improve human factors, human error, safety culture, or safety climate. The articles ranged from improving human reliability analysis methods to the bibliometric analysis of safety culture. Approximately half of the articles contained methods to improve the aspects of safety through tools, methods, or suggestions for better practices. All 66 articles matching the search criteria are listed in Appendix 1.

The journals have different scopes and aims, which explains why some of them do not produce any matches for the specified search criteria. Journal of Hazardous Materials specifies its scope “to the hazards and risks that certain materials pose to public health and the environment”. It excludes workplace health and safety altogether (*Journal of Hazardous Materials - Journal - Elsevier*, no date). Also, Fire Safety Journal resulted in zero matches and states their scopes as “all aspects of fire

safety engineering” (*Fire Safety Journal | ScienceDirect.com by Elsevier*, no date). The third journal that resulted in zero articles was Risk Analysis, which promotes a wide range of disciplines, such as behavioural, engineering, health, and social sciences, as well as focuses on “risk assessment, management, perception, and communication in the topic areas of human health, safety, and the built and natural environment” (*Overview - Risk Analysis - Wiley Online Library*, no date). Based on the scope, Risk Analysis would seem to include suitable subjects that some articles might be found matching the search criteria. However, the obstacle was the industry, as the articles mentioning the search terms were construction or maritime-related. Otherwise, the results align with the scopes and aims reported by the journals. Safety Science has the broadest scope and publishes once a month. In contrast, the Journal of Loss Prevention in the Process Industries and Process Safety Progress containing the second and third most articles, are published less frequently, and their scopes are more specified.

4 Methods and tools

This section presents and discusses the methods and tools found in the safety journal search. The methods and tools were divided into the categories of the human factor, human error, safety culture, and safety climate-related items. Out of the 66 found articles, only the ones that include a new method or a tool or an improvement to an already existing tool were considered. The aim was to find the method or tool that shows the most promise in positively utilizing human factors, minimizing the effects of human error, or improving safety culture and climate and evaluate their usability in industrial settings. The most promising methods are then used in the applied part for the interviews to evaluate their promise furthermore.

4.1 Human factor-related items

Altogether 15 articles were categorised under human factors. Out of these articles, 11 contained a method or a tool. Three articles were chosen to be presented here based on their clarity, range, practicability, and applicability. The chosen articles were categorised under *risk management*, *safety performance*, and *behaviour-based safety*. Figure 9. presents the different categories that the human factor related articles could be distributed.

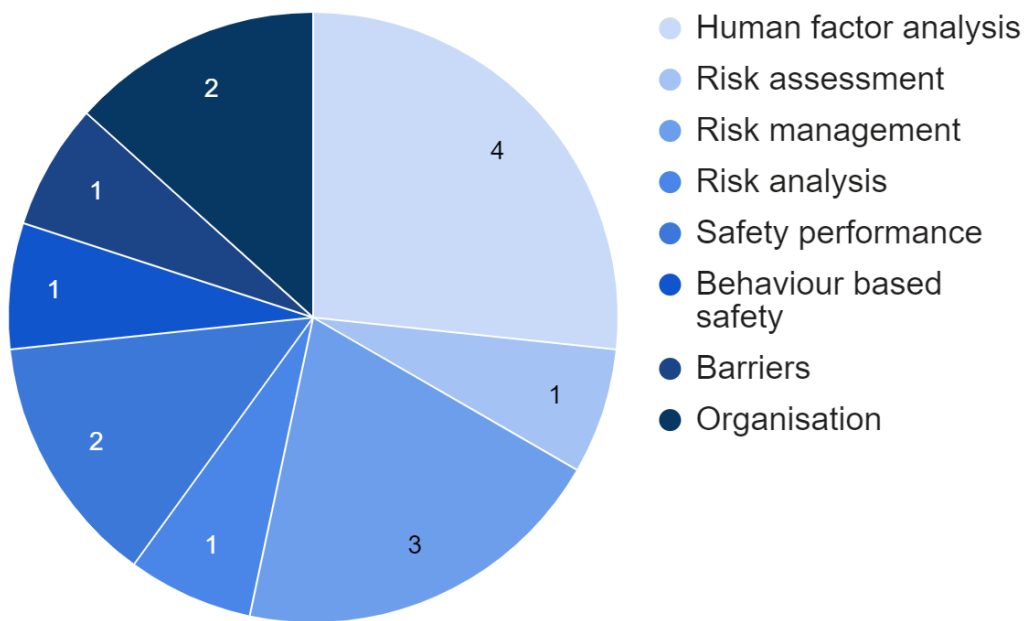


Figure 9. Categorization of human factor-related articles.

4.1.1 Post-Incident Behaviour-Based Discussion

McDonald (2020) developed the post-incident behaviour-based (PIBB) discussion method to complement incident investigations in cases of near-miss incidents where human factors played a part. The purpose of the technique was to: “guide the operators involved in a near-miss incident through a process that stimulates introspection, emphasises safety through their own leadership, and strengthens behaviours to proactively anticipate and address potential safety hazards” (McDonald, 2020). In other words, the technique encourages operators to remain observant of their safety and to assess and take responsibility for their safety actions as well as the safety actions of their peers. The PIBB discussion is performed after the interviews for the incident investigation are completed. The point is not to interrogate the employees but to encourage dialogue about how their decisions affect the work environment (McDonald, 2020).

The method consists of five different categories for discussions. The categories aim to comprehend the integration of human factors into safety culture and correct the human behaviours that could lead to incidents (McDonald, 2020). The categories

include *investing in the employees, implementing leadership, understanding the sensory experience, revealing vulnerabilities, and fostering motivation*. Figure 10. shows the categories related to the PIBB discussion.



Figure 10. The cycle of post-incident behaviour-based discussion (reproduced from McDonald 2020).

For the PIBB discussions to succeed, the discussion leader, attendees, location, and content must be prepared beforehand (McDonald, 2020). The main goal when choosing the facilitator, location, and content is to make the attendees feel at ease and comfortable during the discussion. The attendees include the employees involved or who witnessed the near-miss incident and anyone else who would benefit from the discussion (McDonald, 2020). However, management is not included as it is vital that the attendees feel open to discussion and do not perceive a risk of being criticised. The location and discussion leader need to be neutral. It is recommendable that the facilitator knows about the incident and the investigation of it before the discussion, and it is crucial to match the content to the culture of the organisation (McDonald, 2020).

The discussion itself goes through each of the steps presented in Figure 10 and asks questions to establish the behaviour of the attendees. In the first step, *invest in the employees*, an open and comfortable environment is created by asking questions about the employees themselves to find what motivates them. The second category,

realise leadership, highlights the skills of the employees, their leadership roles, and that they are a critical part of a team. The *understanding the sensory experience* part takes a brief look at the incident while focusing on recognising warning signs to expect or prevent incidents in the future. In *reveal vulnerabilities*, an exercise of “what could have been” is done to emphasise the potential effects of employees’ decisions on the outcome of the situation. The last category, *foster motivation*, asks, “Why do I work safely?” to connect how the potential effects of their actions on their personal lives. The whole process, including the questions and goals of each category, is shown in Table 2.

Table 2. The questions, exercises, and goals in the PIBB discussion (reproduced from McDonald, 2020).

Category	Questions and exercises	Goal
Invest in the employees	<ul style="list-style-type: none"> Describe a talent you have Describe the best/worst part of your day Describe how you like to be rewarded 	To find what motivates the employees. Gather information to go through with their supervisors on what are the best ways to coach the employees.
Realise leadership	<ul style="list-style-type: none"> Describe your team dynamics; who are the leaders of your team? How are you a leader on your team? Do you feel safe in your work area? Do you expect an incident to happen when you come to work? Do you observe other co-workers engaging in unsafe behaviour? Do you feel comfortable approaching a co-worker if you observe them doing something unsafe? Describe the dialogue you would have with a co-worker that was doing something unsafe. 	To understand the team dynamic and the individual responsibility to work safely and look out for one another.
Understand the sensory experience	<ul style="list-style-type: none"> What is the first thing you thought of when the incident happened? /Describe your thought process as the incident occurred. 	To recognise the situational warning signs and to anticipate or prevent future incidents. Set the scene for the next exercise.
Reveal vulnerabilities	<p>How bad could it have been—Exercise</p> <ul style="list-style-type: none"> Create a hypothetical worst-case scenario that is like the incident Draw the hypothetical incident and the surrounding area Locate the safety measures (fire extinguishers, emergency exists etc.) in the picture Discuss different scenarios <p>After the exercise:</p> <ul style="list-style-type: none"> What are some things we could do every day to remind each other to be safer? What behaviours do you do (or will you do) to make sure you are working safely? 	To help the employees to realise how small changes in their decision-making process can have major effects on the outcome of the situation. Also, to recall safeguards from memory.
Foster motivation	<ul style="list-style-type: none"> Why I work safely? 	To motivate them to work safely by reminding what is important in their personal life.

The PIBB discussion seems to be a good method to increase open discussion, communication, and dialogue, as well as concern and awareness for the actions of the employees and their co-workers. However, the article by McDonald (2020) only includes the presentation of the method and not any data, research, or examples of how the implementation of the method has worked. Also, the discussion needs a well-versed discussion leader to facilitate the conversations and guide the dialogue so that the employees feel free to share their thoughts. The discussion leader needs

to be able to do a thorough summary of the discussion so that the organisation obtains the most information. Such a facilitator might be hard to find.

The article mentions that the method is especially applicable for smaller production facilities, where products are customised and varied, so automation cannot be used to remove the risk of human error. Additionally, the organisation's safety culture needs to be familiar with behaviour-based safety (McDonald, 2020). These factors show that the method requires an already-developed safety culture and receptive employees.

4.1.2 Human Factor Risk Management

Bevilacqua and Ciarapica (2018) developed a new procedure called Human Factor Risk Management (HFRM) to integrate human factors into a Refinery Risk Management System. The procedure aimed to identify and investigate human factor risks, generate association rules for harmful events, and suggest preventive and safety measures to inhibit or minimise high-risk events (Bevilacqua and Ciarapica, 2018). To achieve this aim, three main steps were taken in the article. Firstly, to identify and investigate human factor risks, historical data from 10 years on near misses, accidents or injuries, operating accidents, and environmental accidents in a refinery was gathered, and a panel of experts was utilised to define the performance shaping factors (PSFs) and risk associated with harmful events. Secondly, a conceptual model was proposed to study the connections among harmful event typology, human error causes, refinery plant areas involved, PSFs, risk index, and corrective actions, using an algorithm for generating association rules. Lastly, the results, gathered using the association rules model, were gone through. The capability of these results to assess human practices and human factors that influence high-risk events was discussed, and different actions for improvement were given.

The procedure is meant to be integrated into a refinery's existing safety, quality, and environment (SQE) management system. It is used when human error is related to a harmful event, either an accident or injury or work order, related to a corrective, on

condition or planned maintenance (Bevilacqua and Ciarapica, 2018). The method requires a computerised maintenance management system (CMMS), where all work orders are filled, and accidents, injuries or near misses are reported. The HFRM procedure includes the identification of the relevant information about the harmful events and event description, identification of the human error causes, identifying and evaluation of the significance of the PSFs, evaluation of the risk or potential risk of the events, and identification of the follow-up actions (Bevilacqua and Ciarapica, 2018). In case of a harmful event, the analysis follows the HFRM procedures when the event is related to human error. Otherwise, the traditional (SQE) procedure is used. The procedure is presented in Figure 11.

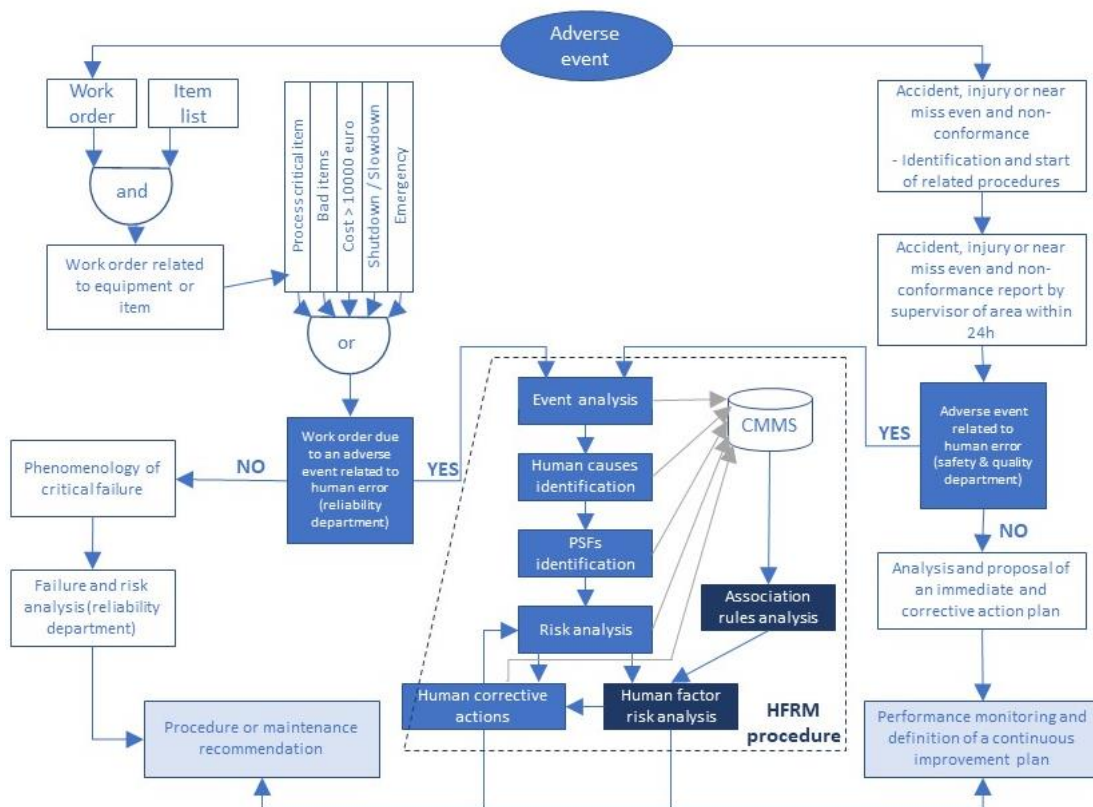


Figure 11. HFRM procedure integrated into an existing harmful event procedure (reproduced from Bevilacqua and Ciarapica, 2018).

From the start of the procedure, the *event analysis* requires that all the required data is registered in the CMMS. The required data, according to the article, include the type of harmful event, the work situation, the date of the event, the plant area, the

part of the bodily injury, and the description of the event. In the *human cause identification*, the cause of the error is selected from a defined list developed for the refinery sector, Table 3 (Bevilacqua and Ciarapica, 2018). Next, the *PSFs are identified* to recognise the contributors to human performance and to provide a basis to quantify those contributors systematically. The PSFs are also listed in Table 3. In the *risk analysis*, the risk index for each case of a harmful event is calculated with probability and consequence, which results in three categories: low risk, medium risk, and high risk. *Human corrective actions* are decided based on the investigation of the adverse event and the action is chosen to avoid the recurrence of the event. All these factors are fed into the CMMS. Based on this data, a *Human Factor Risk Analysis* is recommended to be performed monthly to provide risk reduction suggestions to reduce the risk of human error. This analysis utilises the *association rules* technique to recognise relationships among the factors. Using different algorithms, association rules discover regularities between data sets (Garg, 2018). This method used the Apriori algorithm (Bevilacqua and Ciarapica, 2018). Accident data of a refinery of 2076 events from 2005 to 2015 were analysed utilizing the method. The results obtained from the analysis provided, for example, the plant areas and personal safety factors that had the highest risk indexes.

To conclude, the procedure uses data gathered from a refinery and a machine learning tool to investigate and identify human factors' risks and recommend preventative and safety measures to reduce adverse events. The HFRM procedure is applicable to be added to an already existing risk management procedure. This makes it seem to be easily integrated into the safety procedures of a company. However, the procedure requires a CMMS and a team to gather the results, run the association rules analysis, and draw a conclusion from the results to suggest, all of which require labour resources. The size of the refinery also complicates the analysis if there are more items to analyse. Also, as the human error causes, PSFs, and corrective actions are all chosen from already prepared lists based on the historical data of the refinery, especially the corrective actions might place some of the needed actions on wrong personnel groups, as the corrective actions include mostly operator-based actions.

Overall, the process seems potential as it can utilise data from the refinery it is applied to. When used frequently, it provides overviews of the recent harmful events and points out specific targets to improve.

Table 3. List of different factors and items in the HFRM procedure (reproduced from Bevilacqua and Ciarapica, 2018).

Factors	Items
Adverse event typology	Near miss Accident or Injury Operating accident Environmental accident
Plant area	List of different plant areas at the refinery.
Human error cause	Operation carried out without authorization Necessary operation/procedure was forgotten Incorrect choice of raw material Lack of precision/inappropriate speed of performance/haste Warning given incorrectly/insufficiently/to the wrong person PPE (Personal Protective Equipment) used badly/faulty Inadequate knowledge of regulations and procedures Made inoperative a control system Incorrect loading/lifting/substitution of equipment Incorrect/inappropriate use of equipment/appliances Incorrect position or posture during the developed activity Maintenance/action/operation carried out on equipment in run Bad habits Lapse of concentration/detrimental behaviour
Performance Shaping Factors (PSFs)	Training level Available time for task execution Attention towards suppliers/stakeholders Human-machine interface Quality of Information (lack of communication) Company safety culture Level of Experience Lack of Supervision
Risk index	Low Medium High
Corrective actions	Interview with the injured person Safety talk Training on the use of PPE Intensify the training program Internal testing or assessment of modifications Identify extra PPE for the workers Verbal warning Written warning to the employee Disciplinary sanction for the employee Penal sanctions for the external contractor firms/operators Control of external operator/contractors

4.1.3 Task Improvement Process

The task Improvement Process (TIP) is a tool developed by the energy company BP to simplify the Safety Critical Task Analysis (SCTA) by the Energy Institute (EI). It was designed for operations and maintenance personnel without requiring support from an expert. The aim was to make human performance thinking more attainable and more utilised in day-to-day operations (Miller and Grounds, 2019). The TIP can reduce the probability of mistakes, improve the detection or recovery from mistakes, and reduce the consequence of mistakes, by identifying possibilities to improve the design of critical tasks (Miller and Grounds, 2019). The process was described to be similar to the Root Cause Analysis after an incident but is a proactive version that is designed to prevent incidents by analysing the task and finding improvements to decrease the likelihood of mistakes. Figure 12 shows the Task Improvement Process.

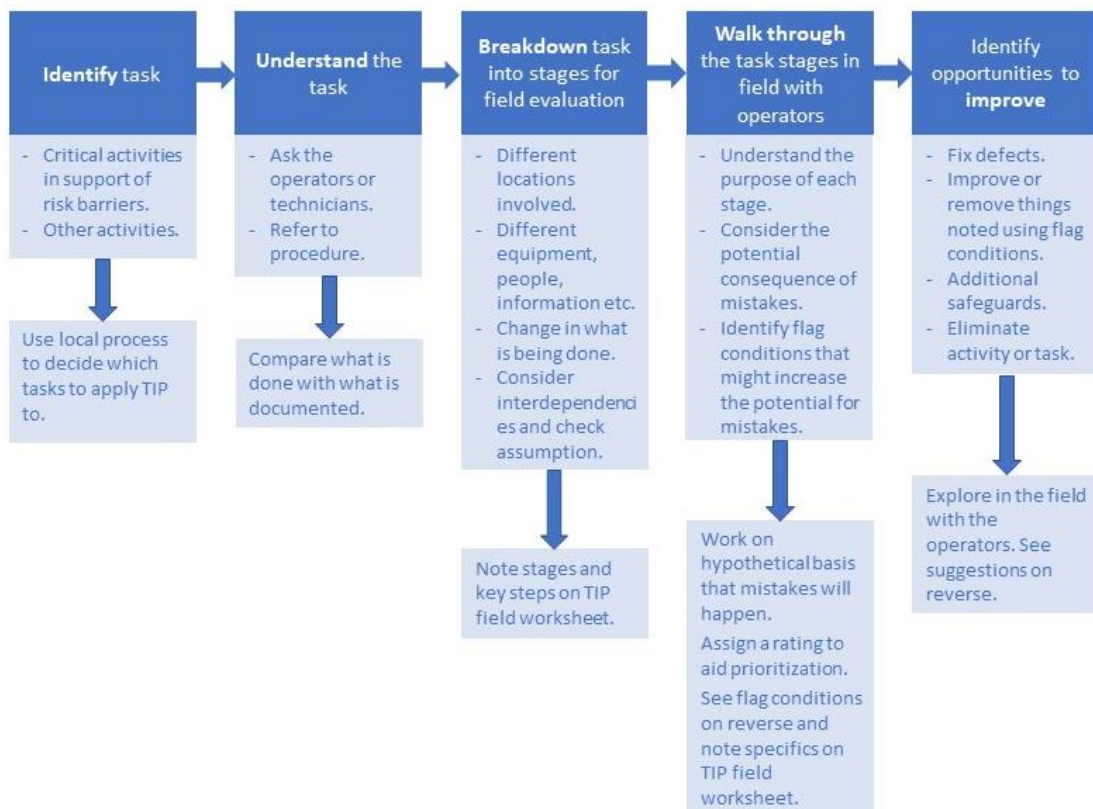


Figure 12. The Task Improvement Process (TIP) developed by BP (reproduced from Miller and Grounds, 2019).

The process is applied to a critical task where mistakes could lead to a major accident. This can be a task that is critical to the design, operation, maintenance, or risk barriers, as well as any task that could lead to significant consequences (Miller and Grounds, 2019). The TIP focuses on how the task is executed in practice. A TIP help sheet, flag conditions, a TIP field worksheet, and any relevant documents, such as P&IDs, are needed to carry out the process. Flag conditions are things that have been shown to affect human performance (Miller and Grounds, 2019). The steps are the same as in Figure 12. Firstly, the task to apply the TIP is decided. Secondly, the task needs to be understood and ensured that the actions match with what is documented. In the third stage, the task is broken down into steps, all walked through in step four identifying flag conditions. The flag conditions identified by Bp are shown in Table 4. Lastly, the ideas to improve or eliminate the things identified in step four are noted. Additionally, an e-learn course is also provided on the TIP (EI - Publishing, 2021).

Table 4. Flag conditions determined by (reproduced from Miller and Grounds, 2019).

Flag condition	Guidance or examples	Opportunities to improve (apply hierarchy of controls)
Steps where mistakes could be made.	Do you know which stages of the task could result in a high consequence event following a mistake?	Consider capturing key stages of task for verification effort. Provide feedback following key steps to allow people to spot a mistake and remedy it. Consider interlocks.
Steps that cannot be done or are inefficient to do in reality.	Are there opportunities for the person to find a different way? Think about a cold, dark night – would it get done?	Look for opportunities to make the task more effective and efficient to complete safely.
Unusual, infrequent, unfamiliar, or novel situations.	Does the person have the necessary skills, experience, and capability?	Consider linking procedures to competence programme. Add independent verification or checks and hold points?
Boring, trivial, or repetitive actions.	Could the person “switch off” or do the task on auto pilot? Could new information or changes be missed?	Consider – can the task be shared? Would independent checks be helpful?
Difficult system or equipment interface, labelling, controls, alarms.	If the operator went to the wrong plant area would the labelling and procedure identify that to the operator?	Verify that key equipment, valves, and lines are labelled and correctly noted in procedure.
Steps where there might be insufficient time available.	Time pressure can have a big effect on reliability – could perceived or actual time pressure exist?	Seek to improve management of any pressures felt during execution of critical steps, consider expectations set in job planning and toolbox talks.
Complex or difficult to understand steps.	Is it clearly understood what needs to be done? Does the procedure make this clear?	Verify clarity and usability of procedures, visual aids, and instructions – make sure these are used to keep track or place.
Unclear signs, signals, instructions, or other information.	Is information from signs, signals, documentation etc. unclear, missing detail or confusing?	Look for ways to provide people with clearer information, signs, signals, and instructions.
Difficult working environment (noise, heat, cramped conditions, lighting, ventilation, ease of access).	Look how the environment can cause a mistake, E.g., noise – can reduce communication quality, lighting and line of sight could cause someone to miss key information.	Identify potential environmental improvements (e.g., use of sound buffering, improved lighting positioning of equipment).
Relies on recognising emerging hazard, risk, or change.	Could the person be engaged in activity and miss a situation change?	Introduce or expand on hold points and checks during task to identify and take on board changes etc.
Potential for interruptions or distractions.	Does the task involve a need for high vigilance or concentration? Is the task completed in a busy area? Can the operator identify potential interruptions?	Seek to improve management of potential distractions during key stages of task – do not interrupt signs, reduce radio traffic, sign post as warning in procedure. Give tools to enable recovery in event of being distracted. Introduce hold points.
Involves multi-tasking.	Could the person be distracted by doing something else part way through the task? (e.g., manual filling a tank)	Seek to improve management of any multi-tasking through job planning and management of emerging work.
Right tools might not be available or used.	Does the person have all they need close to hand to complete the activity? (e.g., hand tools, procedure etc.)	Think about what is needed to do the job and how to make it more accessible.
Relies on good communications, with colleagues, supervision, contractor.	Could information quality be poor during verbal and written communication?	Use communication protocols to support passing of correct messages (e.g., readback, 2-way communication, dual media).

The EI has also noted the TIP and its potential strengths. The main strengths include that the process offers an efficient approach to SCTA, especially as it does not require a specialist. It enables personnel to conduct a variation of SCTA, which will benefit when performing other tasks as the personnel are more equipped to identify potential errors. It can result in the reinvigoration of initiatives around operational and procedure reviews, and the process done in the field is more in the comfort zone of the operators (Energy Institute, 2020). However, the EI also notes that bringing the SCTA closer to the frontline personnel might make it challenging to consider the whole picture, and some improvements might go undetected. Furthermore, monitoring and controlling the SCTA process might cause difficulties if operator personnel are responsible implementing of the procedures (Energy Institute, 2020). Overall, the TIP seems easy to implement and straightforward, but the time required from the personnel and which tasks should be implemented to get the most significant improvements must be studied.

4.2 Human error-related items

The least number of articles was associated with human error in the literary search, as seen in Figure 8. Altogether 11 articles were categorised under human error, and four were considered methods or tools in the scope of this thesis. Two articles were chosen to be presented here based on their clarity, practicability, and applicability. Other articles found in the literary search included, for example *learning from accidents article*, three articles discussing *human error concepts*, and two articles *predicting actions and consequences*. The two chosen articles were under *risk assessment and human error concepts*. Figure 13. shows the number of articles in all the different categories.

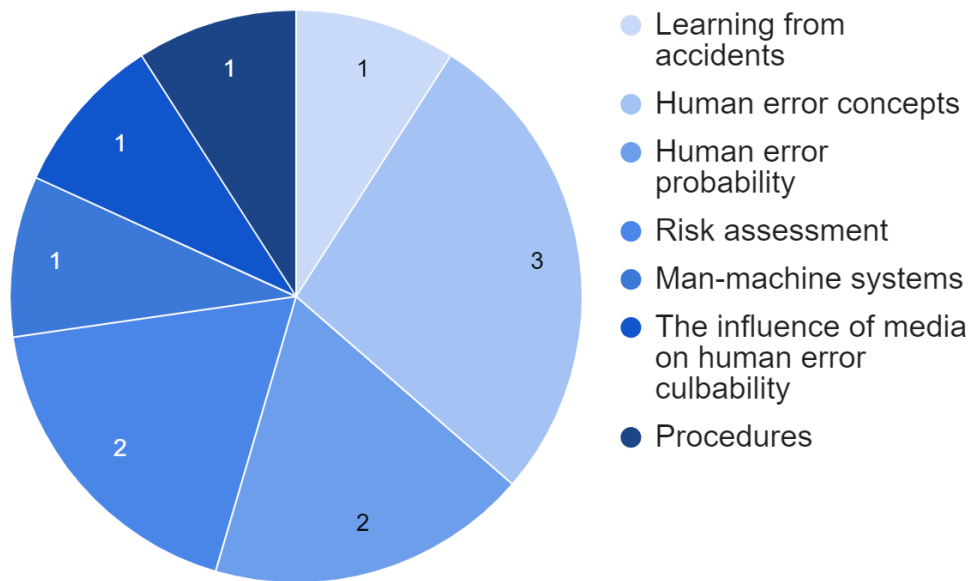


Figure 13. Categorization of human error-related articles.

4.2.1 A novel qualitative prospective methodology for analysing human error

Calvo Olivares et al. (2018) developed a prospective qualitative methodology to assess human error. The method is said to not depend exclusively on retrospective information, to be implementable without expert judgement, and to enable predicting potential accidents before they occur (Calvo Olivares *et al.*, 2018). The method was specified for small and medium-scale facilities with simple processes. The method was described in the article, after which it was applied to a medium-capacity biodiesel plant. The method includes two main assessment stages. The first is aimed at the system to identify the information given by various measurement devices. The second is the analysing the operator and their decisions based on the available data (Calvo Olivares *et al.*, 2018). The different phases of the method presented in a flow diagram are shown in Figure 14.

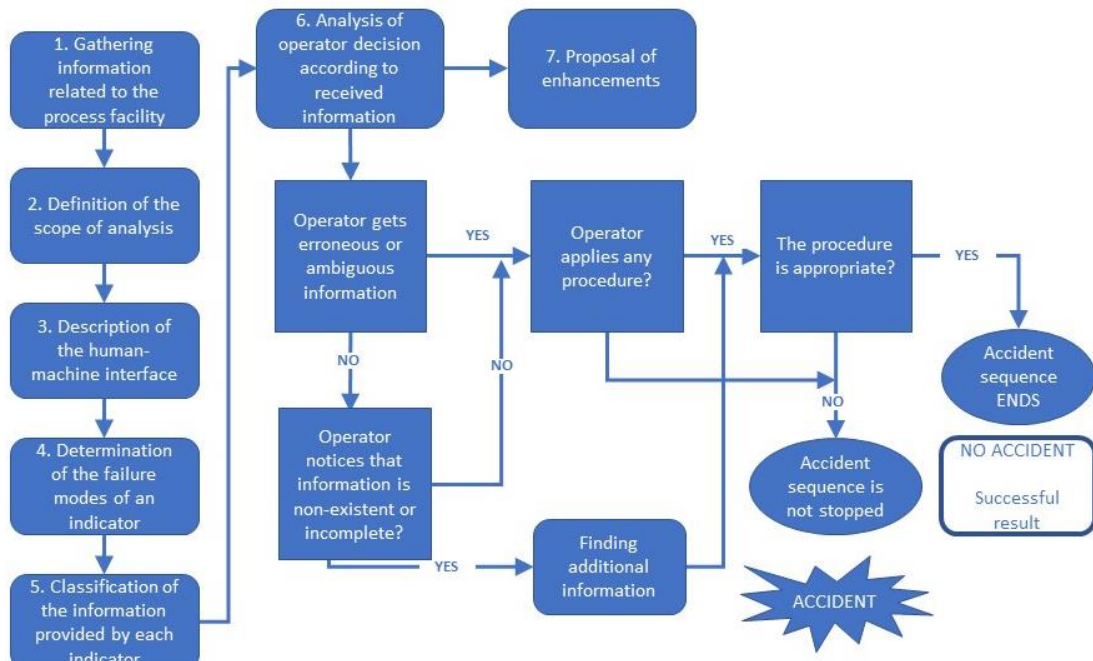


Figure 14. Flow diagram for the novel qualitative prospective methodology for analysing human error (reproduced from Calvo Olivares et al., 2018).

The first stage of gathering information from various measurement devices is the first five questions in Figure 14. The second stage of analysing the operator starts from question 6 in Figure 14. The methodology tries to answer questions such as which process parts are critical in terms of safety, what can initiate an incidental sequence, what information certain elements provide, and which of those elements will affect the operator to deviate from the correct solution to an accident sequence. In Figure 14, the first step of *gathering information related to the process facility* collects the integral information, including plant functioning, procedures, operator instruction materials, current supervision tasks, and plant design materials. The second step, the *definition of the scope of analysis*, defines a starting point, the event that initiates the accident sequence, and the events that that sequence can lead to. The third step, the *description of the human-machine interface*, identifies and describes the elements that allow controlling the process, including temperature, pressure, flow, and level indicators. Their location, type, and transmitters are considered. *Determination of the failure modes of an indicator* is the fourth step. It includes determining the failure

modes of the previously identified elements using Failure Modes and Effects Analysis (FMEA).

The FMEA is used to assess a system, a design, a process, or a service to recognise the different plausible ways system component failures can occur (Ericson, 2015). The aspects considered in the FMEA are the item, component, function, failure mode, failure cause, local effect (detection mode), and the effect on the system. With this analysis, the indicators can be categorised as ambiguous, inaccurate, or non-existent based on the information they provide (Calvo Olivares *et al.*, 2018). This categorisation is the fifth step, the *classification of the information provided by each indicator*. In addition to the categories mentioned above, an incomplete option is included. Ambiguous information from an indicator does not show the actual situation with an element under control. Inaccurate or erroneous information shows information that is inaccurate or wrong. Non-existent information shows no data due to a fault or an indicator being disconnected. Incomplete information is when insufficient information is available to justify decisions based on procedures or instructions. Then the stage of analysing the operators' decision, *analysis of operator decision according to received information*, is reached. The aim is to analyse the decisions made by the operators based on the received information in each situation recognised in the previous steps. Based on the information received and the operator's actions, the accident sequences either lead to an accident or stop. These different possibilities allow the final step of the *proposal of enhancements*. The identified routes to accidents are gone through, and modifications are proposed. These might involve design, structure, or layout changes, adding or upgrading procedures, and improving supervision and operator training (Calvo Olivares *et al.*, 2018).

Calvo Olivares *et al.* (2018) identified some advantages and disadvantages of the methodology. The advantages included easiness of implementation, applying to any technological system, not requiring exclusively retrospective information or expert judgement, and can be completed by an engineer trained in human factors, as well as that the methodology allows for recognizing potential error sequences even after

the accident event has started (Calvo Olivares *et al.*, 2018). On the other hand, the disadvantages included the time and effort required for the analysis when the size of the process increases and the inability to represent the processes happening simultaneously (Calvo Olivares *et al.*, 2018). Additionally, the methodology requires good communication in the organisation so that the operators are aware of the correct actions recognised in the process.

Overall, the process emphasises that the causes of human error are based on the information that the operator receives and not on the decisions of the operator to apply the procedure they thought was correct. This way of thought shifts the blame on human error away from individual operators and towards systematic ways to hinder the occurrence of accidents caused by human error.

4.2.2 Re-designed Just Culture process

Reason (1997) developed the concept of Just Culture to ensure and emphasise fairness, trust, learning, and accountability in organisational culture. This was defined by Reason (1997) as “an atmosphere of trust in which people are encouraged, even rewarded, for providing essential safety-related information, but in which they are also clear about where the line must be drawn between acceptable and unacceptable behaviour”. Reason (1997) also developed a decision tree framework to help managers fairly decide the potential culpability of individuals involved in cases of human error or non-conformance after an incident. Figure 15 shows the framework. However, some scientific studies have challenged the validity of establishing the culpability of a person based on a simple framework (Dekker, 2008; Hudson *et al.*, 2008).

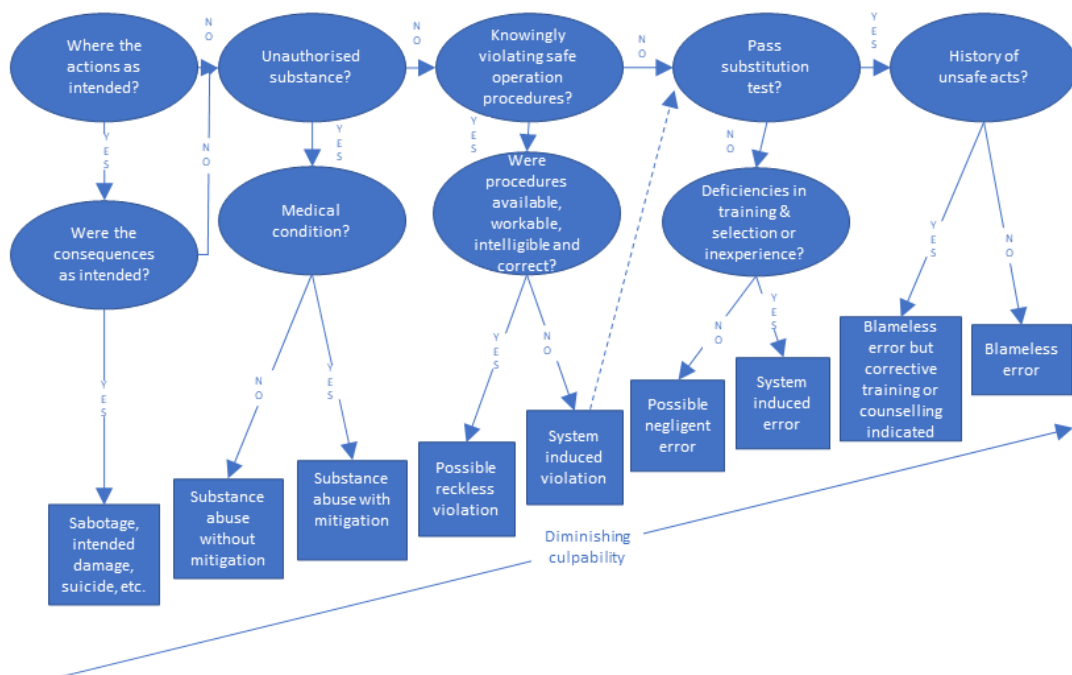


Figure 15. Just Culture decision tree by (Reason, 1997).

Bitar et al. (2018) created a re-design of the Just Culture process for the upstream operations of the company responsible for oil and gas production and processing. The aim was to move the mindset in the organisation away from the tool being used as a disciplinary tool for individual behaviour to see its potential as a tool to spot system weaknesses (Bitar *et al.*, 2018). Bitar et al. (2018) raised problems associated with the original Just Culture process. These included that the process was used as a basis for dismissal, there was no systematic training for the application of the process, there was no systematic governance process or quality monitoring system, the process was used to emphasise discipline rather than understanding causal and contributing factors, and the terms “violation” and “negligent” used in the framework were interpreted as implying individual fault from the start of the process. Additionally, similar problems were recognised in the literature. These problems included that it was unclear how supervisors, managers and executives were held accountable, and that the culpability of a person was influenced by different factors, making the choice subjective rather than objective (Bitar *et al.*, 2018). Considering these problems, as well as the observations from focus groups of senior and mid-level leaders and a broad range of stakeholders, the “new” Just Culture process was

created by Bitar et al. (2018), shown in Figure 16. A larger version of the image in Figure 16 can be found in Appendix 2.

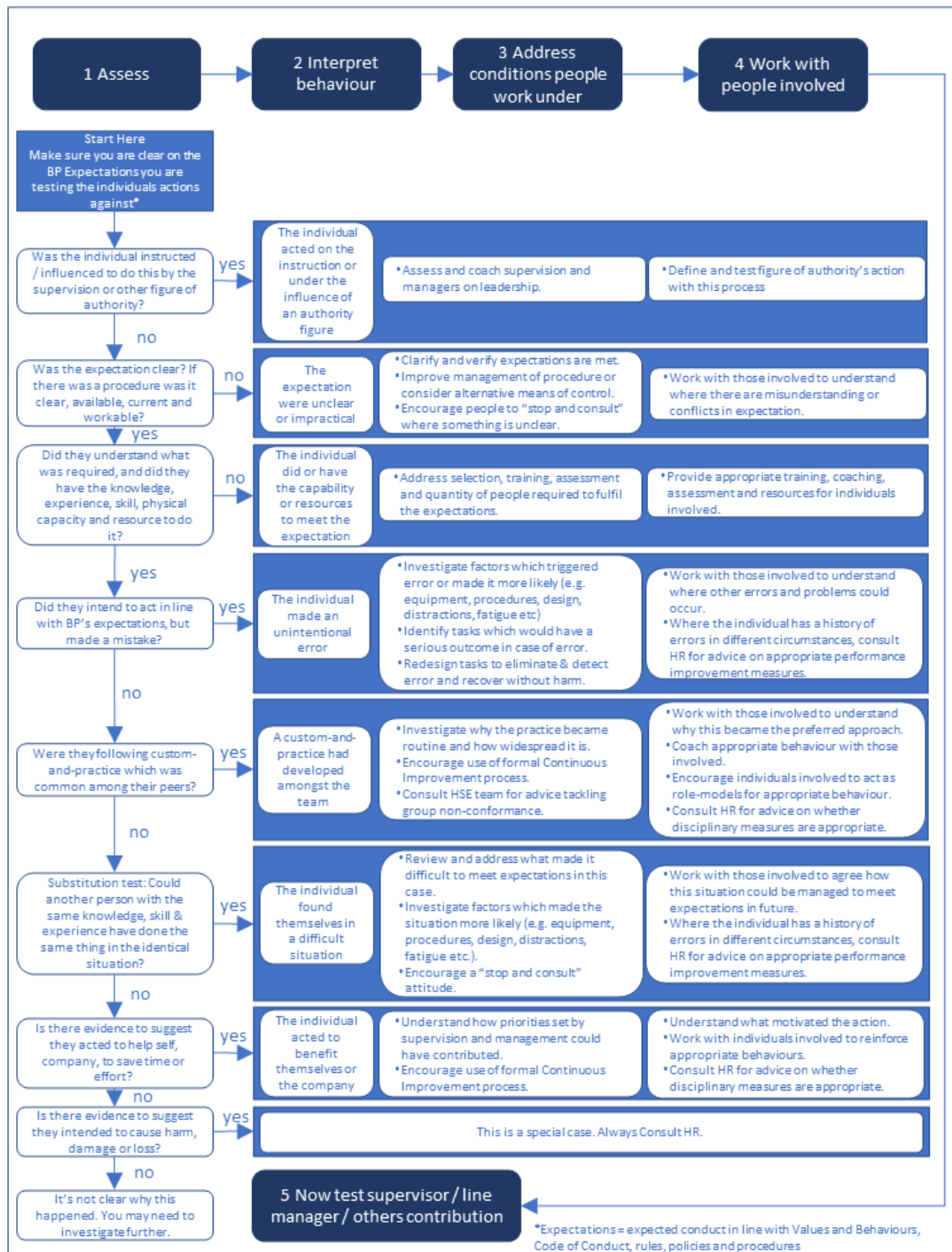


Figure 16. The “new” Just Culture process (reproduced from Bitar et al., 2018).

The re-designed process consists of eight questions. It is said to be used after an investigation of an incident or a near miss, where the actions were thought not to be aligned with the expectations of the company (Bitar *et al.*, 2018). The new process focuses on the workplace influencing factors and not on the individual, and it offers suggestions to address the conditions people work under and ways to work with people involved. Furthermore, the managers who can perform the reviews are specified, and more training is required. In addition, the process can be done at all levels of the hierarchy, not only on the front line, and there is a systematic learning process to assess the findings. The differences between the “old” and the “new” Just Culture process are shown in Table 5.

Table 5. The user experience compared between the two processes (reproduced from Bitar *et al.*, 2018).

Aspect of process	“old” version	“new” version
Scope	Focus on the front line	All levels of hierarchy included
Who does the reviews?	Line manager or HR	Limited to site managers trained in the JC process
Initiation of a Just Culture review	Following an investigation of an incident	Following an investigation of an incident or a near miss, where an individual is thought not to have acted in line with company expectations
Human Resources involvement	Depended on custom and practice in regions	Specified within the re-designed process
Training	Slide pack issued	Training programme with case studies and support materials, facilitated by a former operations leader
Question content	Focus on the individual	Focus on the workplace influencing factors
Question sequence	Flow chart provides for one answer	Question sequence can give potentially more than one answer allowing for richer insights
Supplementary instructions	No additional suggestions in flow chart	Additional suggestions to “Address conditions people work under” and “Work with people involved”
Guidance on discipline	Guidance slide based on Management of consequences framework	Apply local HR policy with guidance from a HR professional
Who can decide on the discipline?	Any line manager or HR professional using the process	A leader trained in the JC process consults with a HR professional
Learning	No systematic process	Quarterly reports reviewed by operations leadership team

Bitar et al. (2018) evaluated the process by going through their company database of 353 Just Culture cases. They found that the corrective actions shifted from training, coaching, or disciplinary actions to addressing system defects with the re-designed process. Also, 90 per cent of the primary underlying contributing factors were system issues (Bitar *et al.*, 2018). The recognised limitations of the “new” process included that despite the training some questions regarding the application of the process remained, and the individuals who were on the receiving end of the process were not interviewed (Bitar *et al.*, 2018).

Overall, the re-designed Just Culture process shifted the focus from individual actions to wider systematic ones. It requires more effort as the reviewers need proper training, and the database and reports need to be reviewed. However, it has easily implementable chances if a Just Culture process is already in use, to improve the conduction of the examination.

4.3 Safety culture-related items

Safety culture was the most occurring theme in the literature review, with 24 articles classified under it. Additionally, it contained the most variation in the different categories the articles dealt with. Topics such as *history*, *regulations*, and *bibliometric analysis* were unique to safety culture. The most popular topics were *safety management* and *assessment*. Altogether eight articles were about methods or tools. The two chosen articles were under *safety assessment* and *safety culture concepts*. The different categories are shown in Figure 17.

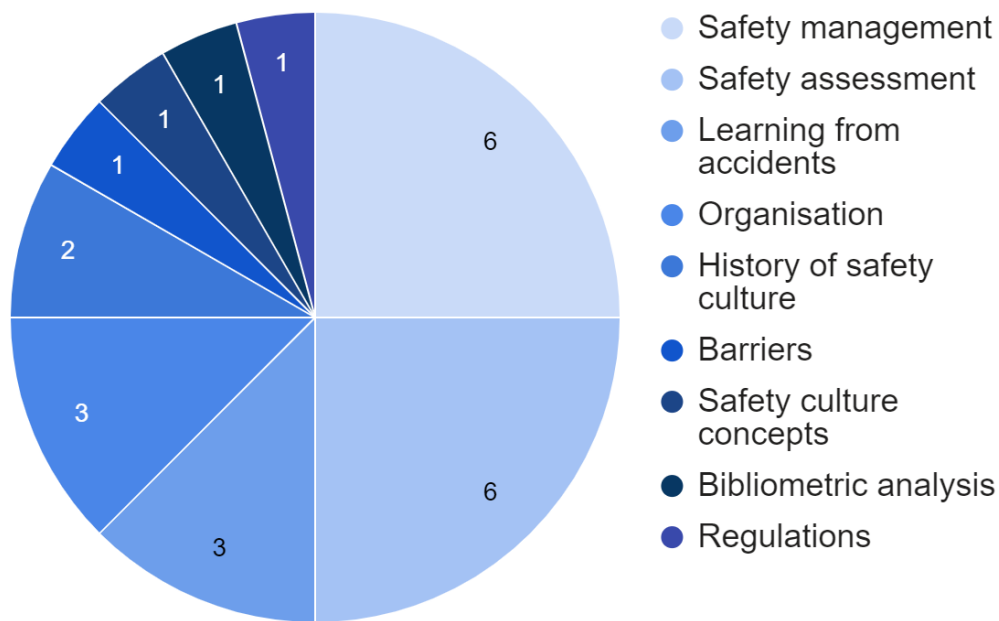


Figure 17. Categorization of safety culture-related articles.

4.3.1 The Egg Aggregated Model

Different models are used to represent the concept of safety culture. However, there has not been a comprehensive model to represent the main aspects of safety culture. Vierendeels et al. (2018) created a model called the Egg Aggregated Model (TEAM). The model aims to give an integrated and holistic overview of safety culture, considering all aspects of safety within an organisation and explaining their relations (Vierendeels *et al.*, 2018). The uniqueness of the model is that it considers a variety of scientific disciplines related to safety research in organisations, like engineering, sociology, and psychology.

The model is presented as a metaphor for an egg. The shell of the egg is the perimeter of the group, the observable factors are the yolk, the protein is the perceptual and the personal psychological factors that can be referred to as psycho-social factors for safety, and the air in the egg represents the basic assumptions, core values and belief that are essential part but invisible. The model visualised by Vierendeels et al. (2018) is shown in Figure 18.

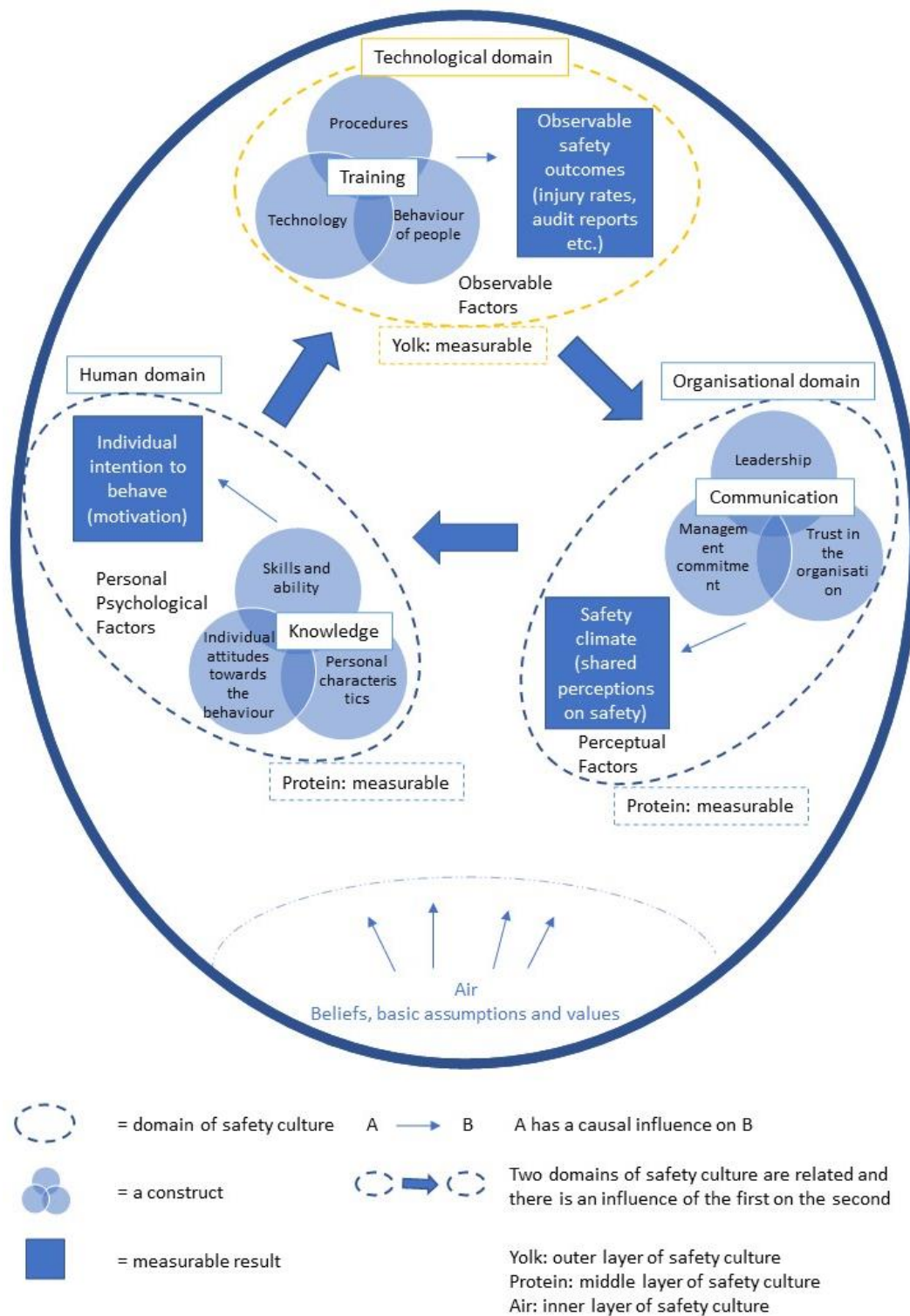


Figure 18. The Egg Aggregated Model of safety culture by (reproduced from Vierendeels et al., 2018).

The model was built by considering different safety culture models and combining their overlapping factors into a comprehensive entity. The different models utilised are listed in Table 6. With the first four models in Table 6, Vierendeels et al. (2018) created five categories: *technology*, *procedures*, *person*, *behaviour*, and *training*, and listed the elements that each model brought to each category. With these, the difference between the observable and non-observable factors was created. In the Egg Aggregated model, the observable factors are represented with the yolk of the egg, including *technology*, *procedures*, *behaviour*, and *training* of the five categories. The *person* category was defined as the non-observable factor. Next, the *person* category was divided into *individual* and *organisational* constructs based on the fifth and sixth models in Table 6. In Figure 18, these are the proteins of the egg. The seventh model in Table 6, was used to organise the *organisational* construct to the combination of *leadership*, *management commitment*, and *trust in the organisation*, which creates a *safety climate*, as seen in Figure 18, inside the *organisational* domain. The eighth and ninth models in Table 6, were used to organise the *individual factors*, all of which led to the *intention to behave*, as seen in Figure 18 in the *human* domain. Finally, the tenth model in Table 6, was used to show the *layers of safety culture*, which create the egg metaphor. The yolk is the outer layer of safety culture and represents the observable factors. The protein is the middle layer of safety culture and shows why the observable factors exist. Lastly, the air in the egg is the inner layer of safety culture and describes the beliefs, basic assumptions, and values of the safety culture of an organisation.

Table 6. List of models considered when making the Egg Aggregated Model (Vierendeels *et al.*, 2018).

	Name of model	Origin of model	Where used in the Egg Aggregated Model
1	The three E's model	(National Safety Council, 1974) (cited in (Vierendeels <i>et al.</i> , 2018))	To create five categories: technology, procedures, person, behaviour, and training, and combine the elements of each model under the categories. Divide observable and non-observable factors.
2	Total Safety Culture model	(Geller, 1994)	
3	Reciprocal Safety Culture model	(Cooper, 2000)	
4	P2T model	(Reniers <i>et al.</i> , 2011)	
5	The Safety Climate and Performance model	(Griffin and Neal, 2000)	To divide the person category into individual and organisational constructs.
6	Model for safety performance and safety outcomes	(Christian <i>et al.</i> , 2009)	
7	A summary of the principal factors involved in navigating the safety space	(Reason, 1997)	To organise the organisational construct
8	Theory of planned behaviour	(Ajzen, 1991)	To organise the individual factors
9	Path model showing direct and mediated pathways to safety behaviours	(Fugas <i>et al.</i> , 2012)	
10	Organisational cultural model	(Schein, 1990)	Layers of safety culture

The Egg Aggregated Model is designed to represent safety culture in one comprehensive picture. The idea of the model is memorable, but it requires some effort to comprehend the different connections in the model. Compared to the safety culture models presented in section 2.3 in Figure 4 and Figure 5, this model shows more about how safety culture is constructed. In contrast, the dss⁺ Bradley curve and the evolution of safety culture by Hudson (2001) show different levels of safety culture and how safety culture is developed to achieve better safety performance. In this model, the different relations that construct safety culture are visible, and they can be used to understand the consequences when improving specific sections of safety culture. Overall, the model is memorable as it utilises the concept of an egg, but to understand the concept the model must be thoroughly studied.

4.3.2 Ranking of process safety cultures

A method to externally evaluate process safety culture in major hazard industries was developed by Zwetsloot et al. (2020). The tool aimed to repeatably and reliably rank the safety cultures of major hazard companies. In the European Union, the Seveso III legislation requires adequate technology, a process safety management system, and safety communication, but legal requirements regarding safety culture only exist for nuclear power plants and aviation ('The Chemicals Act (Control of Major Accident Hazards involving Dangerous Substances) Regulations 2015 (S.I. No. 209 of 2015)', no date; Allford and Hailwood, 2015; Zwetsloot *et al.*, 2020). In Finland, safety culture is mentioned in 58 § of decree 21.5.2015/685, "Decree on surveillance of the handling and storage of dangerous chemicals", to be covered by safety management systems. Consequently, safety culture in major hazard industries is each organisation's responsibility, so it might be regarded as an example of going beyond compliance (Zwetsloot *et al.*, 2020). External assessment of safety culture could help authorities to evaluate companies' safety situations better and intervene earlier in problematic situations possibly inhibiting accidents (Zwetsloot *et al.*, 2020). For this reason, the Major Hazard Inspectorate of the Netherlands developed a tool to assess the safety culture in major hazard companies indicatively.

The project to create the tool started with developing a draft of the tool from 2014 to 2015 (Zwetsloot et al., 2020; Zwetsloot & Bezemer, 2014). The basic requirements were set as to be user-friendly for the inspectors, suitable to a whole variety of major hazard companies, able to differentiate between good and not-as-good safety cultures, require limited additional inspection time, and, if possible, have predictive value for compliance with legislation and safety performance (Zwetsloot *et al.*, 2020). The idea of the tool was to be used after an inspector has spent a day doing their routine inspection in a major hazard company and to assess the different aspects of the safety culture of the company with the tool in approximately 15 minutes. The tool has 14 different aspects and a combined 30 items. Four aspects were identified as the most crucial to safety culture, and they had three or four items each, while other aspects had one or two questions. The four most important aspects were safety

leadership, safety communication, involvement of employees, and learning culture (Zwetsloot *et al.*, 2020). Equal weights were given to all items in the assessment. The questions were framed as “to what degree...” The response scale was set to a 5-point scale from very poor to excellent, with a “don’t know” option as the sixth option. The inspectors were given a concise explanation of how each item should be interpreted to avoid inconsistencies. The aspects and items are presented in Table 7.

Table 7. The aspects and items assessed in the tool with a response scale of 1 = very poor, 2 = poor, 3 = average, 4 = good, 5 = excellent, and 6 = don't know (reproduced from Zwetsloot et al., 2020).

Aspects	Item To what degree...
Leadership	is senior management committed to safety?
	is senior management competent with respect to safety?
	is senior management visible on the shop floor to promote safety proactively?
	does senior management address people in case of unsafe acts
Production versus safety	do the actions of senior management demonstrate a balance between safety and production?
Vision management	does senior management sees itself as responsible for the causation of incidents (including losses of containment)?
Role supervisor	do the supervisors motivate their team to improve safety?
Safety communication	does the organisation communicate a clear and consistent safety message?
	do managers and employees share information about safety?
	do employees experience safety meetings as important?
Participation	do employees employ initiatives to improve safety?
	is safety 'alive' at the shop floor?
	are employees actively involved by the managers in dealing with safety issues?
Learning culture	does the plant implement lessons learned from incidents and near-misses?
	do lessons learned from incidents lead to improvements in safety culture
	does the organisation monitor the safety climate (the perceptions and attitudes of the employees that are relevant for safety)?
	does the plant actively identify lessons learned from incidents occurring in other organisations?
Procedures	does the organisation review and adapt its procedures to improve safety practices?
Audits	does the organisation timely implement all findings from safety audits?
	does senior management use the outcomes of audits as input for management reviews?
Registration	are employees effectively stimulated after incidents to reflect on safer work practices?
	do employees see it as important to report deviations (e.g., near misses, unsafe or unexpected situations)?
Maintenance	is maintenance up to date?
	is there sufficient attention for safety in times shutdowns, retro fit, etc.?
Contractors	does the company develop (process) safety plans jointly with their contractors?
	does senior management demonstrate its responsibility for the safety of contractor and subcontractor personnel?
Process and work safety	is there dedicated attention for the relevant process safety scenarios?
	is there dedicated attention to personal safety risks?
Complexity	is senior management aware of the potential impact of unexpected events (e.g., process disturbances, earthquakes, security issues, variation in raw materials, etc.) on safety?
	does senior management anticipate on unexpected events?

The tool underwent a qualitative evaluation and proof of concept and a quantitative evaluation and validation. Zwetsloot et al. (2020) found that the time taken to complete the assessment by the inspectors was approximately 15 minutes, the variation between two inspectors at the same plant was no more than one point on all questions, and the tool could differentiate between good and not good safety culture. For the quantitative evaluation, the tool was digitalised. It was used by the Major Hazard Inspectorate of the Netherlands for almost half of their major hazard

inspections in 2016, resulting in 509 times using the tool during 174 inspections of major hazard plants. Zwetsloot et al. (2020) found that the “don’t know” response frequency was over 20% for 11 of the 30 items. Hence, they decided to drop the aspects of registration and contractors from the statistical analyses due to the effect on reliability. The data was found reliable and valid as a good safety culture score was linked with a positive correlation to a good safety management system and a negative correlation to the number of non-compliances.

Zwetsloot et al. (2020) also discussed some concerns raised by the inspectors. Firstly, some items were difficult to assess as some topics were outside the scope of the inspections. Secondly, several inspectors felt that their knowledge was insufficient to be able to adequately answer several items as it was their first time inspecting certain plants. Thirdly, some inspectors reported that they felt the tool to be rather subjective. Lastly, the applicability of the tool to major hazard facilities with very few people, for example, warehouses, was questioned. As the inspectors taking part in the quantitative evaluation were not trained in using the tool, the assessments are based on the limited observations of the inspectors. They might be why the tool felt subjective and why there were frequent “don’t know” responses. Additionally, Zwetsloot et al. (2020) noted that the inspectors have a technical background that might affect the variation in the social observations among inspectors. The suggestions for improvement given by Zwetsloot et al. (2020) included offering training for the inspectors, preparing for safety culture aspects before the inspections, slightly adapting the inspections process such as to include asking questions about issues like safety communications, discussing the answers with other inspectors present at the inspections, and by linking relevant questions to the inspection methodology.

The assessment outcomes were found to be relatively positive, exceeding expectations of what is often suggested as the state of safety culture in major hazard companies in the Netherlands (Zwetsloot *et al.*, 2020). A point was raised that there might be a bias that causes culture to be assessed in a relatively positive way. This might be due to the inspectors being reluctant to report critical observations when

there is no concrete evidence, and such evidence is hard to find in regard to culture (Zwetsloot *et al.*, 2020). The possible bias needs to be considered when utilizing the tool.

External safety culture assessment tools can become an essential part of the operations of major hazard companies. It can offer feedback, identify blind spots, and offer valuable data as well as understand the perceptions of external stakeholders, such as authorities, policymakers, insurers, and media. This kind of tool that seems easy to use, does not increase the inspection times significantly, and can differentiate between companies might come as a required part of inspections to assess safety culture.

4.4 Safety climate-related items

Safety climate had 16 articles classified under it. Out of these four were methods or tools. Uniquely, safety climate had three articles dealing with individual behaviour and personality. The significant categories with safety climate were leadership, safety assessment, and behaviour and personality. The different categories are shown in Figure 19. The two chosen articles were under leadership and safety assessment.

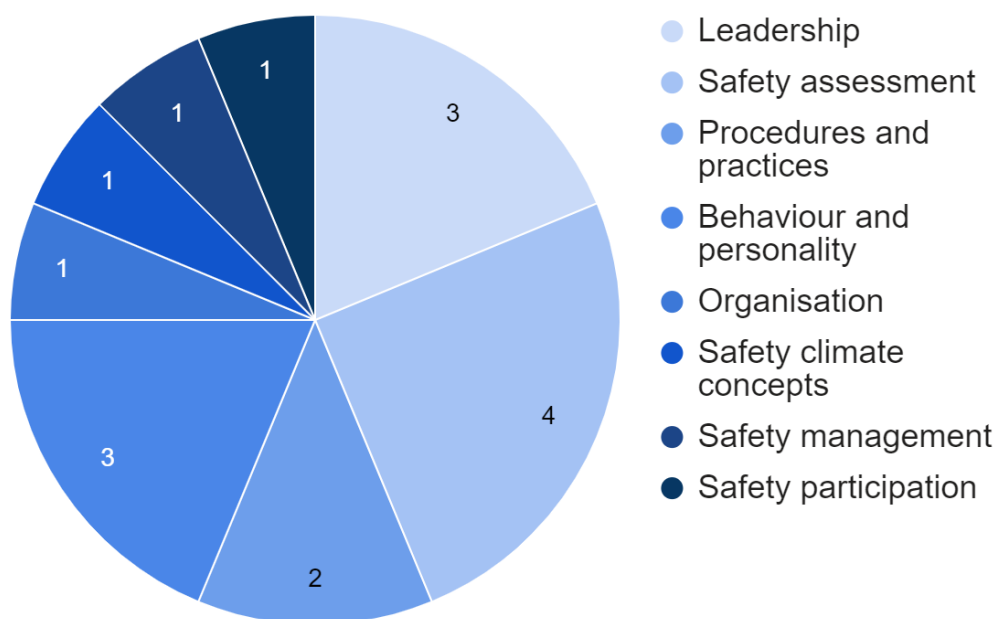


Figure 19. Categorization of safety-climate related articles.

4.4.1 Transformational and active transactional leadership behaviour intervention

Clarke and Taylor (2018) developed and implemented a leadership intervention methodology. The aim was to study how transformational and active transactional behaviours affected employees' leadership and safety climate perceptions. Transformational leadership emphasises motivation, morale, and inspiring followers (Bass, 1999). On the other hand, active transactional leadership emphasises active management by exception and contingent reward (Clarke and Taylor, 2018). Transformational leadership has been studied to be universally effective, while transactional leadership has varied in effectiveness (Judge and Piccol, 2004). Safety-critical environments require active transactional leadership to maintain safety by proactively identifying errors (Clarke and Taylor, 2018). Additionally, transformational and active transactional leaderships complement each other in safety-critical environments. However, safety interventions to train supervisors have not focused on combining the two leadership behaviours (Clarke and Taylor, 2018). Thus, Clarke and Taylor (2018) studied a leadership training methodology combining transformational and transactional leadership behaviours.

Clarke and Taylor (2018) conducted the study at a large chemical processing plant with operations-based and office-based employees and their supervisors. The process included a workplace safety survey, training for the supervisors, and a second survey after eight weeks. The surveys studied leadership style, safety climate, and safety behaviour. Leadership style was studied with the MLQ-5x questionnaire including 45 questions. Safety climate was studied with a safety climate survey by Clarke and Flitcroft (2011), including 26 questions. Lastly, safety behaviour was studied with questions dealing with safety compliance and participation developed by Griffin and Neal (2000). The supervisor training consisted of two three-hour-long workshops on transformational and active transactional leadership. The training included exercises and an action plan to record specific goals. The second surveys, post-training, were identical to the first surveys.

Clarke and Taylor (2018) found that the training significantly improved the perceived safety climate. The frequency of leader behaviours remained the same, meaning that leaders did not change how often they performed their leadership tasks, such as safety exchanges with employees. Some improvements were found in safety behaviour but were not deemed significant (Clarke and Taylor, 2018). The changes in leadership behaviour were also found to improve the employees' perception of safety priority, especially in specific safety dimensions, such as management commitment, communication, work pressure, and work environment.

Safety intervention training on transformational and active transactional leadership behaviours was proven effective by Clarke and Taylor (2018) in improving the safety perceptions of the employees on safety climate. The method seems easy to implement, consisting of six hours of supervisor training.

4.4.2 Development of a safety climate tool

Kalteh et al (2020) developed a safety questionnaire to assess the safety climate, specifically in the oil and gas industry. The tool aimed to consider the characteristics of an organisation in addition to the more widely used structures of safety climate in a safety climate assessment. Kalteh et al. (2020) noted on the importance of industry-special safety climate assessment tools when working in safety-critical complexes. Additionally, socio-technical systems and macroeconomics were deemed integral development points for the tool. Socio-technical systems emphasise the interaction between individuals, tools, and equipment in organisational design (Kalteh *et al.*, 2020). At the same time, macroeconomics is a socio-technical approach, that consists of five subsystems organisation, job and tasks, humans, tools and technology, and environment (Kalteh *et al.*, 2020). Kalteh et al. (2020) defined the tool as a safety culture tool, but according to the definitions stated in part 2.4, the tool is classified here as a safety climate measure.

The development of the questionnaire tool was done in two stages. First, using a directed and deducted approach, the twelve main safety climate factors were recognised and paired with the macroeconomic subsystems. These are shown in Table 8. Secondly, definitions were created for these twelve themes, and with the data collected in the first step, multiple items were drafted for each theme for the assessment tool. These definitions and items are shown in Table 9. Each item had a four-step scale to evaluate them.

Table 8. Safety climate themes and macroeconomics subsystems (reproduced from Kalteh et al., 2020).

Safety climate factors	Macroeconomics subsystems
Effectiveness of safety management (ESM)	Organisation
Management's attitude to safety (MAS)	
Training, awareness, and safety policy (TASP)	
Peer support (PS)	
Work schedule (WS)	
Job demands (JD)	Job and task
Confrontation of tasks and safety (CTS)	
Behavioural features and commitment to safety (BFCS)	Human
Work equipment and tools (WET)	Tool and technology
Personal protective equipment (PPE)	
Workplace hazards (WH)	Environment
External environmental factors (EEF)	

The validity of the questionnaire was tested, and a case study was run. Both showed high correlations between the different dimensions of the tool and safety climate (Kalteh *et al.*, 2020). The factors in this study were compared to other studies and it was found that two groups can be identified. One with common factors, such as management commitment and colleague support, and the other with industry and society-specific factors, that relate to the specific characteristics of the industry, such as work schedule, work equipment and tools, and personal protective equipment. This highlighted the importance of industry-specific safety climate assessment questionnaires (Kalteh *et al.*, 2020).

Kalteh et al. (2020) developed an industry-specific safety climate questionnaire. The tool considers the specific characteristics of the industry and gives a more detailed picture of the safety climate of an organisation. This seems reasonable as the company gets more information on, for example, the personal protection equipment, and then can get a whole picture of the different views in the organisations and improve safety. This tool was developed for the oil and gas industry in the Persian Gulf, so the items must be reviewed before implementing in other similar sectors.

Table 9. Safety climate definitions and questions (reproduced from Kalteh et al., 2020).

Dimension	Definition	Items
Effectiveness of safety management	This dimension explains the safety unit's efforts in improving the organisation's safety, the type of look at the organisation's safety, the level of knowledge of safety officers, the proper handling of employee insecure behaviours, employees' trust in this unit, and the authority to enforce safety laws.	<p>1. Proper behaviour of safety officers in the organisation has encouraged staff to comply with safety instructions.</p> <p>2. Visits and evaluations of the HSE unit have a positive impact on safety of the work environment.</p> <p>3. Organisation's safety unit has the authority to enforce safety instructions.</p> <p>4. Safety staff are familiar with the workplace hazards.</p> <p>5. I am confident in the ability of safety unit staff to resolve my workplace safety problems.</p> <p>Safety unit uses employee feedback for better implementation of safety plans.</p>
Management's attitude to safety	This dimension focuses on management's attention to the safety of the organisation, the allocation of adequate resources to safety programs, encouraging employees to follow safety instructions, creating a balance between safety and production, familiarity with hazards and safety plans, and efforts to reduce risks.	<p>6. Managers have complete knowledge about safety problems in the workplace.</p> <p>7. Managers try to resolve safety problems.</p> <p>8. In terms of managers, safety and production are equally important.</p> <p>9. Managers of the organisation only pay attention to safety after an accident.</p> <p>10. Managers believe in employee's participation for their workplace safety.</p> <p>11. Managers allow employees to ignore safety instructions.</p> <p>Managers encourage employees to improve the level of workplace safety.</p>
Training, awareness, and safety policy	This dimension includes planning for staff training, providing work-related training materials, setting up a risk reporting system, informing staff about events and results of surveys, and establishing safety in the organisation's programs.	<p>12. Employees do not report unsafe conditions and acts due to fear being punished.</p> <p>13. Safety instructions are compatible with the conditions and risks of my work.</p> <p>14. The complexity of safety instructions makes it difficult to implement them in my workplace.</p> <p>15. Training on workplace hazards and prevention methods has improved the safety of the workplace.</p> <p>The content presented in the classroom is related to the needs of workplace safety.</p>
Peer support	This dimension includes the co-workers' attitudes towards each other about the risks, the level of participation, and the sense of responsibility of the staff of a unit to improve the safety and impact of friendly relationships on the promotion of safety.	<p>16. My colleagues do not take any responsibility for the safety of each other.</p> <p>17. A friendly and positive relationship between my colleagues has improved the safety of my work environment.</p> <p>18. My colleagues consult with each other about hazardous situations before starting work.</p> <p>19. My colleagues feel responsible for the safety of the workplace.</p> <p>My colleagues and I help each other to do things safely.</p>
Work schedule	This theme category examines the type of work system and its consequences and impacts on the safety of the work environment.	<p>20. Being away from my family causes my attention to safety to decrease in the work environment.</p> <p>21. The periodic work plan has a negative effect on mental readiness.</p> <p>22. Periodic work plan causes inconsistencies in our program, which has prevented me from doing my work safely.</p> <p>Shift work has a negative effect on employee for compliance with safety instructions.</p>

Job demands	This dimension describes the effect of occupational characteristics and the attitude of individuals about these characteristics on safety behaviours.	23. Before I start work, I make sure it is safe to do so. 24. I can ignore safety instructions in an emergency situation. 25. When I'm at work, I think safety is the most important issue. Work-related fatigue affects my behaviour.
Confrontation of tasks and safety	This dimension explains the impact of psychological and physical needs on each occupation on employee safety behaviours and the interaction of safety laws with job requirements.	26. Workers ignore safety instructions because of their high work pressure. 27. Employees ignore safety instructions due to time limitations. 28. Complying with safety instructions makes my work harder. In my workplace, I have to comply with all orders of the supervisors.
Behavioural features and commitment to safety	This dimension covers the personality traits of each person (calm, nervous, pride, shy, etc.) on the attitude of doing things securely. Also, the effects of individual-related variables such as work experiences and individual attitudes toward safety and risk behaviours are within this category.	29. Some employees of the organisation ignore workplace hazards more than usual. 30. I believe that people who have witnessed an accident, adhere to safety rules better. 31. New people are more likely to be injured because of their relative inexperience. 32. It's very difficult to change unsafe behaviours. 33. I believe that new people with higher education will be more important to safety than experienced people. 34. I believe that experienced people also need to acquire new knowledge in the field of safety. 35. I encourage colleagues to attend training courses. 36. I never joke about safety issues in my work environment. 37. I only pay attention to safety regulations because of the fear of punishment. In my work, safety instructions have the highest priority.
Work equipment and tools	This dimension shows the company, managers and employees' attitude towards the equipment used and the technology changes in the organisation and its impact on the safety of the workplace.	38. I believe newer equipment has higher safety standards. 39. The application of newer equipment reduces risky behaviours. The exhaustion of old equipment has reduced workplace safety.
Personal protective equipment	This dimension shows the attitude of managers and employees to personal protective equipment and their role in reducing workplace hazards.	40. The use of personal protective equipment makes working hard. 41. Personal protective equipment is in accordance with the presence of workplace hazards. The quality of personal protective equipment is suitable.
Workplace hazards	This dimension shows the physical hazards in the gas industry and its impact on safety behaviours.	42. Weather conditions make working hard. 43. The working environment conditions have increased the risks of accidents. 44. Weather conditions can increase workplace hazards. 45. In my work environment, the risk of exposure to hazardous pollutants is high. In my work environment, the likelihood of an accident is very high.
External environmental factors	In this dimension, there are codes that affect the safety of the staff and include external agents such as economic, social, cultural, and political conditions.	46. In the organisation, some ethnicities have higher risk behaviours. 47. Financial problems have caused to pay less attention to safety regulations. I believe that the surveillance of outside organisations improves the level of workplace safety.

4.5 Conclusion on safety research and methods and tools

The top ten safety journals according to Reniers and Anthoné (2012) were gone through. Altogether 66 articles were found from January 2018 to June 2021 containing the human factor, human error, safety culture, and safety climate search terms. Overall, nine methods and tools were chosen and presented in this thesis. The articles were chosen based on whether they were methods or tools, whether they provided improvements to the main aspects, and whether they were for an industrial setting. The articles were divided evenly between the different categories, with three articles on human factors and two on each of the other categories. A summary was given for each article, containing the process of the method or tool and comments on its usability.

Applied part

5 Methodology

This part presents the research methodology and consists of an evaluation and ranking of the presented methods and tools in the literature review as well as the description of the interview process. The evaluation and ranking of the methods and tools were performed to compare the various methods and tools with each other to choose the methods and tools to be considered in the interviews. This is done in part 5.1, while part 5.2 describes the interview process, including the presentation of the interviewees, questions, and execution of the interviews.

5.1 Ranking of methods and tools

The methods and tools presented in part 4 are different with various uses, so comparing them is difficult. However, an evaluation matrix was created to assess the different aspects of each method and tool. This included a separate evaluation of each method and tool based on their easiness of implementation and comprehension, costs, results, applicability to the process and chemical industry, and readiness level. The readiness level was evaluated by utilising the technology readiness level (TRL) approach, which is used to evaluate the maturity of a technology (TWI Ltd, no date). The Innovation readiness level developed by The KTH Innovation Readiness Level (2022) was considered for the evaluation. However, the framework would have required information on a business model and IPR status that are difficult to obtain for the type of methods and tools presented in this thesis. A scale of 1 to 5, where five was the best, was set, and an average was calculated for each method and tool. Table 10 shows the evaluation matrix.

Table 10. Evaluation criteria for the ranking of the methods and tools.

Easiness of implementation	Describes how easily the method or tool could be implemented into use in a facility.	1	Requires significant changes to procedures, practises, systems, and/or appliances.
		2	Requires some changes to procedures, practises, systems, and/or appliances.
		3	Requires a change to procedures, practises, systems, or appliances.
		4	Requires small changes but is compliant otherwise.
		5	Is implementable straight away without changes.
Easiness of comprehension	Describes how easily can the users of the method or tool comprehend the use and aspects of it.	1	Requires significant training for all employees.
		2	Requires some training for all employees or some effort to understand.
		3	Requires some training for a certain group of employees some effort to understand
		4	Requires specific training for a small group or small effort to understand.
		5	All employees can easily understand with small effort.
Costs	Describes how much costs would be caused from applying the method or tool.	1	High cost: Requires new procedures, personnel, practises, systems, and appliances.
		2	Requires two or more of new procedures, personnel, practises, systems, or appliances
		3	Medium costs. Requires one new procedure, personnel, practise, system, or appliance.
		4	Requires some new costs, but no major extra resources.
		5	Low costs or no costs at all. Does not require any extra resources.
Results	Describes what kind of results were presented with the tool	1	No results at all.
		2	An example given of the method, or some test done.
		3	Results indicate the method and tool to be usable.
		4	Data and results provided.
		5	Significant proof of concept.
Applicable in large scale industrial facilities	Describes could the method or tool be applicable for large scale industrial use.	1	Not applicable in large scale.
		2	Designed for smaller size, requires changes.
		3	Might require some changes.
		4	Easily applicable.
		5	Applicable straight away or designed for large scale industries
Readiness level of the method or tool	Using technology readiness level (TRL), measuring the maturity of the method and tool.	1	Research (TRL 1-3): Experimental proof of concept.
		2	
		3	Development (TRL 4-6): Validated and demonstrated in relevant environment
		4	
		5	Deployment (TRL 7-9): Tested and used in actual environment.

Each of the nine methods and tools presented here was evaluated using the matrix in Table 10. For each method, a score was evaluated based on the set criteria and a value was given. An average was calculated for each item based on their rankings in the evaluated categories. This is done in Table 11.

Table 11. The evaluations of each method and tool.

Ranking of the tools and methods (1-5)	Easiness of implementation	Easiness of comprehension	Costs (Cheaper 5 - expensive 1)	Results	Applicable in large scale industrial facilities	Readiness level	Average
Post-incident Behaviour Based Discussion (McDonald, 2020)	3 Requires a discussion leader and some knowledge of safety culture of behaviour-based safety.	4 Easy to comprehend the method.	3 Requires a discussion leader.	1 No data on results.	4 Designed for specialized facilities but no limits why not larger facilities.	1 No data on results, difficult to evaluate.	2.7
Human Factor Risk Management (Bevilacqua and Ciarapica, 2018)	2 Requires that the company has a SMS and CMMS.	3 Requires understanding on the association rules technique.	3 Requires an addition to the management system, and possibly some changes to practices.	4 Results seemed to give areas of improvement.	2 Larger industries mean more data to analyse and more complicated analysis.	5 Used to evaluate the data from a facility.	3.2
Task Improvement Process (Miller and Grounds, 2019)	3 Requires change of practises if similar actions are not already in place.	3 Like to root cause analysis, but proactive. Understanding what the steps require might need some instructions.	4 Requires time from personnel.	1 No results provided, but apparently method is in use in Bp facilities.	4 Done in certain sectors so size is not significant to the use of the method.	5 Method apparently is in use in Bp facilities.	3.3
A novel qualitative prospective methodology for analysing human error (Calvo Olivares <i>et al.</i> , 2018)	4 Can be implemented to any technological system.	2 Requires comprehension and active input from the personnel.	4	2 An example of the method was provided in the article, but no more data.	1 Method specified for SMEs.	3	2.7
Re-designed Just Culture process (Bitar <i>et al.</i> , 2018)	3 If the Just Culture process is in use, easy to implement. Otherwise requires training and practice changes.	3 If the Just Culture process is in use, easy to understand with some training.	3 Requires time from personnel and training for managers.	4 Showed changes and suggestions in data provided in the article.	5	5 Method apparently is in use in Bp facilities.	3.8

The Egg Aggregated Model (Vierendeels <i>et al.</i> , 2018)	1 The use for the model in day-to-day use is difficult.	2 The model requires proper studying to understand the connections.	5	1 No data	3	1 There is no specific use for the model.	2.4
Ranking of process safety cultures (Zwetsloot <i>et al.</i> , 2020)	4 Designed so that the tool is easy to use and takes maximum of 15 minutes.	4 Done by inspectors that are used to fill safety questionnaires.	3 Requires external inspector or personnel that can evaluate safety.	5 Provided results that had been found reliable.	5	5 Tested in actual environment.	4.3
Transformational and active transactional leadership behaviour intervention (Clarke and Taylor, 2018)	4 Requires trainings.	3 Requires understanding of the leadership concepts and their aspects.	4 Major costs are the trainings.	3 Provided results that seemed to be positive for the method.	5	3	3.7
Development of a safety climate tool (Kalteh <i>et al.</i> , 2020)	4 Can be used similarly as any safety climate tool.	5 Like other safety climate questionnaires.	4	4 Provided data on the tool.	4	3	4.0

Based on the evaluation in Table 11, the methods and tools were ranked from top to bottom. The method *ranking of process safety cultures* had the highest average, while *the Egg Aggregated Model* had the lowest. The most significant deviation between the items was in the implementation, results, and readiness level categories. The rankings can be seen in Table 12.

Table 12. Ranking of the methods and tools.

Method or tool	Average value
Ranking of process safety cultures	4.3
Development of a safety climate tool	4.0
Re-designed Just Culture process	3.8
Transformational and active transactional leadership behaviour intervention	3.7
Task Improvement Process	3.3
Human Factor Risk Management	3.2
Post-incident Behaviour Based Discussion	2.7
A novel qualitative prospective methodology for analysing human error	2.7
The Egg Aggregated Model	2.4

One method or tool of each human factor, human error, and safety culture category was chosen to be included in the interviews. The chosen methods and tools were *the ranking of process safety cultures* by Zwetsloot et al (2020), the *re-designed just culture process* by Bitar et al (2018), and *human factor risk management* by Bevilacqua and Ciarapica (2018). These were chosen based on their rankings in their category and considering the overall theme of the method or tool to achieve a comprehensive combination for the interviews.

5.2 Interviews

The interviews had three aims. Firstly, to gather the safety professional's perception of the new methods and tools. Secondly, to gather information on how the process and chemical industry currently perceives human factors and safety culture. Thirdly, to examine what solutions would be needed to improve human factors and safety culture. Information was also gathered on what factors are essential for the companies when choosing new methods or tools.

5.2.1 Interviewees

The interviewees represented three categories: risk engineers from If P&C Insurance Ltd, safety managers or equivalents from Finland's process and chemical industry, and university professors or lecturers teaching safety in Finnish universities. All the interviewees were contacted by email, and their interest in participating in the interview was asked. The risk engineers were chosen based on their area of responsibility being the process and chemical industries. The companies chosen for the interviews included process and chemical companies with facilities in Finland. These contained both more prominent manufacturers as well as smaller facilities. The chosen interviewees from the companies were safety managers or persons in similar roles. The university personnel were chosen by going through the course catalogues of different universities in Finland and searching for courses that covered process safety, human factors, or safety culture. The persons responsible for the courses

were chosen to be the interviewees. Altogether, there were twelve interviewees, four insurance personnel, five company personnel, and three university personnel.

5.2.2 Questions

Questions were created under four categories with aims to

1. Gather information about the interviewee and their position in their organisation.
2. Inquire about the interviewee's understanding of the concepts of the human factor, human error, safety culture, and safety climate, and questions related to utilising these terms.
3. Ask questions about the three methods and their usability in the process and chemical industry.
4. Discuss the application of recent safety research in the interviewee's day-to-day actions.

The questions were modified to suit each interviewee category, but the theme remained unchanged. Most of the questions were open-ended, allowing the interviewees to express their opinions and knowledge freely. The questions are listed in Table 13. The whole question forms are shown in Appendix 3.

Table 13. Questions in the interviews.

Category	Questions for			
	Company	Insurance	University	
Organisation	Company	Organisation	Organisation	
	Industry		Field	
Interviewee	What is your name?			
	What is your role in your organisation?			
	How long have you been working in your organisation?			
	What are your main responsibilities?			
	What is your role regarding human factors and safety culture?			
Concepts	Are these terms used in your organisation? What do they mean in your organisation?	Are these terms used in the organisations you evaluate? What do they mean in your opinion?	Are these terms used in your teaching? What do they mean in your opinion?	
	<ul style="list-style-type: none"> Human factor, human error, safety culture, safety climate 			
	Do you agree or disagree with these common definitions for the terms in the previous question?			
	Does your company use a certified safety management system?	Do the organisations you evaluate use certified safety management systems?	Do you see a need in safety related teaching to discuss safety management systems?	
	Estimate which level your company's safety culture is according to dss+ Bradley curve.	If you think about the organisations you evaluate, what level are they in the dss+ Bradley curve?	Do you see a need in safety related teaching to teach safety culture using the dss+ Bradley curve?	
	Do you utilise safety climate surveys to study the current situation in your organisation? If yes, what kind and how often?	If you think about the organisations you evaluate, how common is the utilisation of safety climate surveys to study the current safety culture?	Do you see a need in safety related teaching to teach different safety cultures and their measuring using questionnaires?	
	What kinds of human factor and safety culture tools and methods are currently used in your company?	What kinds of human factor and safety culture tools and methods are currently used in the organisations you evaluate?	What kinds of methods are currently used to teach human factors or safety culture?	
	What kinds of factors are important when choosing new methods for improving safety?			
	Methods and tools: Human factor: Human risk management	What are the advantages and disadvantages of the method?		
		Does your company use a computerised management system, where accidents, injuries, or near misses are reported?	If you consider the organisations you evaluate, how common is using a computerised management system, where accidents, injuries, or near misses are reported?	Do you feel that students should be taught about: computerised management system, where accidents, injuries, or near misses are reported? how the acquired data could be used to minimise accidents?
How are the results used to minimise future accidents?				
How often is the data gone through?				
Would you consider an artificial intelligence or machine learning program to improve the application of results of accident investigations?				
Is the method applicable for industrial use?				
Is the method something you could consider applying in your organisation?		Would you recommend the method for the companies you evaluate?	Could the method be included in your teaching?	
Methods and tools: Human error: Re-	Does your company use Just Culture process by Reason or a similar process?	Are similar processes used in the organisations you evaluate?	Is the Just Culture process or a similar process taught to students?	

design of Just Culture process	What are the advantages and disadvantages of the method?		
	Do you feel that your organisation in the case of accident, incident, or near miss investigation:	Do the organisations you evaluate in the case of accident, incident, or near miss investigation:	When discussing incidents or near-miss situations in teaching should you concentrate on:
	Focuses on the front line or applies the investigation to all levels of hierarchy?		
	Focuses on the individual or focuses on the workplace influencing factors?		
	The shift in recent safety research is to consider more and more the overall factors, like workplace influencing factors and all levels of hierarchy, and not only the individual. In your opinion, is this shift in the right direction and have you noticed it in your organisation?		
	Is the method applicable for industrial use?		
	Is the method something you could consider applying in your organisation?	Would you recommend the method for the companies you evaluate?	Could the method be included in your teaching?
	Methods and tools: Safety culture: Ranking of process safety cultures	Do you see that there is a need for ranking safety cultures externally?	
What are the advantages and disadvantages of the method?			
Does your organisation map safety culture? If yes, how, and how often?		How does mapping of safety culture seem in the organisations you evaluate? How often should it be mapped? Is the current situation, too low, too much?	Should safety culture mapping be taught to students?
Is there a need for an industry-specific questionnaire to map safety culture?			
Is the method applicable for industrial use?			
Is the method something you could consider applying in your organisation?		Would you recommend the method for the companies you evaluate?	Could the method be included in your teaching?
Recent safety research		Do you feel that your organisation's safety methods are up to date, utilizing the most current information and technology regarding safety?	Do you feel that the safety methods of the organisations you evaluate are up to date, utilizing the most current information and technology regarding safety?
	How often new methods to improve safety are researched and reviewed?		
	As best as you recall, when was the last improvement made on human factor or safety culture?	How often improvements are made on human factor or safety culture in the organisations you evaluate?	
	Do you feel like you have time to follow new methods/ new tools in your day-to-day work?		
	Where do you get new information on human factor and safety culture?		

5.2.3 Implementation of Interviews

The interviews were executed remotely. An hour was reserved for the interview, but the time taken varied from 40 minutes to 90 minutes. The interview consisted of presenting the aim of the thesis and going through the questions in order. The interviewee was asked to answer a question at a time and give the answer to the best of their knowledge. Additional questions were asked if the question required clarification. The interviews were recorded with the permission of the interviewees. The interviews were performed in either Finnish or English based on the interviewee's wishes.

6 Results and discussion

In this section, the results of the interviews are presented and discussed. The presentation of the results is divided into three parts. Results related to the terms human factor, human error, safety culture, and safety climate are handled in part 6.1.1. Part 6.1.2 discusses the perception of the interviewees on the methods and tools presented. The results related to the application of new research are discussed in part 6.1.3. Additionally, the reliability of the results is commended. The discussion part presents the findings from the results in a concise manner. The concepts related to human factors, human error, safety culture, and safety climate are commented on in part 6.2.1. The results regarding the methods and tools and their applicability are discussed in part 6.2.4. Finally, the reliability of the method is commented on.

6.1 Results

Overall, 12 interviews were held with five different company representatives, four insurance employees, and three university employees. All the companies had operations in Finland, the university employees were from Finnish universities, and the risk engineers were based in Nordic countries but were responsible for risk

surveys worldwide. Some background information was gathered from the interviewees. This information included their role in the organisation, the duration of their employment in the organisation, their primary responsibilities, and their responsibilities regarding human factors and safety culture. The duration of their employment in the organisation is shown in Figure 20, and the primary responsibilities are listed in Table 14.

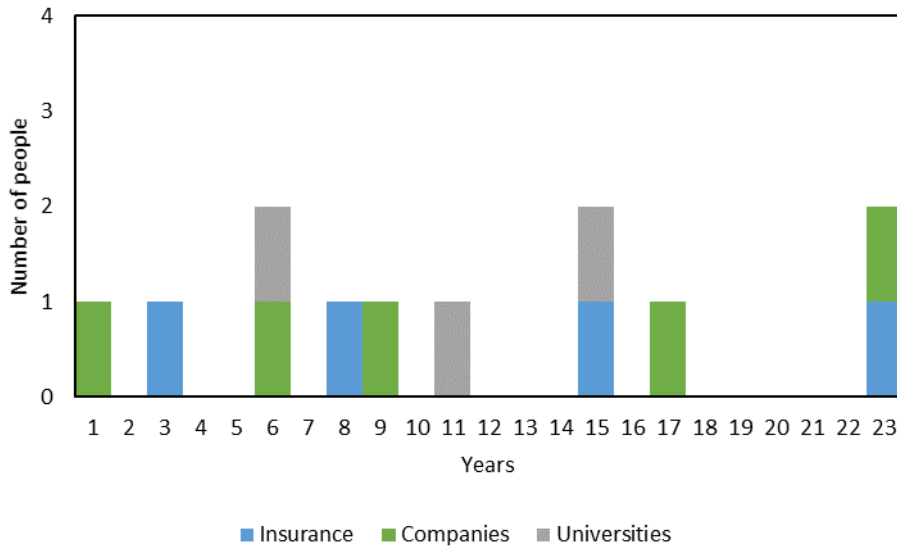


Figure 20. The duration of employment for each category of interviewees in years.

Table 14. The primary responsibilities of the interviewees.

Companies	Insurance	Universities
"Improving safety in regard to safety culture and human factors through safety trainings"	"Negotiate international insurance program for large scale companies"	"Research and teaching"
"Human, environment, and work safety"	"Risk surveys on companies within oil, gas, petrochemicals, fertilisers, smelters and some smaller companies with high risk."	"Leader of a research team. Teaching a course"
"Personnel safety"	"Risk surveys for chemical industry"	"Teaching a course "
"Safety, environment, health and quality"	"Risk surveys in the chemical industry and with companies handling flammable liquids"	
"Environment, health and safety"		

Figure 20 shows that the duration of employment ranged from one year to 23 years. Between the categories, there is little difference. Both categories of insurance and companies had persons relatively new to their positions and persons with a long

career in their organisation. The university personnel are placed in the middle between six and 15 years of working in their organisations. The primary responsibilities in Table 14 were similar in the categories, with an exception in each category. In the insurance category, three of the four interviewees were responsible for completing risk surveys with different companies, mainly in the process and chemical sector. One of the interviewees was responsible for insurance negotiations in the field. Meanwhile, four out of the five interviewees from companies were responsible for some variation of health, safety, environment, and quality (HSEQ) management. The exception in this category was one company which had created a position for improving human factors and safety culture, and the interviewee had an extensive background in these subjects. Finally, two out of the three interviewees of the university category were full-time employees of their universities, doing research and teaching, while one person was teaching a safety-related course annually in a university and had an extensive background in the safety-related field.

6.1.1 Human factors, human error, safety culture, and safety climate

The perception of the interviewees on the main terms in this thesis was gathered, and the concepts often regarded with these terms were discussed in this part of the interview. At the start of the interviews, the participants were asked if the four terms were used in their organisations and what they mean when they think of them. In universities, all the terms were used to some extent when teaching a safety course. With risk engineers, safety culture is measured in risk surveys, a factor considered when choosing to insure a factory. Human factors and errors are present in discussions with clients when losses happen. However, the solutions most often recommended are technological. Regarding companies, the usage varies more. Safety climate is used in one case, while safety culture and human factor are used in all companies. It is also remarked that the terms might sometimes get mixed up or misunderstood. The participants' perception of the terms is shown in Table 15.

Table 15. The interviewees' perception of the integral terms of this thesis.

	Companies	Insurance	Universities
Human factor	<p>"Three-part concept, how the person works in the organisation, the culture and the values, then the job factors, and lastly the human, their psychology, sociology. And the reconciliation of these three parts to minimise safety"</p> <p>"There is always something else than the technical side, this is the human presence"</p> <p>"Things related to humans and their actions, and their choices."</p> <p>"What are the contributing factors in the background"</p>	<p>"The various aspects where human activities are included. How operators are trained how they are, how they are capable of doing their job, their qualifications, their competence, experience, how they understand routines and instructions, how they interact, how they work overall"</p>	<p>"We study more of the human ergonomics fields, which is wider than some definitions of human factors"</p> <p>"The role of human in a socio-technical system"</p>
Human error	<p>"When a person has made a wrong choice and there is not a technical solution is the view in the company"</p> <p>"Originally about ten years ago the human error was called as a glove error, and they just happened. Then the factors behind the error begun to be emphasised."</p> <p>"Mistake made by a person manually"</p> <p>"Everybody makes mistakes. Often only the error is considered, not the factors behind it"</p> <p>"We are focusing on the factors behind the error"</p>	<p>"Human error is operator error or else, where someone makes a mistake where it can be attributed to various factors, like lack of training, lack of knowledge, lack of understanding."</p>	<p>"Part of human factors"</p> <p>"Actions that do not lead to the desired end, without the intervention of an event"</p>
Safety culture	<p>"Safety culture is something that can be said in general that this is how we work. But it varies in different work environments"</p> <p>"The starting point of everything in our organisation, defines at which role does safety have in the organisation"</p> <p>"Related to the organisations culture, how important is safety"</p> <p>"How we work"</p>	<p>"How is the organisation working with safety? What kind of systems are in place, what kind of discussions take place? Are you encouraging people to report unsafe acts, unsafe conditions, or are you? Are you promoting that? Who do you blame in cases of accidents."</p>	<p>"Part of organisational culture and the way of work"</p> <p>"Culture and climate go hand in hand"</p> <p>"I use the definition of Schein. Safety culture is linked with organisational culture. The pattern on basic believes and attitudes."</p>
Safety Climate	<p>"I don't know how you would define these, safety culture as bigger and climate in a smaller scale"</p> <p>"I think it means that what the situation is, is it good, is safety regarded as expensive."</p> <p>"Related to safety culture, how freely personnel can discuss the safety."</p> <p>"How mistakes and complaints are brought forward, with the goal to stop incidents from occurring again."</p>	<p>" I think it's part of the culture, how people interact, how do they communicate, how do they collaborate between various levels in the organisation."</p>	<p>"Safety culture at a given point of time, can be measured with questionnaires"</p> <p>"The artefact of culture, how easy it is to be in an organisation, to raise things and to interact"</p>

Overall, safety climate is the only term where the perception differs. Human factors are seen as something other than the technical side of things, the human presence, their actions, the factors in the background affecting the performance of the human, and the role of the human in a socio-technical system. Human error is perceived as a mistake or a wrong choice. Safety culture could be condensed into the phrase “how we work”, which is regarded as an essential part of organisational culture. Meanwhile, the perception of safety climate is a part of the culture, how easily things are raised to a discussion in an organisation, and how safety is regarded.

The interviewees were given common definitions for these terms, and their opinions were asked. With the answers above, the understanding of the terms was studied, and it was determined if there were any deficiencies when communicating about the terms. The participants’ answers are shown in Table 16. Additionally, Figure 21 combines the interviewees’ answers in one picture, where the colour green indicates agreeing with the definition, yellow means either some different views or some improvements, and red indicates disagreeing with the definition.

Table 16. The interviewees' opinions of common definitions for the terms.

	Definition	Companies	Insurance	Universities
Human factor	" Human factors refer to environmental, organisational and job factors, and human and individual characteristics which influence behaviour at work in a way which can affect health and safety" (Health and Safety Executive, 1999)	"I agree, but it effects everything, not only health and safety " "Seems ok" "Yes" "yes" "I don't have anything to add"	"Not anything missing, difficult to see why environmental factors are related to human factors. " "I agree" "I agree with that" " No improvements at the moment, with more time probably could find some small tweaks in regard to my understanding, but good overall."	"Additionally, the intended and unintended actions for example in cases of stress" "Agree. Additionally, human factors and ergonomics that is also improving the factors" "I don't understand why the environmental and organisational factors are brought into a human matter. I would hope that with human factors you could concentrate on the human and their interactions"
Human error	"The failure of planned actions to achieve their desired ends – without the intervention of some unforeseeable event" (Reason, 1990)	"I agree to some point, but the conclusion to end up in human error does not give us any data to improve safety" "yes" "Yes" "Yes, quite complicatedly worded" " Quite general, we are trying to not use this "	" Quite general, doesn't it depend on the human, the human makes the error, the human fails" "yes" "I agree " "In my opinion this does not take into consideration where something brakes and for this reason something occurs, and this is not clear from this."	"Human error is a small part of human factors" "Yes" "Yes, exactly"
Safety culture	"To consists of the conscious and unconscious basic beliefs, values, attitudes, and practices of safety in an organisation." (Levä, 2003)	"Fine" "Yes, we have emphasised this" " Yes, almost for word for word from our materials " "yes" "Yes, this exactly, how the organisations work, moulded with time, can be difficult to change"	" Yes, values, attitudes, practices " "Yes" "yeah" "I agree, but I would add the structures that the organisation defines are integral part of safety culture. The ways of working, how the organisation is structured."	" Commonly used, similar international sources are good also" "I am not overly fond of how safety culture is defined, but it is something like this" "Yes, similar to Schein"
Safety Climate	"Safety perception of an organisation at a given point of time. Reflection of the culture of an organisation, it is visible and measurable, and it describes the current state of the organisation and its internal environment." (Goncalves Filho and Waterson, 2018)	" If you believe that culture can be measured, then you can get climate. It is okay for me, but I would not do it. It can tell something about the attitudes." "The picture of the moment" "Yes" " Safety culture is difficult to measure so it is reasonable to have this " "Yes, it is measured."	"Quite general " "Oh, visible and measurable? First time I've seen that stated, so directly that anything that has to do with the cultural aspects of an organisation you can actually put a number on it. Not sure about that." " I guess safety culture and safety climate goes along with each other so. " " I think safety climate is more than just a perception. In my opinion the commitment is also a part of it. How measurable the factors are, is something I question. "	" Exactly " "Agree" " Perception is a challenging word here, second sentence I agree with. "

	Companies	Insurance	Universities
Human factor	Green, Yellow, White	Green, Yellow	Yellow, White
Human error	Green, Yellow, White	Yellow, Green	Green, White
Safety culture	Green, White	Yellow, Green	Yellow, White
Safety climate	Green, Yellow, White	Yellow, Red	Green, Yellow, White

Figure 21. The interviewees’ opinions on the definitions, where green = agree, yellow = some different views or improvements, and red = disagree.

As seen from the answers in Table 16 and Figure 21, the definition of safety climate caused the most differences. The measurability of safety culture and the word “perception” in the definition were questioned. Although, half of the participants agreed on the definition. On the other end was safety culture, which had the most agreed definition. The role of the practices set by the organisation was raised as an improvement for the definition. The definition of human error was also quite well agreed upon. The generality of the definition was commented on. Finally, with the definition of human factors, multiple additions were raised by the university personnel. Additionally, the role of environmental and organisational factors was questioned, as human factors were seen as a human subject.

Some differences are visible when the answers from the Table 15 and Table 16 are compared. Concerning the interviewees’ perception of human factors, the individual part from the definition and Figure 1 is emphasised. However, a few answers are given that include all the aspects of the definition. In the case of human error, the views match relatively well. One of the interviewees from the university gave the exact definition chosen for this thesis. Otherwise, the definition was said to be quite general. When considering safety culture, the answers given by the interviewees line well with the definition. The definition shown to the interviewees is more precise

than the interviewees' answers, and the interviewees' answers show that the narrative that safety culture is "how we work" is vital in the process and chemical industry. Finally, safety climate, which had the most variation, can broadly be divided into two categories according to the interviewees' answers: the ones that felt that it is how people interact with each other and how complaints are brought forward, for example, and the ones that pointed out the time aspect of it, being the reflection of safety culture at a given point in time. The measurability caused doubts when the interviewees' opinions were asked about the definitions. When comparing the different interviewee categories, the university representatives knew the definitions best beforehand, and for the given definitions, they only had comments for the definition of human factors. The insurance and company representatives had similar definitions and views on all the concepts, but regarding safety climate, insurance was the most against the idea that safety climate is measurable.

6.1.2 Methods and tools

The perception of the interviewees on the tools and methods is presented in this part. Additionally, the interviewees were asked what methods and tools are currently used in the participants' organisations and the factors that are important to the organisations when choosing a new method or tool to implement. The current tools are shown in Table 17, and the factors to be considered are shown in Table 18.

Table 17. According to the interviewees, the methods and tools currently used in their organisation or client organisations.

Companies	Insurance	Universities
<p>"Stop Work Authority (SWA) and questioning attitude. Different levels, from personal protective layers to working together"</p> <p>"Internal root cause analysis tool: Solologic Causelink, other tools available."</p> <p>"In incident investigation training we have this social psychology of risks in use. Additionally, models to be filled (integral model with four aspects, and workspace, group space, head space tool."</p> <p>"In incident investigation we have a check list of human factors. In regard to safety culture, we have regular safety moments, safety tours with specific hosts and safety conversations."</p>	<p>"Lean, 5S"</p> <p>"Toolbox talks, where safety moments are discussed. Shared learning sessions, learning from incidents in other sites and distributing the knowledge."</p> <p>"Procedures, training, guidelines, safety meetings, where the task and previous incidents are discussed"</p> <p>"Different methods to gather safety, PBS, safety walks, safety observation. Behaviour based safety."</p>	<p>"Analysis method for human factors, with safety culture, maturity models are used. A newly created model of measuring safety culture is used"</p> <p>"Resilience engineering, safety 2, and safety differently, adaptive safety management"</p>

The methods and tools the interviewees associated with improving human factors and safety culture were often related to incident investigations or regular safety meetings and walks. In addition to the safety meetings, training, and conversations, some behavioural and psychological methods were mentioned, such as behaviour-based safety and social psychology of risks.

Table 18. List of important factors when choosing a new method for improving safety.

Companies	Insurance	Universities
<p>"We don't choose new methods. You can improve and develop new methods, but you don't just implement new methods. We make new methods. Main concern is do we have a need for it."</p> <p>"Large group to think about the specific criteria for the tool. Easy to use, useable, useful, doesn't take too much time, can do what is it meant to do"</p> <p>"The methods are concrete and there are examples of their use."</p> <p>"Currently, we are focusing on the tools we have, to get the full potential out the of tools. Important factors include that the implementation of the method is justified for the purpose it is wanted, and that it is suitable for all the sub organisations."</p>	<p>"Being in line with the safety instructions of the plant"</p> <p>"The method being concrete, easy, easy to report, results understandable to all levels of employees, to provide uses, and to motivate to maintain the methods and developments. If the employees do not see that there is a use for certain method, it will not work. Transparent handling.</p>	<p>"Being based on scientific research. Validated with proper tests"</p> <p>"Most important is to focus on the role of the human in all aspects of the work"</p> <p>"Validity of method, are they scientifically proven to be effective, is it suitable for the situation, is it standardised, is it needed, current culture in organisation, on what level of safety is the organisation? First picking the low hanging fruits with technical solutions before applying extended methods for example the safety 2, what methods fit the company and its requirements?"</p>

When looking at the integral factors when choosing a new method, the usefulness and the need for improvement were the most required answers. Additionally, practicality, scientific proof of concept and results, easiness to use, understandability, and applicability to all levels in the organisation, were also mentioned multiple times.

Altogether, three methods or tools were included in the interviews, with one related to human factors, one related to human error and one to safety culture. The methods and tools were presented to the interviewees with short descriptions, around three to five minutes, with graphics of the methods to showcase them. If something about the method was unclear, clarifications were given based on the interviewees' questions. The questions for each method or tool included their advantages and disadvantages, questions on how the organisations currently handle their safety issues which are related to the themes these methods and tools are options for, a question about a larger trend related to themes, and lastly the applicability of the method or tool in industrial use. The themes related to the three methods and tools were (1) the utilisation of computerised systems to record and reduce incidents,

accidents, and near misses, (2) the relation of human error as individual behaviour or workplace-influenced factor, and lastly, (3) recording of safety culture.

6.1.2.1 Human Factor Risk Management

The first method was the Human Factor Risk Management by Bevilacqua and Ciarapica, 2018 from part 4.1.2. The procedure aimed to identify and investigate human factor risks, generate association rules for harmful events, and suggest preventive and safety measures to inhibit or minimise high-risk events. Table 19 shows the interviewees' answers on the advantages and disadvantages of the method. Table 20 shows the answers on using artificial intelligence to prevent accidents and incidents and the applicability of the method.

Table 19. The interviewees' opinions on the advantages and disadvantages of the method.

	Companies	Insurance	Universities
Advantages of the method	<p>"Idea is good and using data to find these risks is a fantastic idea, but that's it. One plus side would be the data could provide something at some point"</p> <p>"Our current system for global level is antique. So, we have to use word-files, so this kind of system sound good."</p> <p>"Seems systematic"</p> <p>"Can be used to lead with knowledge. Can combine the data and draw conclusions based on the data"</p>	<p>"Always good that these are analysed. However, it is important that the responsible party is determined for the method and the party who is responsible of the results and their application."</p>	<p>"Being systematic is always good"</p>
Disadvantages of the method	<p>"No big companies would use this currently. Can this method find anything we could not say beforehand using basic logic? Too complicated for large companies "</p> <p>"Is there a possibility to find multiple reasons for an error?"</p> <p>"The maintenance side only fills a limited amount of information, so it depends on how much the method requires."</p> <p>"No one system where the data from maintenance and accidents communicate with each other. In small organisations, the number of incidents is not big, so is there enough data."</p>	<p>"Does this require training? Maintenance operators might not have the time or knowledge to perform this. So requires extra resources. Might be good as I'm not sure how well or throughout human cause identification is done currently"</p> <p>"This type of an analysis is an important part of accident analysis already. The connection of accident system to maintenance system has not been seen anywhere. I think from my experience the aspects here are already covered in for the larger industries and high-risk industries. But by other aspects and another thing is that yeah, you can do this monthly or a quarterly basis, but you're still analysing things that have happened."</p> <p>"Need to define which type and size of events this is used. Too many and too complicated, people will not use it in the right way"</p> <p>"I have not seen one factory where there is a computerised management system and accidents reporting system that communicate with each other. This method falls to it that this kind of system is not plausible in factories. Additionally, the methods for incident evaluation need to be simple and usable, and this method seems to require more time than what people would have."</p>	<p>"Always need to be filled properly to have proper data. If the reason for the error is chosen from a list, the first to come to mind is often chosen"</p> <p>"The premise is wrong in my opinion. Does not improve human factors, it does recognise human errors and the factors related to them"</p>

The consensus among the interviewees was that incident and near-miss investigations are essential. However, this method is not possible to use, is not concrete enough, takes too much time, and the amount of data is questioned. Currently, the method is impossible to use as it requires a system where the maintenance management and accident reporting systems communicate or are in the same system. These kinds of systems are not currently available in the industry. The amount of data in a complex production facility would be huge and add to the personnel's workload. However, smaller facilities would need more accident data to run the machine learning programs properly. Hence, the facility size where this method could be applied is unclear.

Table 20. The interviewees' answers for the applicability of the method and the use of artificial intelligence and machine learning in incident investigation.

	Companies	Insurance	Universities
Opinion on AI and machine learning	<p>"I would hope that it is a tool in the future. I'm not very optimistic what the time frame would be. It would require a lot of concreteness. The time to results share is not that good in my opinion"</p> <p>"In my opinion it has a lot of potential. Humans can be in a hurry, and it can affect the results of incident investigation. The AI could give some pointers to the researchers."</p> <p>"Could have a benefit. If there is a lot of data, the AI could better find the trends in it."</p> <p>"For sure could be useful, for data that is so big that there is no time to go through it with other resources"</p> <p>"Is a good thing when there is enough of data."</p>	<p>"It is probably quite good, but the question is how it is brought into practice. It requires precise analysis on how it changes things"</p> <p>"That's a couple of years ahead. With my experience there is always little twists to things, and you could use machine learning or AI in one way to structure information, but it is a long shot to let it choose the factors behind the incidents."</p> <p>"I don't know. I know too little on artificial intelligence to comment"</p> <p>"Could have a point and can be in the future. Not currently for factories. Requires data, and I would see that currently the factories have not time to fill the data."</p>	<p>"Is probably a good tool, if you have enough data."</p> <p>"I'm not very familiar with this. I think there are possibilities in the future. I'm not negative towards it but carefully positive"</p>
Is the method applicable?	<p>"Yes, if I would live old enough. I could see this used in small part of the organisation, but not in a whole organisation"</p> <p>"Yes, if it does not take too much time to fill the data"</p> <p>"We are a large organisation, so no, but with some restrictions could be applied in some form"</p> <p>"In my opinion, I don't see a use in our sized facility, maybe bigger organisations could have more use."</p> <p>"Difficult to see as the systems does not communicate."</p>	<p>"With this short introduction the process description seems to work"</p> <p>"Yeah, no, it's already implemented in the industries that I work with. But then there are other less hazardous industries which probably have not implemented a system like that, which could probably benefit from it, but it's not relevant for the customers that I work with."</p> <p>"We mostly look for property damages, but if there is not an accident investigation method used in the company, one is needed and recommended, but not necessary this"</p> <p>"Not currently. It is difficult to see how this would suit the daily routines in the factories. Additionally, none of my clients have commented that this kind of methods would be used or even needed. I can see this in the future, but currently more traditional methods fulfil the need."</p>	<p>"Could be applicable for big companies where there is enough data"</p> <p>"No comments, there are many similar methods, this does not seem special"</p>

The interviewees' opinions on using artificial intelligence or machine learning to improve safety in the process and chemical industries have similarities. Some believe it would be a useful way to use data to make decisions. Others feel like it is not currently usable in the facilities but would be at some point in the future. The current methods are more important than changing everything to support machine learning-based tools. Multiple interviewees point out that there needs to be enough data to utilise artificial intelligence or machine learning. Also, there must be enough time for the operators or other employees to properly fill in the data in the system.

The consensus around the applicability of the method tips towards it not being applicable. The representatives from more prominent companies do not see the method being applied to the whole company. In contrast, interviewees from smaller companies feel like they need more data to utilise the method. The interviewees in the insurance category stated that their customers, already have a similar system in place and this would not improve the situation. The university personnel remind that the method needs enough data, and this method is not special. Overall, computerised maintenance management systems are an integral part of the industry, and the interviewees feel that the data is currently used systematically and gone through to reduce risks. This method would not apply to larger use in the industry.

6.1.2.2 Re-designed Just Culture process

The second presented method was the re-designed Just Culture process by Bitar et al., 2018 which was presented in part 4.2.2. The re-designed Just Culture process aimed to move the mindset in the organisation away from the tool being used as a disciplinary tool for individual behaviour to see its potential as a tool to spot system weaknesses. The interviewees were asked about their familiarity with the Just Culture term and the advantages and disadvantages of the method. The answers are shown in Table 21.

Table 21. The interviewees' familiarity with Just Culture and the advantages and disadvantages of the re-designed just culture process.

	Companies	Insurance	Universities
Familiarity with the original Just Culture process by (Reason, 1997)	<p>"Yes, not this, but a method much wider and bigger."</p> <p>"Yes, our global organisation uses this."</p> <p>"Yes, I'm familiar with this kind of method. We have implemented similar method in the last year, this kind of tree for violation or deviation situations."</p> <p>"I'm not familiar with this. In the 5 why? Questioning, similar things are noticed, but this goes further in the questions. "</p> <p>"Yes, I'm familiar."</p>	<p>"I'm not familiar with this, I have not done root cause analyses."</p> <p>"Not as an analysis tool. No, I haven't seen."</p> <p>"I do not recall seeing this kind of process before"</p> <p>"My focus is on the property damage. If the human factor leads to accidents, it is not part of my interest."</p>	<p>"The principles of workplace culture are taught."</p> <p>"Similar methods are taught. For example, incident investigation method called AcciMap. This kind of systematic process analysis is reasonable, the role of the human comes through."</p> <p>"I try to avoid using the term Just Culture, but the thought behind is used in teaching."</p>
Advantages of the method	<p>"The biggest advantage is that the human is not blamed right away. "</p> <p>"A good thing that things are reviewed systematically."</p> <p>"Provides transparency. It provides structure to evaluating."</p> <p>"Easier to get the improvements from this"</p> <p>"Could clarify our current method. Could reach a deep and thorough level. And if everyone knew this that this is used, they would know that the questioning is not personal, but just part of the procedure."</p>	<p>"Good questions"</p> <p>"I see advantages with helping to evaluate what went wrong. You need to ask the right questions to get the reasons why it happened"</p>	<p>"A good method for evaluation as the questions are good."</p> <p>"The solution proposals are left to a surface level, but I cannot say if there's a model that would be more specific. More advantages than disadvantages. But does this provide all the missing information?"</p> <p>"Tries to help people to note things from one person to the situation"</p>
Disadvantages of the method	<p>"We can't create a watertight questioning, as the questions are yes and no questions which are quite black and white approach. Easy to abuse if the method is used with the wrong reasons. "</p> <p>"A lot of mentioning of contacting HR, which I have noticed that is more common in American culture, and not common in Finland."</p> <p>"We have a no blaming culture, so it is important to note that this does not search for a guilty person, but the factors."</p> <p>"Difficult to answer a clear yes or no to the questions."</p>	<p>"Some of the questions I'm kind of thinking that they would be covered in a root cause analysis. With human error you are easily biased. "</p> <p>"I don't know if this covers all the aspects. There can always be something you miss with this."</p> <p>"The problem with all methods is that people need to be trained, so the methods need to be clear and easily to comprehend. This chart seems complex."</p>	<p>"This brings forward the different national cultures and if this would be implemented in Finland, the method does not consider the questioning from the employee to the supervisors' actions. Can be a little simplifying"</p>

Overall, all but one company personnel were familiar with Just Culture, or their company used a similar process. The insurance personnel were not familiar with the term or the tool. The university personnel were familiar with and used the principles behind the term and method in teaching. For the advantages of the method, the interviewees noted the person not being blamed, the method providing systematicity, transparency and structure to evaluating employees, and the questions bringing forward new information as long as the questions are properly designed. As the disadvantages, the interviewees stated the difficulty of responding with a clear yes or no to the questions, the possibility of bias, and the cultural differences within the method. The mentioned cultural differences by the interviewees were the culture of contacting the human resources unit in multiple steps of the method and the culture of how the employees question their supervisors' instructions. They felt that the human resources unit in Finland is not included similarly in incident investigations relating to an employee as they do in the United States of America (USA). In Finland, the employees are more accepting of questioning their supervisors' instructions than in the USA.

Additionally, the interviewees' perception of where their organisation, clients, or teaching focuses in the case of accident, incident, or near-miss investigation was discussed. All university personnel stated that regarding teaching, they focus on all hierarchy levels and the workplace influencing factors instead of the individual when discussing incident investigations. All company representatives mentioned also focusing on all levels of hierarchy and workplace influencing factors in their incident investigations. However, one interviewee remarked that it depends on the size and impact of the incident on how far they go through the hierarchy levels. Additionally, another interviewee remarked that they have introduced more focus on the sharp end when investigating an incident, but all the levels of hierarchy are still considered. The insurance employees remarked that it varies between clients. One interviewee felt similar to the company and university representatives. One said that "they tend to focus on the frontline, (with) those who have been directly involved", but there is "a stronger focus on workplace influencing factors than just the individual factors."

Lastly, the interviewees' opinion on the shift in recent safety research from focusing on the individual to considering more and more the overall factors and the applicability of the method was asked. The results are shown in Table 22.

Table 22. The interviewees' perception of the recent shift in safety research and the method's applicability.

	Companies	Insurance	Universities
The shift in recent safety research is to consider more and more the overall factors, and not only the individual. Is this shift to the right direction and have you noticed it in your organisation?	<p>"Yes. This is very clear. And the step has been taken a long time ago."</p> <p>"Yes, and when we start to review incident, it is very important to review all the levels."</p> <p>"It is the right direction."</p> <p>"Yes, it important to review why the person has made the decision and the factors behind it."</p> <p>"Yes, without question is the right direction."</p>	<p>"I have not noticed a change, but I feel that in the chemical industry it has been paid attention already for so long that the changes have been made a while ago."</p> <p>"Yes. I mean, of course people should be held accountable for their actions."</p> <p>"Yes, that is how you need to do it."</p> <p>"Yes, this is right. The responsibility to improve this is on the higher levels. I have not come across leaders that would not realise their responsibility."</p>	<p>"Yes, I teach just this."</p> <p>"In a big picture, yes. But is this current emphasis going too far as a person has their responsibility. Sometimes it feels like when trying to find these workplace influencing factors that sometimes the person can work in a stupid way and recognise it themselves."</p> <p>"Yes, this is taught with the history of safety."</p>
Is the method applicable?	<p>"Yes, we use it already."</p> <p>"As it is, I would not take it into account. We would improve it to suit the culture of our factory, for example translate it."</p> <p>"With a quick glance, some parts of this seem better than what we currently have in use."</p> <p>"Yes, could be an exercise to check a case that has been done with 5 why? Method to see how the method works in relation to it. "</p> <p>"Yes, in my opinion as a part of the investigation for the human factor."</p>	<p>"The questions seem reasonable so yes."</p> <p>"Yeah, I mean some parts are already implemented in the clients with more mature safety culture. "</p> <p>"Yes, I think, but I haven't read it in detail."</p> <p>"In my opinion, this seems quite complicated. I would say that there are methods to improve human factors, but this method would not be something I would recommend especially."</p>	<p>"Can be. I think that it is always good that there are concrete questions, and it provides instructions on how to improve."</p> <p>"Yes, especially the left side of the figure is useful in teaching. I don't see any reason why this couldn't be use in companies also."</p> <p>"Yes, in some capacity."</p>

All the interviewees recognised the shift in recent safety research to consider more and more the overall factors, like workplace influencing factors and all levels of hierarchy, and not only the individual. The university personnel teach it, and the insurance employees recognise it too. One company and insurance personnel also remarked that the shift was made a long time ago in the process and chemical industry. As for the applicability of the method, the responses are overall positive.

One company points out that they use the method already, while another comment that some parts of this seem better than what they currently use. First, one company would modify the method before applying it to their company, by translating it. Another company representative notes that it would be interesting to compare this method and its findings to old cases done with the five why? -method. The insurance employees feel the method is applicable, and some parts are already implemented. However, one representative commented that the method seems quite complicated and “there are methods to improve human factors, but this method would not be something I would recommend especially”. The university personnel state that the method is applicable in teaching in some capacity. They emphasise the concrete questions that provide instructions on improving and the usefulness of the left side of Figure 16. The method was deemed applicable for industry use.

6.1.2.3 Ranking of process safety cultures

The final tool presented was the ranking of safety cultures by Zwetsloot et al., 2020 presented in part 4.3.2. The method aimed to repeatably and reliably rank the safety cultures of major hazard companies. The interviewees were asked if there was a need to externally evaluate safety culture and method’s advantages and disadvantages. The answers to these are shown in Table 23.

Table 23. The interviewees' answers on the need for external safety culture ranking and the advantages and disadvantages of the method.

	Companies	Insurance	Universities
Is external safety culture ranking needed?	<p>"I don't see the necessity of external evaluation of safety culture for authorities. It is integral to do these things."</p> <p>"Nowadays Tukes sends this kind of questionnaire."</p> <p>"Every organisation can become blind to their own actions. But does it have to be an external evaluator, it can also be a new internal person."</p> <p>"Tukes does this kind of classification."</p> <p>"Yes, why not external and also internal. We could get interesting data with this (if it was in Finnish)"</p>	<p>"It is good to do this kind of thing and look with the eyes of an outsider"</p> <p>"No, I mean you can, but not by using a questionnaire like this. Just based on the few first questions here, I can't see how you're going to answer and how you were able to make a qualified assessment of the safety culture in 15 minutes with those questions."</p> <p>"It's a little of what we do. We have our risk grading tool, and it covers some questions in this"</p> <p>"This is what I do. This is the current way of doing. These subjects are part of what we ask, but the safety culture is in a side role. We usually talk about more concrete questions, but these are in the back of the questions"</p>	<p>"Yes, it is needed. We created our own tool, which point was that you could do it by yourself, while this is done by an outsider"</p> <p>"It is necessary, and this would make it more concrete. Normally, having something to measure makes leading easier."</p> <p>"This is a basic audition-based questionnaire"</p>
Advantages of the method	<p>"It is done by a safety professional from inside of the company"</p> <p>"It goes to the level of the culture"</p> <p>"Is useful, the same list can be used as self-evaluation. External auditor can see the evolving better when they visit once a year."</p> <p>"It is important to know how the data obtained from the questionnaire is used."</p>	<p>"The outsider sees more, but what can one see in a day"</p> <p>"It could be a good idea as a tool for companies who want to work with safety culture in a structured way."</p>	<p>"This leads to conversations on the right things. This is a checklist of the main things"</p> <p>"I can't say very precisely, but looks comprehensive, and recognises improvements."</p> <p>"I see an advantage in writing these down. But it isn't classification. It can provide some pointers to concentrate on when the next visit is done"</p>
Disadvantages of the method	<p>"As it is for external sources, is the state of will behind the evaluation to find ways to make improvements for safety or finding a price or a score for safety."</p> <p>"If you think about smaller companies where safety culture is not prioritised, it can be different how these things are shown. And can be dependent on the person who does the evaluation."</p> <p>"Can't be too done much, all the time cannot go to this. The resources need to be clear."</p> <p>"Quite quickly you need to fill the questionnaire"</p>	<p>"No harm for us as an insurance company, but it is again one consult more"</p> <p>"Some of these elements are already part of our service in complex hazardous industries. Some of these parts we cover in the property service, particularly the learning culture and leadership parts. But then again, here you are asking the questions on the visible part of the culture. I mean it's the tip of the iceberg. You don't see the safety culture, which is the iceberg below"</p>	<p>"This has a lot of points, so it is difficult to recognise the most important ones."</p> <p>"The main difficulty with these kinds of things is that the auditor is there for a day or two and based on that they try to fill this. The audition and safety culture evaluations are different types of processes. Evidence is needed and difficult to get. If it is combined to other materials, it could provide more."</p>

The opinions on external safety culture evaluation and ranking varied among the interviewees. The company representatives questioned why it needed to be an external auditor to perform the evaluation and highlighted that an internal safety professional could do the evaluation too. Additionally, two company representatives mentioned that Tukes already does this kind of safety culture questionnaire-based investigations. The insurance employees noted that this is needed and what they do in their audits in some capacity. The university personnel agreed that this kind of external evaluation is necessary. As for the advantages, the interviewees see that this can bring forward unseen things, the questionnaire is structured and comprehensive, and this can be used to recognise improvements. Meanwhile, the disadvantages brought forward by the interviewees included not recognizing the important parts in the multiple categories in the method, the time taken by the auditor to properly answer, the possible frequency of the evaluation, the background factors why the method is done, the factors in safety culture recognised by this, and the amount evidence the auditor can gather to properly evaluate. One interviewee raised the background factors, why the method is performed, and by this, they meant that the method is done because the authorities want to improve safety or if there are other reasons like money behind it.

Additionally, the interviewees were asked how they map safety culture, if they used a questionnaire specified to the industry if there was a need for one and the usability of the method. The answers to these questions are shown in Table 24.

Table 24. The interviewees' answers on the need for a specific questionnaire and the method's applicability.

	Companies	Insurance	Universities
Is there a need for field specific questionnaires?	<p>"If you want to measure culture, you need to specify it"</p> <p>"I'm not sure if its more work than what is useful"</p> <p>"It is extremely important that the questionnaires are specific."</p> <p>"Yes, this kind of list looks good"</p> <p>"I think these are relevant questions for us. Safety culture is although not dependant on the field."</p>	<p>"yes"</p> <p>"It depends on what kind of things are wanted to find out."</p>	<p>"It would be good, if you think of companies, they are more prone to buy things that are modified to them, for example in language. It is always better if it is specified, but many questionnaires fit multiple fields."</p> <p>"We don't use industry specific questionnaires in teaching, because we have students from all fields of technology and by using very specific questions some would feel that it does not consider them."</p> <p>"You need to specify them, if it is not, it is too generic. In any case 80 per cent of questions can still be the same."</p>
Is the method applicable?	<p>"I would need to discuss this at what void this would fill and what would we do with the data."</p> <p>"This could be good for an external evaluation."</p> <p>"Yes, rare enough, you could see a trend. Being done once a month, would be too much."</p> <p>"Yes, the results are seen easily"</p> <p>"Why not, this is perfectly good."</p>	<p>"I don't know currently how often these are done by outsiders, but I would think that in the chemical industry many use outside consulting in these safety matters."</p> <p>"Probably could. If you want to do a good job and if you want to bring something back to the client which they can use, then yeah, you will need more than 15 minutes to do that."</p> <p>"Yeah, I think it's applicable. They were good questions to be asked."</p> <p>"Yeah, it could be good to get the industry understand where they are in terms of this"</p> <p>"It could be a simple tool used by the management level, but I would say that they do some point do this already."</p>	<p>"Yes, as an option. There are similar lists, you could present others. They have the same main titles anyway."</p> <p>"The way of thinking fits teaching. If safety culture is improved, these are the things where attention is paid, but this questionnaire is not necessary."</p> <p>"With some reservations, you could find a use for this. It would need some modifying. It has potential"</p>

As seen in Table 24 above, the interviewees' opinions on specifying safety culture questionnaires for the field vary. The university personnel note that it is essential to

specify the questions to cater to the needs of companies, for example, in language, and to provide accurate results, even though they remark that “many questionnaires fit multiple fields” and “In any case, 80 per cent of questions can still be the same”. However, in teaching, industry-specific questionnaires are not taught to involve all students from different fields. The opinion varies the most in the company category. Two persons note that “I’m not sure if it is more work than what is useful” and “safety culture is although not dependant on the field”, while two persons note the importance of measuring safety culture with specific questions for the field. The insurance employees note that it is important to specify, and it depends on what the questions are trying to find out. Regarding the method’s applicability, the interviewees’ views are relatively positive. The company representatives note that the method seems good if it is done rarely enough to visualise trends, that it is needed, and that the data is utilised helpfully. The industry personnel felt that this kind of tool is in some capacity used already, it had good questions, and this could help the industry to understand where they stand in the matter of safety culture. The university personnel note that there are similar tools like this, this uses the different aspects of safety culture, and the tool would request modifying, but it has potential.

6.1.3 Application of new research

In the final part of the interview, the interviewees evaluated if they had time to follow new research and where they received information on human factors and safety culture. The time-to-follow research results are shown in Figure 22, and the information sources are shown in Figure 23.

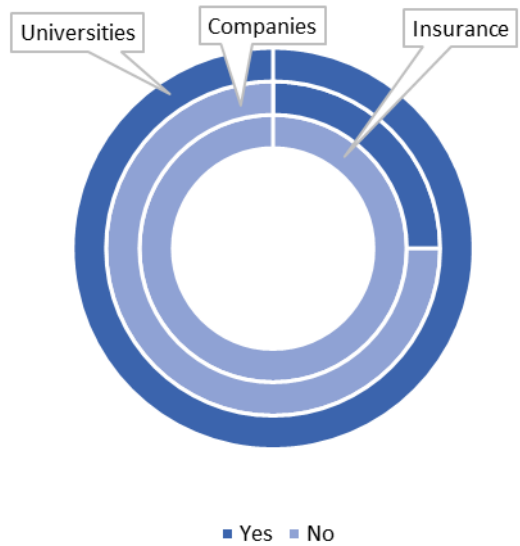


Figure 22. Do the interviewees have time to follow the research?

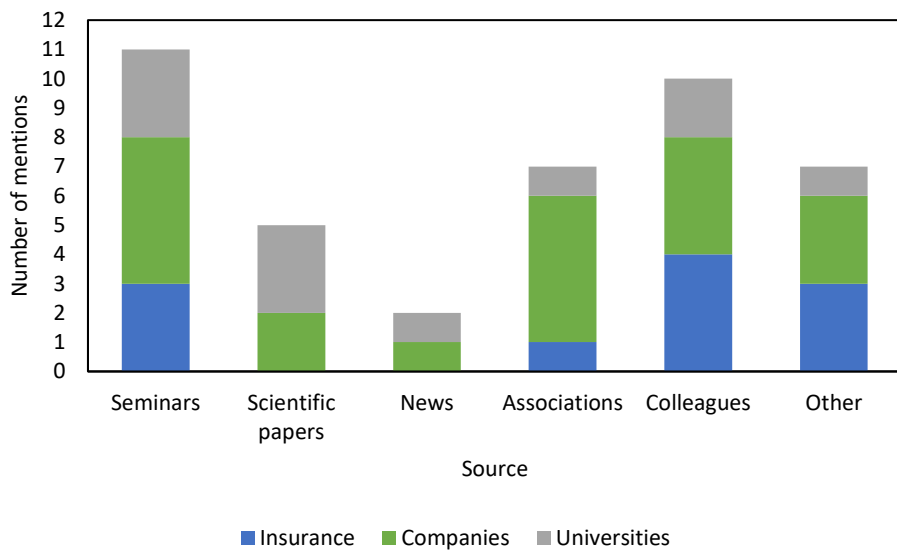


Figure 23. Sources of acquiring new safety information.

The results regarding having time to follow research show that university personnel have time to follow the research, while all insurance employees and most company personnel do not have time. This is consistent with the primary responsibilities the interviewees stated. The job description for university researchers is research, so they are expected to have time to follow new research in their field. In contrast, risk engineers and safety managers, in turn, have different responsibilities. However, some company personnel expressed that it would be beneficial to them to have time

to follow some new research. The exception in the company category was the same interviewee responsible for improving human factors and safety culture in their organisation. As their job description was specified for this field, they had time to follow new research. As for the information sources in Figure 23, the most mentioned sources were seminars, associations, and colleagues. Additionally, the *other* category obtained multiple mentions. In the other category, LinkedIn and customer/company visits were both mentioned three times, and a podcast called The Safety of Work was mentioned once. Many of the interviewees mentioned webinars in addition to seminars, and they are included in the same category. Organisations in the process and chemical industry rely on networking-based social sources, such as seminars, colleagues, and associations, to get new information on safety-related issues.

6.1.4 Reliability of the results

The results were gathered as a qualitative study, and the number of interviewees was 12. Thus, the results represent a small part of views in the field. As societal factors, such as national culture, have been linked to influencing organisational safety culture (Noort *et al.*, 2016; Tear *et al.*, 2020), it is essential to note the underlying societal factors that influence the interviewees' perception of organisational safety culture. All the interviewees were from Nordic countries, mainly from Finland. Therefore, the results represent the Nordic understanding of the issues discussed. Most interviews were performed in Finnish, and some answers were translated into English to discuss the results. Some tone differences that might have been created with the translation are possible. The questions were open-ended, and in some cases, the interviewees interpreted the questions differently from the original intention. Clarifying questions were asked in the interviews to steer the interviewee towards the intended path. If the interviewee did not know how to answer a question, "I don't know" was accepted as the answer and left from the results. Additionally, as the questions were not sent before the interviews, for example, the methods that are currently used in their organisations are just examples the interviewees came up with and do not represent all the safety measures of the organisations.

6.2 Discussion

This part discusses the presented results from parts 6.1 and 5.1 and comments on the findings from the results. The results are examined in four entities. Firstly, the ranking of the methods, done in part 5.1, is reviewed. The advantages and disadvantages of ranking the found methods and tools are observed, and some comments are made on what could have been done differently. Secondly, the results related to the main four concepts of this thesis, human factor, human error, safety culture, and safety climate, are discussed. The different views on the definitions of the concepts are pointed out, and some remarks are made about the repercussions of defining the same concepts differently.

Thirdly, the application and requirements for introducing new methods are examined, as well as the current methods and tools, concerning the four main concepts of this thesis mentioned by the interviewees. Lastly, the comments of the interviewees on the three methods and tools chosen to be presented in the interviews are discussed. The advantages and disadvantages of each method are examined, and their applicability to industrial use is remarked.

6.2.1 Examination of the ranking matrix for the methods and tools

The methods and tools found in the literature review were ranked based on different criteria. No pre-existing ranking method was used. The Innovation Readiness Level framework, which is used to guide idea development and assess idea status across key dimensions (The KTH Innovation Readiness Level, 2022), was considered as it would suit innovations. However, it would have required information on business models that were not available on these methods and tools presented in the research. For this reason, the ranking was done based on the technology readiness level method, which is used to evaluate the maturity of a technology (TWI Ltd, n.d.), but modifying the criteria to fit the need of the methods and tools found in this thesis. The selected criteria were easiness of implementation and comprehension, costs, results, applicability to large-scale industrial facilities, and technology readiness level.

These criteria were chosen to achieve an overall picture of the methods and tools. The criteria were not weighted in any way, so the ranking changes, if any criteria, are given a multiplier. Additionally, not all the information was evident in the articles for each method or tool. Even as the evaluation criteria were specified in Table 10, the difference between each grade is challenging to evaluate only from the specific articles showcasing the methods and tools. As the difference in the average scores from the best to worst method or tool is only 1.9 points, a change in the grades by one point significantly affects the scores. Additionally, the evaluation was not done for a specific plant, and the uses for the methods and tools varied, so evaluating the methods and tools for the needs of a specific company or a plant would change the scoring. This kind of ranking method would need to have more specific boundary conditions to yield reasonable results. However, the ranking provides some value for this use as a way to highlight the potentiality of a particular method or a tool compared to other new methods and tools.

6.2.2 The interviewees' views on the four main concepts

The perception of the interviewees on the definitions of human factors, human error, safety culture, and safety climate was noted to vary. The most significant variation was in how the interviewees defined safety climate. This could be due to the term safety climate being the most unknown term and the term where the definitions in the scientific literature vary the most (Luo, 2020). The repercussions for defining the terms differently inside the process and chemical industry field could be various. If the terms are used to improve safety and the safety professionals of the company do not understand, misuse, or leave something out when using the terms, how clear is safety communication inside the company and to external stakeholders? Çakit et al., 2019 found out that the perceived safety culture in the petrochemical industry affected personnel safety motivation and formation of safety behaviours. Although the perceived safety culture and the understanding of the safety culture concept are two different things, understanding what safety culture is helps to understand what is needed to improve it. Additionally, safety is being highlighted more and more and

proactive safety is in demand. Human factor and safety culture-related concepts are applied increasingly as their effectiveness has been noted. Also, if safety professionals cannot agree on a definition, how can the larger masses understand the concepts if they are defined differently in different sources and companies. The university personnel knew the definitions better than the company or insurance interviewees. This can be expected as their job description is to work in research, where the definitions are more prominently visible. Defining the terms clearly inside the company and throughout the field would be necessary to improve the situation.

6.2.3 Application and requirements for new methods and tools

When choosing a method, the main concern is whether the method is useful and needed in the organisation. The safety personnel of the process and chemical industries have various factors they require of the methods and tools so that they would be ready to implement. These requirements include that the method fulfils an area that needs improvement. It should be useful, practical, easy to use, understandable, and applicable to all levels of the organisation. It should also have scientific proof of concept and deliver reliable results. This brings forward an excellent opportunity for researchers to develop methods and tools for improving safety that are fulfilling the needs of organisations in the process and chemical industry. The companies want solutions that can be easily implemented and that save money while improving safety. Similarly, companies are more likely to implement methods modified to their specific needs, for example, in the language used in the plant. If the methods and tools created by scientific research do not meet the needs of companies, the methods and tools will not be used.

There are a lot of methods and tools created, but companies tend to use the same methods they have had for years, even though there might be better options. One of the reasons behind this is that companies need more resources to put into the search for new methods. Based on the interviews, most company representatives and none of the insurance interviewees have time to follow new research. So, how can companies find new methods if their safety professionals do not have time to follow

research? The interviewees noted that seminars, associations, colleagues, and online sources, such as LinkedIn and podcasts, are the most utilised sources to acquire information. So, to introduce a new method or a tool, seminars, association newsletters, and social media are the best ways to bring forward the research to reach the safety managers of companies. Acquiring information through colleagues is listed as one of the ways to obtain new information. However, as it is difficult to influence communication sharing between colleagues, researchers must be well-networked with industry employees to spread the information with colleagues. Similarly, being well networked in social media improves the chances of news of new methods and tools reaching industry safety professionals (Dwivedi *et al.*, 2021).

Additional communication channels between research and the industry include new personnel from schools, other employers, or an outside source, like an insurance company or a governmental authority. New personnel can be hired to fill a specific need. In this case, their job description can include following or creating new methods and tools and determining their value for the company. For a student, it is unrealistic to expect a vast knowledge of new methods and tools in the field of human factors and safety culture, as in most Finnish universities, there is only one course for safety matters, and the presented methods and tools are not industry specific since there are students from multiple different fields on the courses or the courses need to go through all different aspects of industrial safety and the time used for human factors and safety culture is limited. A new employee with previous experience can be expected to have more knowledge of new methods or tools. One of the companies interviewed already had a job description for improving safety culture and human factors, where they had time to follow new research on the matter. On the other hand, insurance companies or governmental authorities can demand that companies apply new safety measures and, in this way, implement new methods or tools in the industry. Then, the question is, do they have the time to follow new research? It is unlikely that a governmental authority would be a trailblazer in the safety field, requiring a new method or a tool that was not in use anywhere else. However, they could implement practices from other fields. Similarly, the insurance employees

mentioned acquiring new information from customer/company visits, that they could recommend to other companies.

In any case, it is improbable that new methods from research are implemented straight in the companies. Additionally, one company representative mentioned that they do not apply new methods but instead create methods on their own or improve old ones. This requires an internal team to create and improve the methods and tools in the company. This way, the company can target more specifically the need for the method and create it to fill the requirements of the company. However, it requires extensive knowledge and research in the field.

6.2.4 The presented methods and tools and their application

Two out of the three presented methods were seen as applicable to larger industrial use by the interviewees. Some comments and modifications would be required before the methods could be implemented but overall, they seemed promising or reminded something already in use.

The perception of the interviewees on the three methods varied inside the three categories of company, insurance, and university, as well as between the categories. The differences among the company interviewees came from the size of the company and their production, different levels of safety development regarding human factors and safety culture, as well as the structure of the company. Some interviewees commented that their main safety guidelines come from global headquarters. For some of the methods to be implemented in their local factory, they would have to be approved elsewhere. So, suppose companies are searching for methods that can be applied to whole organisations with multiple functions. In that case, finding effective methods for complex organisations with different facilities in multiple countries is difficult.

The insurance employees most often had similar opinions on the methods. They noted that similar aspects of each method are already implemented in some capacities. The question then is, can new methods bring improvements for the companies in some way, even if some of the aspects of the new methods are already

in use. However, the engineers focus on property risk and most often recommend technology-based solutions.

The university representatives had different focuses on their research on top of their teaching duties and looked at the methods and tools from different perspectives. One university representative had created a safety climate questionnaire for the transportation field and was familiar with the different questionnaire requirements, like the third method. Another university representative focused on human factors and ergonomics. Overall, the university representatives saw the concepts behind the methods usable in teaching, but the methods themselves were nothing special to teach about. However, they would be somewhat useful in the industry. The insurance representatives felt that the safety culture questionnaire would most likely be implemented. The company interviewees most agreed upon the re-designed just culture process to be most applicable to them.

The first method, human factor risk management, was ranked based on the article not to be that easily implementable, value of 2 out of 5, on the basis that it requires both CMMS and SMS. However, most company and insurance representatives noted that, in reality, the systems do not communicate similarly to the way the method required, rather than that the problem would be the systems themselves. The university personnel did not point this out. The size of the facility to have the required data for the analysis was also questioned, as some interviewees pointed out that a smaller facility does not provide enough accident data. At the same time, for larger facilities, the method might need to be simplified. The size of the facility was also pointed out when the article was presented in part 4.1.2. Additionally, the extra resources to perform the method was pointed out by the interviewees and recognised when presenting the method.

Ultimately, the question is whether a combined system or systems that can communicate with each other to record accidents and determine accident-prone areas would improve safety. As one of the insurance employees noted, "You're still analysing things that have happened". As well as one of the university representatives brought forward that the method recognised human errors and the

human factors related to them but did not improve human factors. However, many interviewees remarked that the method is systematic and that being systematic with data is always good.

Overall, the method was deemed not applicable for larger use in the industry. To make it suitable and desirable for the industry, the method would need to be more concrete and specify the size of the facility to have enough data to provide proper results, but not too much data to go through. Additionally, if the method were tested in the facilities the interviewees were familiar with, the biggest hindrance would be the lack of communication between the CMMS and SMS. If there currently are no facilities where the two communicate in a way the method requires, this problem would need to be solved before the method could be applied. Furthermore, more information would need to be distributed to the industry safety professionals on the uses of artificial intelligence and machine learning, as the interviewees felt that while they are promising, they are not yet current solutions for the process and chemical industry. Although the method was deemed somewhat promising, the obstacles are difficult to overcome.

For the second method, the interviewees were somewhat familiar with the original Just Culture process, which the method was based on. All but one company interviewees were familiar with the process, or their company used a similar process, while none of the insurance personnel was familiar with it. The university interviewees were familiar with the original method and the principles. The method was ranked the third highest in part 5.1, and the interviewees found many advantages. The main advantages were transparency, systematicity, good questions, and moving blame from the human to the situation. However, a couple of the interviewees noted visible differences between the culture in the method and their perception of the culture in Finland. These differences should be dealt with before the method can be applied. The main three cultural objects were the language, involving the HR in the process, and the relationship between employees and their managers. The language is easiest to solve by translating the method into the desired language. Changing the method to involve HR less or more is more complex. A

company can determine how and in what steps the HR should be involved to protect the employee. On the other hand, specifying the involvement of human resources and moving forward from regional customs and practice was one of the main points in the re-design. It can probably improve the situation inside a multinational company if they want to unify their practices, but modifications could be useful for companies based on other cultural areas. Including the cultural differences between the employee and manager, would change the method, and require modifications to the suggested improvements given in the method.

Interestingly, when asking the interviewees' perception on where their organisation, clients, or teaching focuses in the case of accident, incident, or near miss investigation, all company personnel noted to focus on all levels of hierarchy and workplace influencing factors in their incident investigations. At the same time, the insurance employees mentioned that it varies between clients. Two of the company interviewees elaborated that, for one, the size and impact affect how far they will go through the hierarchy levels, and for another, they have introduced more focus on the sharp end when investigating an incidence. The difference between the views of the insurance and company interviewees might be due to the risk engineers seeing more companies and having more to compare the proceeding to or due to the companies determining all hierarchy levels differently or varying it between cases, as seen from one of the company representatives. In any case, the insurance interviewees agreed that the companies focus more on workplace influencing factors than just individual factors.

Overall, the method was deemed applicable. One company interviewee noted that they use it already, while another would modify it to suit the culture of their factory. The most significant areas of improvement for the method would be to modify it to fit the culture that the companies desire, the training for the application of the method should be clear, and the questions could be more straightforward.

The third method, ranking of safety cultures externally, caused the company interviewees to be wary about the factor of external ranking. They agreed that the questions were good and could point out aspects and improvements from the safety

culture of a company. However, they questioned whether there was a need to externally evaluate safety culture in the process and chemical industry and rank the companies. Two company interviewees noted that Tukes (Finnish Safety and Chemicals Agency) already does safety culture evaluations. The information Tukes provides on these on the internet is limited. Their website briefly describes their periodic inspections, where different aspects are evaluated on a scale from zero to five (*Periodic inspections | Finnish Safety and Chemicals Agency (Tukes)*, no date). The aspects of safety culture are visible in some of the questions, but the questions are not as specific as the third method was. Additionally, one of the university interviewees remarked that the surveillance Tukes does is not as specific as what the authorities in the Netherlands do, which is where this method was performed initially. For this reason, this method could provide a more comprehensive assessment. The university interviewees agreed that external safety culture questionnaires are necessary, but this method is similar to other methods and a basic audition-based questionnaire. The insurance employees noted that these kinds of audits are included in their job descriptions, and their questionnaires cover some questions from this tool.

As for the advantages and disadvantages, the interviewees commented that recognising improvements and being comprehensive were the main advantages, while the disadvantages varied. The crucial parts of the categories can be challenging to recognise, the method can be done for the wrong reasons, for example, to find a price for safety, and the amount of evidence the auditors can gather during the visit might not be enough. This concern was also raised in the article. They reported that a point was raised that there might be a bias in the assessment of the culture, as the inspectors might be reluctant to report critical observations without concrete evidence (Zwetsloot *et al.*, 2020). As for doing the method for the wrong reasons, the government currently uses similar external evaluations for aviation and nuclear industries. The state of will behind the evaluations needs to be to find improvements for safety rather than just scoring the companies to determine a price to pay based on the scores. However, having an external source evaluating the safety cultures of

companies could help the companies by giving suggestions based on the scores to improve certain aspects of safety culture to help the companies to reach a higher level. Even though outsiders cannot see the culture as well as a professional on the inside, they can notice things the personnel inside the company have not noticed. As safety culture questionnaires are available in abundance, the interviewees were asked if there is a need for field-specific questionnaires, for example, ones that consider the requirements in the process and chemical industry. University interviewees agree that specifying the questionnaires is necessary. For one, the results are too generic if not specified, even though four out of five questions can be the same and many questionnaires fit multiple fields. Companies are also more open to purchasing products that are modified to their needs. The main difference is inside the company category. Two interviewees emphasised the significance of specifying the questionnaires, while two remarked that it is more work than use and that safety culture does not depend on the field. Overall, the interviewees saw the method to be applicable with some reservations. The method could offer feedback and trends, identify blind spots, and offer data.

It is visible from the interviews that there are no solutions that are immediately right for every company. Every method needs modifications, and some companies can be further ahead in safety solutions for improving human factors and safety culture. So, when choosing or recommending methods for different companies, there are multitudes to consider. The right methods and tools can improve safety, but the wrong ones can hinder the employees and use resources negligibly.

6.2.5 More efficient ways to utilise recent safety research

Overall, there are multiple ways for organisations to utilise recent safety research more efficiently. Collaboration projects could be utilized to bridge the gap between research and practice. Already, these are in use in multiple different subjects and fields (biomarkers: Asadullah and Reinke, 2015; process safety education: Boogaerts et al., 2017; nanomaterials: Kirkegaard et al., 2020; process safety: Véchet et al., 2022), but they could be applied to human factors and safety culture research

projects also. Additionally, companies can create positions where the employees have the time and ability to follow recent research and implement the most promising in action. For that matter, one of the interviewed companies had already created a position for improving safety through human factors and safety culture and employed a person with an extensive background in the subject and is familiar with current research. When employees are given the time, they can put more consideration into recent safety research. Furthermore, so much research put out annually; the more efficient way to follow it is through different seminars and the most prominent safety journals. In this thesis, the journals that included the most relevant articles for the process and chemical industries were Safety Science, Journal of Loss Prevention in the Process Industries, and Process Safety Progress. Also, seminars were the most followed medium for acquiring new information on safety determined in this thesis. All but one of the interviewed safety professionals said that they use seminars to attain new information.

Moreover, the companies could have measures inside the company to periodically review their safety methods and determine whether any new methods could be applicable. Additionally, the research needs to apply to industrial facilities. The size, amount of data, and implementing a new method at an industrial facility can inhibit a good research idea from reaching the company. The implementation to match the research to the needs of the company needs to be done either by the research group or the company, or both in cooperation. This requires resources from either one or both. The companies can more easily match the research to their needs than researchers to all companies their research touches. There needs to be a want in the companies to improve safety and research new ways to do it. Without this, they do not have the time or resources allocated to the improvement. Overall, companies could utilise new research more and find ways to implement them into action.

7 Conclusions

The process and chemical industries are high-risk areas where safety is paramount. The means for improving safety have shifted from technological solutions towards the role of humans and the culture. New research is constantly done on improving mastery of human factors and safety culture. However, the industry could utilise this research more efficiently.

7.1 Key findings

The definitions of the main terms of this thesis, namely human factors, human error, safety culture, and safety climate, were chosen from the literature. Safety culture and human error had the most agreed-upon definitions in the literature, while there were variations in the definition of human factors and whether it would include the ergonomics aspect. The definition of safety climate was the most questioned, and in some articles, it was used as a synonym for safety culture. In contrast, other articles used it to describe the quantifiable aspects of safety culture.

Similarly to the literature, the most significant variation in how the interviewees defined the terms was with safety climate. This was observed to be due to safety climate being the most unknown of the terms and to the literature's disagreement. The university interviewees were more familiar with the definitions than the insurance and company personnel. This was logical, as the university personnel are closer to the current research and have time to follow it.

In the literature search, 66 articles matched the search criteria, and the Safety Science journal contained the most articles. Safety culture had the most matches, then safety climate, human factor, and human error. Approximately half of the articles contained methods to improve safety through tools, methods, or suggestions for better practices. Nine articles were chosen to be presented in this thesis. They dealt with safety performance, risk assessment and management, safety performance, human error and safety culture concepts, behaviour-based safety, safety leadership, and safety assessment.

The nine chosen methods and tools were ranked based on an evaluation matrix created in this thesis. The evaluation criteria were the easiness of implementation and comprehension, costs, results, applicability to the process and chemical industry, and readiness level. The method *ranking of process safety cultures* scored the highest in the evaluation. The most significant deviation between the items was in the implementation, results, and readiness level categories. Three methods were chosen to be included in the interviews. These were *the ranking of process safety cultures* by Zwetsloot et al (2020), *the re-designed just culture process* by Bitar et al (2018), and *human factor risk management* by Bevilacqua and Ciarapica (2018).

The deployment of the found tools and methods to safety management systems and in an organisation, team, and personal levels was left to the background during the thesis, as the subject was quite extensive already without this perspective. For this reason, the chapter defining safety management does not get used in any parts of the thesis, unlike what was mentioned in the chapter. So, this thesis does not answer the second research question.

The interviewees saw two of the three methods applicable to larger industrial use. Some comments and modifications would be required before the methods could be implemented, but overall, they seemed promising or reminded something already in use. The university representatives saw the concepts behind the methods as usable in teaching. However, the methods were nothing special to teach about, yet they would be somewhat useful in the industry. The insurance representatives felt that the safety culture questionnaire, *ranking of process safety cultures*, would most likely be implemented. The company interviewees most agreed upon *the re-designed just culture process* to be most applicable to them. It is visible from the interviews that there are no solutions that are immediately right for every company. Every method needs modifications, and some companies can be further ahead in safety solutions for improving human factors and safety culture. So, when choosing or recommending methods for different companies, there are multitudes of aspects to consider. The correct methods and tools can improve safety, but the wrong ones can hinder the employees and use resources negligibly.

For the utilisation of safety research, it was observed that one of the companies had already created a position for a specialist in human factors and safety culture. That person had time to follow new research while all other company representatives did not. Creating opportunities for company employees to follow research could help ensure that the safety methods stay current. Additionally, cooperation between researchers and companies could benefit both sides. Companies would acquire safety methods based on the newest research that could be modified to their needs. At the same time, the researchers could obtain data from existing facilities and utilise it to improve their research even further.

7.2 Observations

When choosing a method, the main concern for companies was whether the method is useful and needed in the organisation. The companies want solutions that can be easily implemented and save money while improving safety. Similarly, companies are more likely to implement methods modified to their specific needs, for example, in the language spoken in the plant. If the methods and tools created by scientific research do not meet the needs of companies, the methods and tools will not be used. The safety professionals in companies do not have time to follow new research. Instead, they learn from seminars, associations, colleagues, and online sources.

While artificial intelligence and machine learning solutions are becoming more common, the interviewees felt that it is still quite far from being applied to the chemical and process industries. Most interviewees said that it has potential and could be a good way to utilise data if the method is concrete enough and there is enough data.

7.3 Limitations and recommendations for further research

This thesis focused on ten publications, with the four search terms, the chosen time frame, and the field specification. This focus might leave exciting and effective methods or tools out of consideration. Additionally, this thesis does not consider how

different methods and tools utilised in different fields could be used in the process and chemical industry. Furthermore, some articles where the field was not specified were included, and their application to the process and chemical industries is not as straightforward.

Other limitations in this thesis include the reliability of the created ranking matrix, the small sample of interviewees, and the regional differences. The ranking matrix is not specifically tested to be implemented as an evaluation tool that provides comparable results, and it had broad criteria set for each of the evaluated aspects. Not all information was available in the articles, and the scoring was challenging to determine in some instances.

The number of interviewees was 12, with five company representatives, four insurance employees, and three university personnel. They represent a small proportion of their fields. Additionally, excluding two insurance employees from other Nordic countries, all interviewees were from Finland. While the methods and tools were mainly from the USA or Central European countries, the application to Finnish companies and organisation culture needs to be considered.

This thesis suggested different ways to utilise recent safety research more efficiently. For the research to apply to the industry, the suitability of the application needs to be considered by the researchers or the companies. Different cooperation projects between researchers and companies could be utilised to find how the collaboration improved the applicability of different research methods.

For insurance, the question arose: Is there a need for broader safety evaluations when doing safety audits? The recurring theme from the risk engineers was that they mainly focus on the material side when they do their audits and cannot comment on the human side. As the importance of the role of the human and the culture have risen in safety, should the insurance field consider the human side more during risk surveys? In addition, one of the methods utilised machine learning. The interviewees were cautiously interested in applying artificial intelligence to safety but considered it still something for the future. This could lead to research on how artificial intelligence solutions could help increase workplace safety.

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Zwetsloot, G. and Bezemer, R. (2014) 'Benchmarking safety culture in major hazards industries in the Rotterdam area (The Netherlands)', in. 16th Process Plant Safety Symposium 2014, PPSS 2014 - Topical Conference at the 2014 AIChE Spring Meeting and 10th Global Congress on Process Safety. Available at: <https://repository.tudelft.nl/islandora/object/uuid:042a595d-9b74-492b-b393-827173d9ea13> (Accessed: 20 May 2022).

Appendix 1.

	Journal	Year of release	Article reference	Keywords	Criteria (human factor, human error, safety culture, safety climate)	Category in Tables 10., 14., 18., & 21.
1	Accident Analysis and Prevention	2020	Michael A. Nees, Nithya Sharma, Ava Shore, Attributions of accidents to "human error" in news stories: Effects on perceived culpability, perceived preventability, and perceived need for punishment, Accident Analysis & Prevention, Volume 148, 2020, https://doi.org/10.1016/j.aap.2020.105792 .	Human error Accidents Crisis communication Media coverage Attribution theory	human error	The influence of media on human error culpability
2	Journal of Loss Prevention in the Process Industries	2020	Yan Fang, M.A.K. Rasel, Peyton C. Richmond, Consequence risk analysis using operating procedure event trees and dynamic simulation, Journal of Loss Prevention in the Process Industries, Volume 67, 2020, https://doi.org/10.1016/j.jlp.2020.104235 .	Risk assessment Process safety Operating procedure event trees Equipment transition Dynamic simulation	human error	Risk assessment
3	Process Safety and Environmental Protection	2020	Changlong Zhu, Meng Qi, Juncheng Jiang, Quantifying human error probability in independent protection layers for a batch reactor system using dynamic simulations, Process Safety and Environmental Protection, Volume 133, 2020, Pages 243-258, https://doi.org/10.1016/j.psep.2019.11.021 .	Human error probability Dynamic simulations Human reliability analysis Independent protection layer Batch reactor system	human error	Human error probability
4	Process Safety Progress	2020	Correa, G. To err is human, or is it? Proc Safety Prog. 2020 https://doi.org/10.1002/prs.1222	risk assessment, safety management	human error	Human error concepts
5	Process Safety Progress	2020	Zhang, R, Tan, H, Afzal, W. A modified human reliability analysis method for the estimation of human error probability in the offloading operations at oil terminals. Proc Safety Prog. 2020	fuzzy CREAM, human error probability, human reliability, oil offloading	human error	Human error probability
6	Process Safety Progress	2021	Smith, PK, Craig, BN, Wang, Q, Larrañaga, MD. Human error analysis of the Montara well blowout. Proc Safety Prog. 2021; 40	active error, latent error, Macondo Deepwater Horizon, situational awareness, West Atlas Well	human error	Learning from accidents
7	Reliability Engineering and System Safety	2019	Haiyang Che, Shengkui Zeng, Jianbin Guo, Reliability assessment of man-machine systems subject to mutually dependent machine degradation and human errors, Reliability Engineering & System Safety, Volume 190, 2019, https://doi.org/10.1016/j.ress.2019.106504 .	Man-machine systems Machine degradation Human error Mutual dependence Piecewise-deterministic Markov process Reliability modeling	human error	Man-machine systems
8	Safety science	2018	Romina D. Calvo Olivares, Selva S. Rivera, Jorge E. Núñez Mc Leod, A novel qualitative prospective methodology to assess human error during accident sequences, Safety Science, Volume 103, 2018, Pages 137-152, https://doi.org/10.1016/j.ssci.2017.10.023 .	Qualitative prospective model Human error Human reliability assessment Accident sequences Human-machine interface	human error	Risk assessment
9	safety science	2020	Justin Larouzee, Jean-Christophe Le Coze, Good and bad reasons: The Swiss cheese model and its critics, Safety Science, Volume 126, 2020, https://doi.org/10.1016/j.ssci.2020.104660 .		human error	Human error concepts
10	safety science	2020	Joseph W. Hendricks, S. Camille Peres, Beyond human error: An empirical study of the safety Model 1 and Model 2 approaches for predicting workers' behaviors and outcomes with procedures, Safety Science, Volume 134, 2021, https://doi.org/10.1016/j.ssci.2020.105016 .	Procedures Process safety Models of safety Predictors of non-compliance	human error	Procedures
11	Journal of Loss Prevention in the Process Industries	2018	Fawaz K. Bitar, Diane Chadwick-Jones, Marcin Nazaruk, Chan Boodhai, From individual behaviour to system weaknesses: The re-design of the Just Culture process in an international energy company. A case study, Journal of Loss Prevention in the Process Industries, Volume 55, 2018, Pages 267-282, https://doi.org/10.1016/j.jlp.2018.06.015 .	Just Culture Safety culture Modern view of incident causation Culpability Incident investigation	human error	Human error concepts
12	Journal of Loss Prevention in the Process Industries	2018	David (Dave) J. Grattan, Improving barrier effectiveness using human factors methods, Journal of Loss Prevention in the Process Industries, Volume 55, 2018, Pages 400-410, https://doi.org/10.1016/j.jlp.2018.07.016 .	Bow-tie Barrier effectiveness Task analysis Human error Human factors Human reliability	human factor	Barriers

	Journal	Year of release	Article reference	Keywords	Criteria (human factor, human error, safety culture, safety climate)	Category in Tables 10., 14., 18., & 21.
13	Journal of Loss Prevention in the Process Industries	2018	Darren McDonnell, Nora Balfe, Linda Pratto, Garret E. O'Donnell, Predicting the unpredictable: Consideration of human and organisational factors in maintenance prognostics, Journal of Loss Prevention in the Process Industries, Volume 54, 2018, Pages 131-145, https://doi.org/10.1016/j.jlp.2018.03.008 .	Maintenance Human and organisational factors Soft sensors Data fusion Weibull proportional hazards model	human factor	Organisation
14	Journal of Loss Prevention in the Process Industries	2019	Esmail Zarei, Mohammad Yazdi, Rouzbeh Abbassi, Faisal Khan, A hybrid model for human factor analysis in process accidents: FBN-HFACS, Journal of Loss Prevention in the Process Industries, Volume 57, 2019, Pages 142-155, https://doi.org/10.1016/j.jlp.2018.11.015 .	Process industries HFACS Human reliability assessment Fuzzy AHP Bayesian network	human factor	Human factor analysis
15	Journal of Loss Prevention in the Process Industries	2020	Jing Wang, Yunxiao Fan, Yuan Gao, Revising HFACS for SMEs in the chemical industry: HFACS-CSMEs, Journal of Loss Prevention in the Process Industries, Volume 65, 2020, https://doi.org/10.1016/j.jlp.2020.104138 .	Chemical accidents HFACS Accident causes SMEs	human factor	Human factor analysis
16	Journal of Safety Research	2021	Wafa Boulagouas, Susana García-Herrero, Rachid Chaib, Sixto Herrera García, Mébarek Djebabra, On the contribution to the alignment during an organizational change: Measurement of job satisfaction with working conditions, Journal of Safety Research, Volume 76, 2021, Pages 289-300, https://doi.org/10.1016/j.jsr.2020.12.006 .	Health and safety Organizational change Working conditions Alignment Bayesian Networks	human factor	Organisation
17	Process Safety and Environmental Protection	2018	Leila Omid, Seyed Abolfazl Zakerian, Jebraeil Nasl Saraji, Esmail Hadavandi, Mir Saeed Yekaninejad, Safety performance assessment among control room operators based on feature extraction and genetic fuzzy system in the process industry, Process Safety and Environmental Protection, Volume 116, 2018, Pages 590-602, https://doi.org/10.1016/j.psep.2018.03.014 .	Safety performance Human factors Process industry Genetic fuzzy system Hybrid intelligent model	human factor	Safety performance
18	Process Safety Progress	2019	Miller, L. and Grounds, C. (2019), Helping humans get it right. Proc. Safety Prog., 38: e12003. DOI 10.1002/prs.12003	human performance, human factors, task analysis, task improvement process	human factor	Safety performance
19	Process Safety Progress	2019	Chen, M., Wang, K., Guo, H. and Yuan, Y. (2019), Human factors of fire and explosion accidents in petrochemical enterprises. Proc Safety Prog, 38. DOI 10.1002/prs.12043	human factor; fire and explosion accident; petrochemical enterprise; HAFCS-PEFE	human factor	Human factor analysis
20	Process Safety Progress	2020	McDonald, J. Using post-incident behavioral analysis techniques to complement incident investigations. Proc Safety Prog. 2020; 39 DOI: 10.1002/prs.12196	behavior, behavior-based safety, hazard recognition, incident investigations, incident prevention	human factor	Behaviour based safety
21	Reliability Engineering and System Safety	2018	Maurizio Bevilacqua, Filippo Emanuele Ciarapica, Human factor risk management in the process industry: A case study, Reliability Engineering & System Safety, Volume 169, 2018, Pages 149-159, https://doi.org/10.1016/j.ress.2017.08.013 .		human factor	Risk Management
22	Reliability Engineering and System Safety	2021	Nooshin Atashfeshan, Mohammad Saidi-Mehrabad, Hamideh Razavi, A novel dynamic function allocation method in human-machine systems focusing on trigger mechanism and allocation strategy, Reliability Engineering & System Safety, Volume 207, 2021, https://doi.org/10.1016/j.ress.2020.107337 .	Automation Dynamic function allocation Bayesian network Reliability Situation awareness	human factor	Risk Management
23	safety science	2019	Saveta Vukadinovic, Ivan Macuzic, Marko DJapan, Marko Milosevic, Early management of human factors in lean industrial systems, Safety Science, Volume 119, 2019, Pages 392-398, https://doi.org/10.1016/j.ssci.2018.10.008 .	Early management Human factors Lean systems Early Human Resources Management	human factor	Risk Management

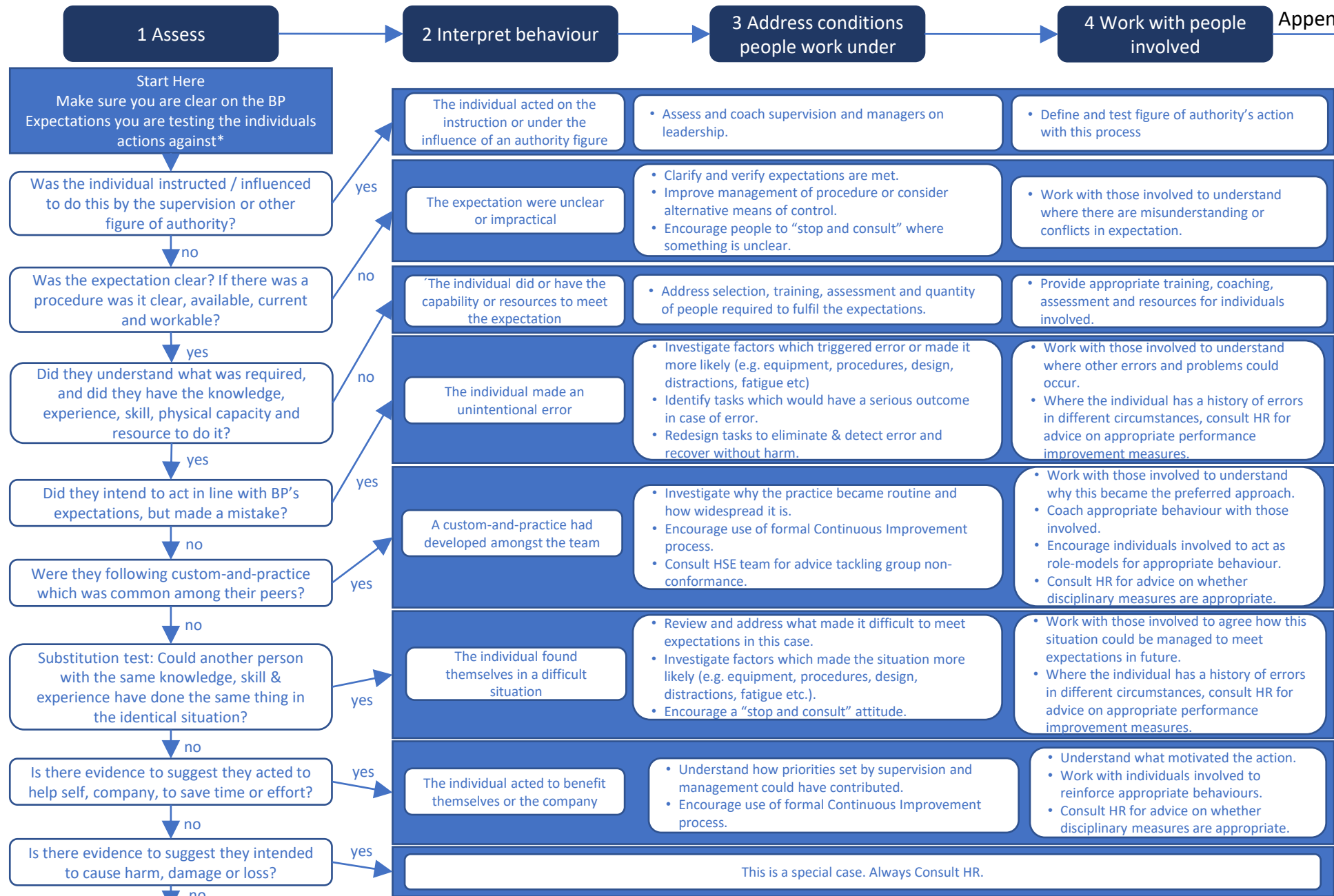
	Journal	Year of release	Article reference	Keywords	Criteria (human factor, human error, safety culture, safety climate)	Category in Tables 10., 14., 18., & 21.
24	safety science	2020	W.M.P. Steijn, J.N. Van Kampen, D. Van der Beek, J. Groeneweg, P. H.A.J.M. Van Gelder, An integration of human factors into quantitative risk analysis using Bayesian Belief Networks towards developing a 'QRA+', Safety Science, Volume 122, 2020, https://doi.org/10.1016/j.ssci.2019.104514 .		human factor	Risk Analysis
25	safety science	2021	C.M. La Fata, A. Giallanza, R. Micale, G. La Scalia, Ranking of occupational health and safety risks by a multi-criteria perspective: Inclusion of human factors and application of VIKOR, Safety Science, Volume 138, 2021, https://doi.org/10.1016/j.ssci.2021.105234 .	Occupational Health and Safety (OHS) Ranking Multi-Criteria Decision Making (MCDM) Human factor VIKOR	human factor	Risk assessment
26	Accident Analysis and Prevention	2018	Sharon Clarke, Ian Taylor, Reducing workplace accidents through the use of leadership interventions: A quasi-experimental field study, Accident Analysis & Prevention, Volume 121, 2018, Pages 314-320, https://doi.org/10.1016/j.aap.2018.05.010 .	Occupational safety Leadership Transformational Active transactional Intervention Training	safety climate	Leadership
27	Journal of Loss Prevention in the Process Industries	2018	Mindy E. Bergman, Stephanie C. Payne, Interdisciplinary collaborations facilitate safety climate research, Journal of Loss Prevention in the Process Industries, Volume 56, 2018, Pages 204-208, https://doi.org/10.1016/j.jlp.2018.08.007 .		safety climate	Safety Assessment
28	Journal of Loss Prevention in the Process Industries	2020	S. Camille Peres, Alec Smith, Farzan Sasangohar, Worker-centered investigation of issues with procedural systems: Findings from interviews with a representative sample of workers in high-risk process industries, Journal of Loss Prevention in the Process Industries, Volume 67, 2020, https://doi.org/10.1016/j.jlp.2020.104264 .	Procedures Safety Thematic analysis Industrial work	safety climate	Procedures and practices
29	Journal of Safety Research	2018	Øyvind Dahl, Trond Kongsvik, Safety climate and mindful safety practices in the oil and gas industry, Journal of Safety Research, Volume 64, 2018, Pages 29-36, https://doi.org/10.1016/j.jsr.2017.12.009 .		safety climate	Procedures and practices
30	Journal of Safety Research	2020	Alexa J. Doerr, When and how personality predicts workplace safety: Evaluating a moderated mediation model, Journal of Safety Research, Volume 75, 2020, Pages 275-283, https://doi.org/10.1016/j.jsr.2020.09.008 .	Safety Situation strength Safety climate Personality Five Factor Model	safety climate	Behaviour and personality
31	Journal of Safety Research	2020	Anna Paolillo, Silvia A. Silva, Helena Carvalho, Margherita Pasini, Exploring patterns of multiple climates and their effects on safety performance at the department level, Journal of Safety Research, Volume 72, 2020, Pages 47-60, https://doi.org/10.1016/j.jsr.2019.12.009 .	Safety Diversity Inclusion Communication Climate	safety climate	Organisation
32	Journal of Safety Research	2020	David Johnston, Mark Pagell, Anthony Veltri, Robert Klassen, Values-in-action that support safe production, Journal of Safety Research, Volume 72, 2020, Pages 75-91, https://doi.org/10.1016/j.jsr.2019.11.004 .	Organizational culture and climate Values Occupational safety Sustainable production Organizational routines	safety climate	Safety climate concepts
33	Journal of Safety Research	2021	Jin Lee, Yueng-Hsiang Huang, Marvin J. Dainoff, Yimin He, Where to focus? Insights from safety personnel and external safety consultants on lessons learned about safety climate interventions – A qualitative approach, Journal of Safety Research, 2021, https://doi.org/10.1016/j.jsr.2021.08.005 .	Safety climate Intervention Qualitative analysis Sociotechnical systems approach	safety climate	Safety Management

	Journal	Year of release	Article reference	Keywords	Criteria (human factor, human error, safety culture, safety climate)	Category in Tables 10., 14., 18., & 21.
34	Process Safety and Environmental Protection	2020	Jing Tao, Fuqiang Yang, Dongyang Qiu, Genserik Reniers, Analysis of safety leadership using a science mapping approach, Process Safety and Environmental Protection, Volume 140, 2020, Pages 244-257, https://doi.org/10.1016/j.psep.2020.04.031 .	Safety leadership Safety performance Bibliometric mapping Scientific knowledge	safety climate	Leadership
35	Process Safety Progress	2020	Zakaria, J, Che Hassan, CR, Hamid, MD, Sukadarin, EH. Safety climate factors at selected chemical manufacturing plant in Malaysia. Proc Safety Prog. 2020; 39:e12096. https://doi-org.libproxy.aalto.fi/10.1002/prs.12096 DOI: 10.1002/prs.12096	chemical manufacturing plant, safety climate assessment toolkit, safety culture, Zohar safetyclimate questionnaire	safety climate	Safety Assessment
36	Safety science	2018	Matteo Curcuruto, Mark A. Griffin, Prosocial and proactive "safety citizenship behaviour" (SCB): The mediating role of affective commitment and psychological ownership, Safety Science, Volume 104, 2018, Pages 29-38, https://doi.org/10.1016/j.ssci.2017.12.010 .	Proactivity Safety behaviour Organizational citizenship Organizational support Affective commitment Psychological ownership	safety climate	Behaviour and personality
37	Safety science	2018	Huw Flatau Harrison, Mark A. Griffin, Marylene Gagne, Daniela Andrei, Assessing shortened safety climate measures: Simulating a planned missing data design in a field setting, Safety Science, Volume 104, 2018, Pages 189-201, https://doi.org/10.1016/j.ssci.2017.11.004 .	Safety climate Planned missing data design Field research	safety climate	Safety Assessment
38	safety science	2020	A.M. Saedi, A. Ab. Majid, Z. Isa, Relationships between safety climate and safety participation in the petroleum industry: A structural equation modeling approach, Safety Science, Volume 121, 2020, Pages 240-248, https://doi.org/10.1016/j.ssci.2019.08.045 .	Safety climate Safety participation Safety knowledge Safety attitude Structural equation modeling Refinery industry	safety climate	Safety Participation
39	safety science	2020	Huw Flatau-Harrison, Mark A. Griffin, Marylène Gagné, Trickle down: The impact of leaders on individual role clarity through safety climate strength across time, Safety Science, Volume 121, 2020, Pages 485-495, https://doi.org/10.1016/j.ssci.2019.09.009 .	Safety climate Multilevel safety climate strength Leader support Role clarity Passive management by exception Conscientiousness	safety climate	Leadership
40	safety science	2020	Haji Omid Kalteh, Mahmood Salehi, Rosanna Cousins, Hamidreza Mokarami, Assessing safety culture in a gas refinery complex: Development of a tool using a sociotechnical work systems and macroergonomics approach, Safety Science, Volume 132, 2020, https://doi.org/10.1016/j.ssci.2020.104969 .	Safety climate Human Factors Macroergonomics Sociotechnical system theory Organizational safety Work system model	safety climate	Safety Assessment
41	safety science	2021	Renana Arizon Peretz, Gil Luria, Yuval Kalish, Dov Zohar, Safety climate strength: The negative effects of cliques and negative relationships in teams, Safety Science, Volume 138, 2021, https://doi.org/10.1016/j.ssci.2021.105224 .	Safety climate Subgroup Climate strength Negative relationship Friendship network	safety climate	Behaviour and personality
42	Journal of Loss Prevention in the Process Industries	2019	Nelly Amaya, M. Dolores Rovira, Susana del Cerro, Mónica Grillo, Rosa Nomen, Julià Sempere, Distributed Safety Management as a tool for creating a safety culture in university students and future professionals, Journal of Loss Prevention in the Process Industries, Volume 57, 2019, Pages 114-119, https://doi.org/10.1016/j.jlp.2018.08.014 .	Behavioural safety Gaining distributed safety GDS Safety culture	safety culture	Safety Management
43	Journal of Loss Prevention in the Process Industries	2019	Yuan Gao, Yunxiao Fan, Jing Wang, Xi Li, Jingjing Pei, The mediating role of safety management practices in process safety culture in the Chinese oil industry, Journal of Loss Prevention in the Process Industries, Volume 57, 2019, Pages 223-230, https://doi.org/10.1016/j.jlp.2018.11.017 .	Safety culture Safety management practice Structural equation model Oil industry Mediating role	safety culture	Safety Management

	Journal	Year of release	Article reference	Keywords	Criteria (human factor, human error, safety culture, safety climate)	Category in Tables 10., 14., 18., & 21.
44	Journal of Loss Prevention in the Process Industries	2020	Gerard Zwetsloot, Jakko van Kampen, Wouter Steijn, Sjoerd Post, Ranking of process safety cultures for risk-based inspections using indicative safety culture assessments, Journal of Loss Prevention in the Process Industries, Volume 64, 2020, https://doi.org/10.1016/j.jlp.2020.104065 .	Process safety culture External indicative assessment Ranking safety cultures Inspection strategies Major hazards	safety culture	Safety Assessment
45	Journal of Loss Prevention in the Process Industries	2020	Chizaram D. Nwankwo, Stephen C. Theophilus, Andrew O. Arewa, A comparative analysis of process safety management (PSM) systems in the process industry, Journal of Loss Prevention in the Process Industries, Volume 66, 2020, https://doi.org/10.1016/j.jlp.2020.104171 .	Process safety management (PSM) Accidents Process industry Comparative analysis	safety culture	Safety Management
46	Journal of Safety Research	2019	Hassan Iqbal, Bushra Waheed, Husnain Haider, Solomon Tesfamariam, Rehan Sadiq, Mapping safety culture attributes with integrity management program to achieve assessment goals: A framework for oil and gas pipelines industry, Journal of Safety Research, Volume 68, 2019, Pages 59-69, https://doi.org/10.1016/j.jsr.2018.12.010 .	Integrity management program Safety culture Oil and gas pipelines Failure-mode-effect-analysis Safety management system	safety culture	Safety Management
47	Process Safety and Environmental Protection	2018	Prerna Jain, William J. Rogers, Hans J. Pasma, M. Sam Mannan, A resilience-based integrated process systems hazard analysis (RIPSHA) approach: Part II management system layer, Process Safety and Environmental Protection, Volume 118, 2018, Pages 115-124, https://doi.org/10.1016/j.psep.2018.06.037 .	Management system Hazard analysis Resilience Process safety systems Operational discipline Process safety culture	safety culture	Safety Management
48	Process Safety and Environmental Protection	2019	Niresh Behari, Assessing process safety culture maturity for specialty gas operations: A case study, Process Safety and Environmental Protection, Volume 123, 2019, Pages 1-10, https://doi.org/10.1016/j.psep.2018.12.012 .	Human factors Hydrocarbon leaks OSHA process safety management Process safety culture SWOT Team leadership behaviors	safety culture	Safety Assessment
49	Process Safety Progress	2019	Mize, J.F. (2019), The roundabout way to disaster: Recognizing and responding to normalization of deviance. Proc. Safety Prog., 38 DOI 10.1002/prs.12014	normalization of deviation (deviance); process safety; near misses; conduct of operations; operational discipline; safety culture	Safety Culture	Learning from accidents
50	Process Safety Progress	2021	Hameed, H, Sarfraz, MA. Measuring vital signs of process safety culture. Proc Safety Prog. 2021	assessing and advancing process safety culture, deferring to expertise, establishing an imperative for safety, fostering mutual trust, normalization of deviance, process safety culture and its core principles, sense of vulnerability	Safety Culture	Safety Management
51	Process Safety Progress	2021	Mize JF. "If you really think it's that important—show me, don't tell me!". Proc Safety Prog. 2021. DOI: 10.1002/prs.12275	process safety culture, process safety management, resource allocation, risk management	safety culture	Organisation
52	Process Safety Progress	2021	Pawolocki FJ. Layer of protection analysis as auxiliary technique in process safety incident investigations. Process Saf Prog. 2021 DOI: 10.1002/prs.12286	fishbone ; PSM, incident investigation, layer of protection analysis, LOPA, process safety culture, PSM culture, root cause	safety culture	Barriers
53	Safety science	2018	Geert Vierendeels, Genserik Reniers, Karolien van Nunen, Koen Ponnet, An integrative conceptual framework for safety culture: The Egg Aggregated Model (TEAM) of safety culture, Safety Science, Volume 103, 2018, Pages 323-339, https://doi.org/10.1016/j.ssci.2017.12.021 .	Safety culture Integrated model Safety indicators Safety management Measuring safety	safety culture	Safety culture concepts

	Journal	Year of release	Article reference	Keywords	Criteria (human factor, human error, safety culture, safety climate)	Category in Tables 10., 14., 18., & 21.
54	Safety science	2018	Anastacio Pinto Goncalves Filho, Patrick Waterson, Maturity models and safety culture: A critical review, Safety Science, Volume 105, 2018, Pages 192-211, https://doi.org/10.1016/j.ssci.2018.02.017 .	Safety culture Maturity model Safety culture assessment	safety culture	Safety Assessment
55	Safety science	2018	Karolien van Nunen, Jie Li, Genserik Reniers, Koen Ponnet, Bibliometric analysis of safety culture research, Safety Science, Volume 108, 2018, Pages 248-258, https://doi.org/10.1016/j.ssci.2017.08.011 .	Bibliometric analysis Safety culture Organisational safety Patient safety Health-care safety Scientific knowledge	safety culture	Bibliometric analysis
56	safety science	2019	M.D. Cooper, M. Collins, R. Bernard, S. Schwann, R.J. Knox, Criterion-related validity of the cultural web when assessing safety culture, Safety Science, Volume 111, 2019, Pages 49-66, https://doi.org/10.1016/j.ssci.2018.09.013 .	Safety culture assessment Cultural web Organisational safety Criterion-related validity Safety culture models	safety culture	Safety Assessment
57	safety science	2019	Valeria Casson Moreno, Enrico Danzi, Luca Marmo, Ernesto Salzano, Valerio Cozzani, Major accident hazard in biodiesel production processes, Safety Science, Volume 113, 2019, Pages 490-503, https://doi.org/10.1016/j.ssci.2018.12.014 .	Major accident hazard Biodiesel Accident scenarios Past accident analysis Lessons learnt Accidentology	safety culture	Learning from accidents
58	safety science	2019	Mohammed Aburumman, Sharon Newnam, Brian Fildes, Evaluating the effectiveness of workplace interventions in improving safety culture: A systematic review, Safety Science, Volume 115, 2019, Pages 376-392, https://doi.org/10.1016/j.ssci.2019.02.027 .	Systematic review Safety culture Safety climate Organizational psychology Occupational safety Intervention	safety culture	Organisation
59	safety science	2019	Jean Christophe Le Coze, How safety culture can make us think, Safety Science, Volume 118, 2019, Pages 221-229, https://doi.org/10.1016/j.ssci.2019.05.026 .	Safety culture Safety market Consulting Waves of debates Guru	safety culture	History of safety culture
60	safety science	2019	Tor-Olav Nævestad, Ingeborg Storesund Hesjevoll, Karen Ranestad, Stian Antonsen, Strategies regulatory authorities can use to influence safety culture in organizations: Lessons based on experiences from three sectors, Safety Science, Volume 118, 2019, Pages 409-423, https://doi.org/10.1016/j.ssci.2019.05.020 .		safety culture	Regulations
61	safety science	2019	Gabriele Baldissonne, Lorenzo Comberti, Serena Bosca, Salvina Murè, The analysis and management of unsafe acts and unsafe conditions. Data collection and analysis, Safety Science, Volume 119, 2019, Pages 240-251, https://doi.org/10.1016/j.ssci.2018.10.006 .	Unsafe Acts Unsafe conditions HFACS Fuzzy Logic	human factor	Human factor analysis
62	safety science	2019	Patrick L. Yorio, Jason Edwards, Dick Hoeneveld, Safety culture across cultures, Safety Science, Volume 120, 2019, Pages 402-410, https://doi.org/10.1016/j.ssci.2019.07.021 .	Organizational safety culture National culture Societal culture	safety culture	History of safety culture

	Journal	Year of release	Article reference	Keywords	Criteria (human factor, human error, safety culture, safety climate)	Category in Tables 10., 14., 18., & 21.
63	safety science	2020	Paul R. Schulman, Organizational structure and safety culture: Conceptual and practical challenges, Safety Science, Volume 126, 2020, https://doi.org/10.1016/j.ssci.2020.104669 .	safety culture organizational structure safety management	safety culture	Organisation
64	safety science	2020	Wei Jiang, Gui Fu, Chun-yang Liang, Wei Han, Study on quantitative measurement result of safety culture, Safety Science, Volume 128, 2020, https://doi.org/10.1016/j.ssci.2020.104751 .	Enterprises Safety culture Quantitative Measurement Analysis	safety culture	Safety Assessment
65	safety science	2020	Md. Khalid Hasan, Tahmina Bintay Younos, Safety culture among Bangladeshi university students: A cross-sectional survey, Safety Science, Volume 131, 2020, https://doi.org/10.1016/j.ssci.2020.104922 .	Safety culture Safety behavior Safety attitude Student University Bangladesh	safety culture	Safety Assessment
66	safety science	2021	Gui Fu, Lin Zhou, Jianhao Wang, Meng Shi, Analysis of an explosion accident at Dangyang Power Plant in Hubei, China: Causes and lessons learned, Safety Science, Volume 102, 2018, Pages 134-143, https://doi.org/10.1016/j.ssci.2017.10.010 .	Keywords: Dangyang Power Plant Pipe explosion Accident analysis Unsafe act Safety management system Safety culture	safety culture	Learning from accidents



5 Now test supervisor / line manager / others contribution

*Expectations = expected conduct in line with Values and Behaviours, Code of Conduct, rules, policies and procedures

Appendix 3.

Interview for thesis on human factor and safety culture

Information on the thesis and interview

The aim of the thesis is to examine new methods and tools from recent safety research to improve human factor consideration and safety culture, and to find out practical ways of applying the research findings to minimize accidents and property loss in the chemical and process industries. Ten journals were considered, and the time frame was set to 2018 to 2021.

The aim of the interviews is to gather the perception of the interviewees on these tools or methods and their usability in day-to-day actions.

The interviewees will be from three categories: If risk engineers, safety managers or equivalent from companies, and university personnel. The companies and persons will not be recognisable, and the results will be handled anonymously, only recognising which category the results are obtained from.

The interview will be approximately an hour, and the content of the interview will be background, questions on perception of human factor, human error, safety culture and safety climate, presenting the tools and methods, questions and discussion on them, as well as discussion on the application of new methods in organizations. The discussion can be held either in Finnish or English. The discussion will be recorded to help with the analysing of the responses. The recordings will not be published.

Background

Company

- Company:
- Industry:
- Category:

If risk engineer

Safety manager or equivalent

University personnel

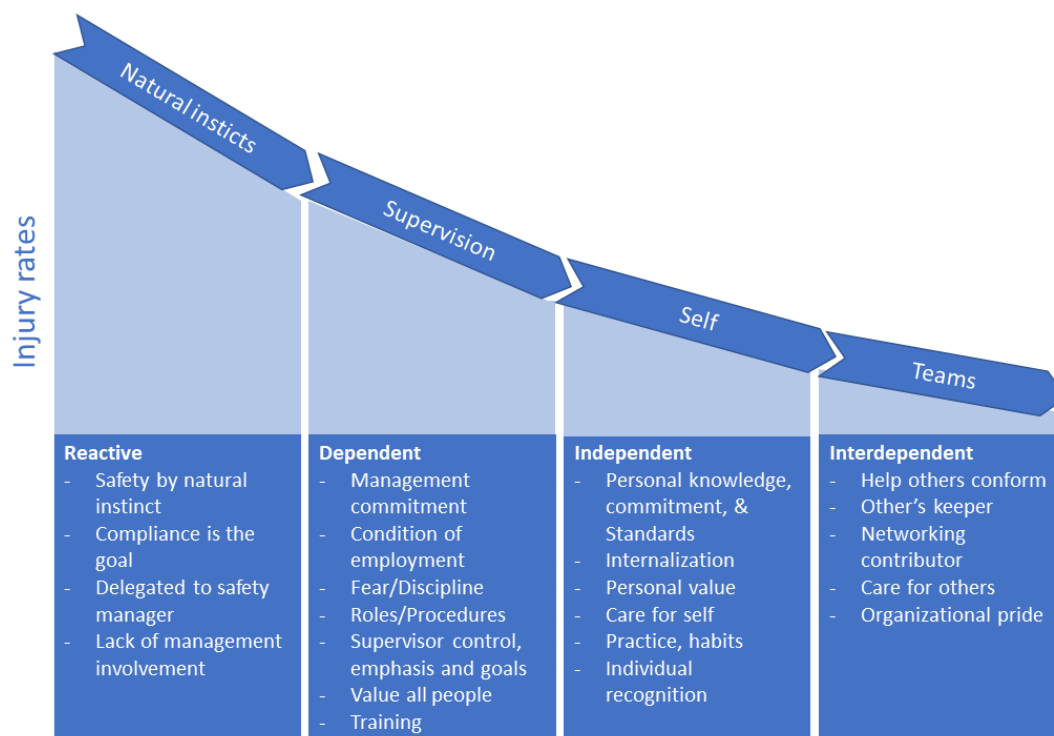
Interviewee

- What is your name?
- What is your role in your organization?
- How long have you been working in the organization?
- What are your main responsibilities in the organization?
- What is your role regarding the duties of safety?

Human factor, human error, safety culture, safety climate and safety management systems

- How would you define:
 - o human factor?
 - o human error?
 - o safety culture?
 - o safety climate?

- Would you agree or disagree with these definitions?
 - o human factor
 - " Human factors refer to environmental, organisational and job factors, and human and individual characteristics which influence behaviour at work in a way which can affect health and safety" (Health and Safety Executive, 1999).
 - o human error
 - "The failure of planned actions to achieve their desired ends – without the intervention of some unforeseeable event" (Reason, 1990).
 - o safety culture
 - "To consists of the conscious and unconscious basic beliefs, values, attitudes, and practices of safety in an organization." (Levä, 2003)
 - o safety climate
 - "Safety perception of an organization at a given point of time. Reflection of the culture of an organization, it is visible and measurable, and it describes the current state of the organization and its internal environment." (Goncalves Filho and Waterson, 2018)
- Does your organisation use a safety management system?
 - o Is the system certified?
- Estimate at to which level your company's safety culture is according to dss+ Bradley curve.



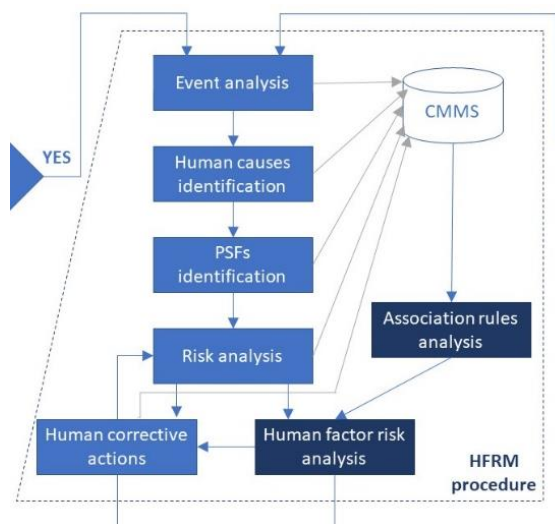
The dss+ Bradley curve (Branchini, 2020; dss+, 2022)

- Do you utilize safety climate surveys to study the current situation in your organization?
 - o If yes, what kind and how often?

Tools and methods

Human factor: Human Factor Risk Management

A new procedure was developed by Bevilacqua and Ciarapica (2018) called Human Factor Risk Management (HFRM) to integrate human factor in a Refinery Risk Management System. The aim of the procedure was to identify and investigate human factor risks, to generate association rules for harmful events, and to suggest preventive and safety measures to inhibit or minimize high-risk events. The procedure is meant to be integrated in an existing safety, quality, and environment (SQE) management system in a refinery. It is used when human error is related to a harmful event, either an accident or injury, or a work order, related to a corrective, on condition or planned maintenance. In case of a harmful event, the analysis follows the HFRM procedures when the event is related to human error, otherwise the traditional (SQE) procedure is used. The method requires a computerised maintenance management system (CMMS), where all work orders are filled, and accidents, injuries or near misses are reported.



Event analysis: registration of required data in the CMMS (type of harmful event, the work situation, date of the event, the plant area, the part of the body injury, and the description of the event)

Human causes identification: the cause of the error is selected.

PSF's identification: The performance shaping factors are recognised.

Risk analysis: the risk index based on probability and consequence is calculated.

Human corrective actions: actions chosen to avoid the recurrence of the event.

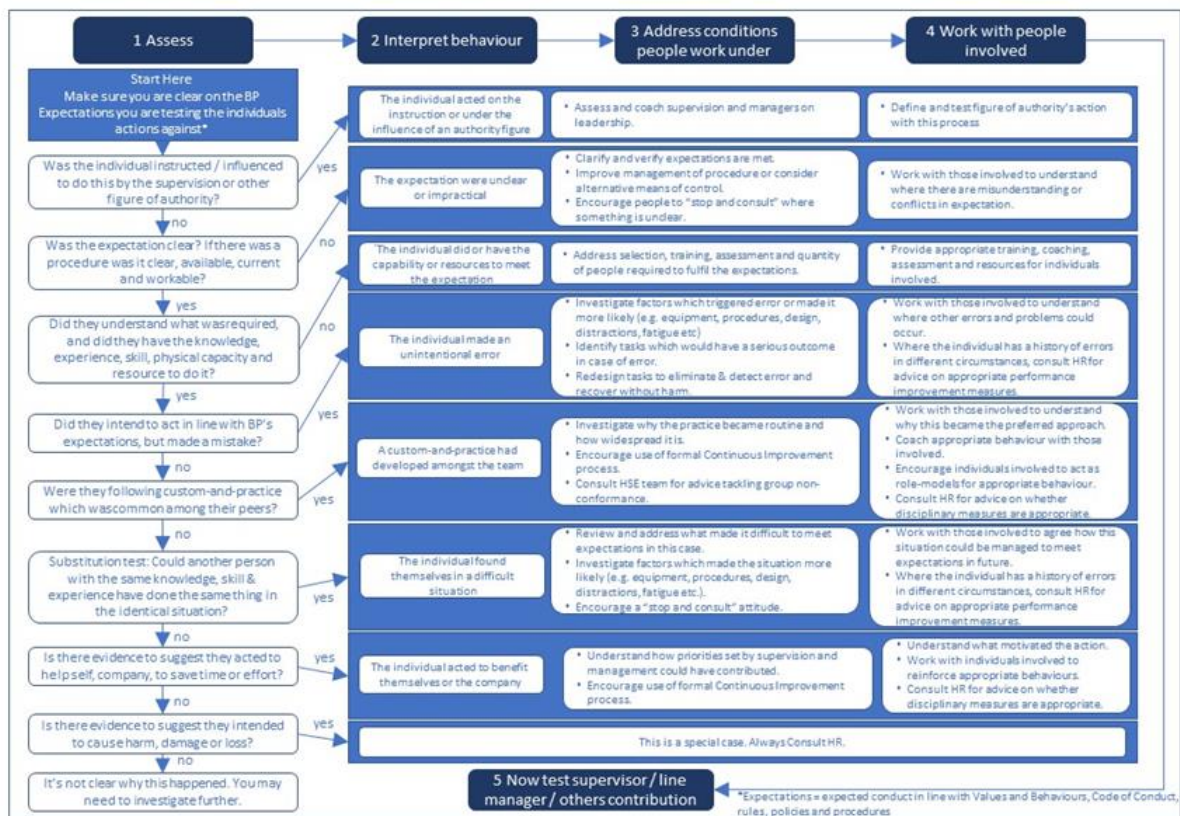
Based on this data, a *Human Factor Risk Analysis* is recommended to be performed monthly to provide risk reduction suggestions to reduce the risk of human error. This analysis utilizes *association rules* technique to recognize relationships among the factors. Association rules discover regularities between data sets.

- Do you see any advantages in the method?
- Do you see any shortages in the method?
- Does your company use a computerised management system, where accidents, injuries or near misses are reported?
 - o How are the results used to minimize future accidents?
 - o How often is the data gone through?
- Would you consider an artificial intelligence or machine learning program to improve application of results of accident investigations?

- In your opinion, is the method something you could consider on applying in your organization?

Human error: Re-designed Just Culture process

To ensure and emphasize fairness, trust, learning, and accountability in an organizational culture Reason (1997) developed the concept of Just Culture. Bitar *et al.* (2018) from BP created a re-design of the Just Culture process for the upstream operations of the company, responsible of the oil and gas production and processing. The aim was to move the mind-set in the organization away from the tool being used as a disciplinary tool for individual behaviour, to seeing its potential as a tool to spot system weaknesses.



- Does your company use Just Culture process by Reason or a similar process?
- Do you see any advantages in the method?
- Do you see any disadvantages in the method?
- Do you feel that your organization in the case of accident, incident or near miss investigation
 - o Focuses on the front line or applies the investigation to all levels of hierarchy?
 - o Focuses on the individual or focuses on the workplace influencing factors?
- The shift in recent safety research is to consider more and more the overall factors, like workplace influencing factors and all levels of hierarchy, and not only the individual. In your opinion, is this shift to the right direction and have you noticed it in your organization?
- In your opinion, is the method something you could consider on applying in your organization?

Safety culture: Ranking of process safety cultures

A method to externally evaluate process safety culture in major hazard industries was developed by Zwetsloot *et al.* (2020). The aim of the method was to repeatably and reliably rank the safety cultures of major hazard companies. The idea was to be used after an inspector has spent a day doing their routine inspection in the major hazard company, and to assess the different aspects of the safety culture of the company with the method in approximately 15 minutes. External assessment of safety culture could help authorities to evaluate the safety situations of companies better and intervene earlier in problematic situations and so possibly inhibit some accidents. There were total of 14 aspects with 30 questions combined. The four most important aspects with their respective questions are shown below.

Aspects	Item To what degree...
Leadership	is senior management committed to safety?
	is senior management competent with respect to safety?
	is senior management visible on the shop floor to promote safety proactively?
	does senior management address people in case of unsafe acts
Safety communication	does the organisation communicate a clear and consistent safety message?
	do managers and employees share information about safety?
	do employees experience safety meetings as important?
Participation	do employees employ initiatives to improve safety?
	is safety 'alive' at the shop floor?
	are employees actively involved by the managers in dealing with safety issues?
Learning culture	does the plant implement lessons learned from incidents and near-misses?
	do lessons learned from incidents lead to improvements in safety culture
	does the organisation monitor the safety climate (the perceptions and attitudes of the employees that are relevant for safety)?
	does the plant actively identify lessons learned from incidents occurring in other organisations?

The remaining 10 aspects are production versus safety, vision management, role supervisor, procedures, audits, registration, maintenance, contractors, process and work safety, and complexity.

- Do you see that there is a need for ranking safety cultures externally?
- What are the advantages of this model in your opinion?
- How about the disadvantages?
- Does your organization map safety culture?
 - o If yes, how, and how often?
 - o Does your company have an industry specific questionnaire to map safety culture?
 - Is there a need for one?
- In your opinion, is the method something you could consider useful for your organization?

Application of new safety research in organizations

- Do you feel that your organizations safety methods are up to date, utilizing the most current information and technology in regard of safety?
- How often new methods to improve safety are researched and reviewed?
- As best as you recall, when was the last improvement made on human factor or safety culture?
- Do you feel like you have time to follow new methods/ new tools in your day-to-day work?
- Where do you get the information?

<input type="checkbox"/>	Seminars	Which?	_____
<input type="checkbox"/>	Journals	Which?	_____
<input type="checkbox"/>	News	Which?	_____
<input type="checkbox"/>	Society	Which?	_____
<input type="checkbox"/>	Colleagues		_____
<input type="checkbox"/>	Other	Which?	_____

Any questions, comments, etc?

Thank you!

I will send the thesis for you when it is ready.

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