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HUMAN FACTOR MANAGEMENT METHOD REVIEW AND SERVICE DESIGN

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TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT
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Tämä diplomityö tutki kemian ja prosessiteollisuudessa käytettyjä inhimillisten tekijöiden arviointi- ja hallintakeinoja. Tavoitteena oli selvittää minkälaisia menetelmiä on olemassa ja mitkä niistä antavat toimeksiantajayritykselle lisäarvoa inhimillisten tekijöiden arviointiin. Menetelmäselvityksen tulokset olivat perustana inhimillisten tekijöiden hallintapalvelun suunnittelulle ja pilotin toteuttamiselle.

Inhimillisten tekijöiden hallintamenetelmiä on runsaasti erilaisia ja aiheen tutkimuksella on pitkät perinteet. Erityyppisiä painopisteitä on tehtävätasolta organisaation hallintotasolle, järjestelmien ja käyttöliittymien suunnittelusta operointiin liittyvien inhimillisten riskien hallintaan sekä onnettomuuksien analysointiin. Tämän diplomityön pääpainotus on menetelmissä, joilla on suoraa vaikutusta päivittäisiin työtehtäviin ja toimintaan. Tämä tarkoittaa menetelmiä, joissa tutkitaan tehtäviä ja laitosten operointia (operatiivinen työntekijän taso); tai arvioidaan turvallisuuskulttuuria, henkilöstön väsymystä, stressiä ja työympäristön muita riskejä.

Tämän diplomityön tuloksia voidaan käyttää pohjana tuleville kehityshankkeille toimeksiantajayrityksessä ja pohjatietona laajemmalle inhimillisten tekijöiden arviointimenetelmien käyttöönotolle tulevaisuudessa.

ABSTRACT

Lappeenranta–Lahti University of Technology LUT
LUT School of Energy Systems
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Human Factor Management Method Review and Service Design

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87 pages, 20 tables, 19 figures, 3 appendices

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Keywords: human factors, safety management, service design

This master's thesis explored human factor management in the chemical and process industries. The aim was to find out what kind of human factor management methods there are, and which would provide added value to the commissioning company. The literature review served as a basis for the Human Factor Management Service design and piloting.

There are multitude of human factors management methods and the research of human factors have long traditions. There are methods with different kinds of focuses from task level to organization management level and from design of systems and interfaces to operational risk management and accident analysis. The main emphasis in this thesis was put on the methods which have a direct impact on day to day work tasks and operation. This means methods which examine human errors while performing tasks and operating systems (operational employee level); and management methods which consider safety culture, fatigue, stress and work environment risks.

The results of this master's thesis can be used as a basis for future development projects and for the wider implementation of human factor management methods within AFRY Finland Oy in the future.

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Heli Pirhonen

TABLE OF CONTENTS

ABBREVIATIONS

ABC	Antecedent-Behavior-Consequences
AEA	Action Error Analysis
ATHEANA	A Technique for Human Error Analysis
BBS	Behavior Based Safety
CREAM	Cognitive Reliability and Error Analysis
CWA	Cognitive Work Analysis
EEM	External Error Mode
EFCs	Error forcing conditions
EPC	Error producing condition
ETA	Event Tree Analysis
FTA	Fault Tree Analysis
HAZOP	Hazard and Operability Study
HEART	Human Error Assessment and Reduction Technique
HEIST	Human Error Identification in Systems Tools
HEP	Human error probability
HFACS-OGI	Human Factors Analysis and Classification System for Oil and Gas Industry
HFE	Human failure event
HFs	Human factors
HMI	Human-machine interface
HRA	Human Reliability Analysis
HSE	Health, safety and environment
HTA	Hierarchical Task Analysis
MORT	Johnson’s Management Oversight and Risk Tree
NHEP	Nominal human error probability
OTA	Operational Task Analysis
PEM	Psychological error mechanism
PRA	Probabilistic Risk Assessment
PSF	Performance shaping factor
PSF_C	Performance shaping factor composite
SCTA	Safety Critical Task Analysis
SHERPA	Systematic Human Error Reduction and Prediction Approach

S-O-R	Stimulate-Organism-Reaction
SPAR-H	Standardized Plant Analysis Risk–Human Reliability Analysis
SPEAR	System for Predictive Error Analysis and Reduction
SRK	Rasmussen’s Skill-Rule-Knowledge framework
STAR	Stop, think, act, review
TESEO	Empirical Technique to Estimate Operator’s Error
TTA	Tabular Task Analysis
UAs	Unsafe acts
WEHRA	Work Environment Health Risk Analysis

1 INTRODUCTION

Human factors are significant contributors to accidents. Industrial sector pays attention to this issue increasingly and human factors management methods provide tools for preventing accidents. Chapter 1.1 presents the commissioning company, Chapter 1.2 includes the research problem, goals, and boundaries and Chapter 1.3 introduces the structure and methodology of the thesis.

1.1 Thesis company and health, safety, environment (HSE) team

AFRY is a leading international engineering, advisory and design company which operates across three business sectors: energy, industry and infrastructure. Operating divisions within the company are: Industrial & Digital Solutions, Process Industries, Infrastructure, Energy and Management Consulting. AFRY has approximately 17 000 employees. The registered office is in Stockholm and the net sales per year of the company is around SEK 20 billion. AFRY experts work globally to create sustainable engineering and design solutions for the future generations. (AFRY, 2020a.)

Health, safety and environment (HSE) studies are vital to optimizing industrial process safety, managing risks, preventing losses and adverse health effects, ensuring safe and comfortable working environment and operating according health and safety standards and regulations. (AFRY, 2020b.) “AFRY uses Safety Stepwise™ procedure for HSE management in projects. Safety Stepwise™ is a systematic procedure for handling safety topics within the life cycle of the project. The main target is as inherent safety as possible in the initial stages of design. HSE activities and tasks are scheduled according to the project schedule and are handled together with normal project management.” (Savunen, 2020.) HSE engineering work contributes to meeting the United Nations sustainable development goals by improving safe working environment and health and well-being of employees and prevents environmental impacts of accidents.

1.2 Research problem, goals and boundaries

There is a great interest to include evaluation of human factors in projects conducted by AFRY Finland Oy. In chemical and process industries large amounts of (toxic, hazardous) chemicals and other potentially harmful substances (such as dust) are handled. Malfunctions and accident scenarios have potentially severe impacts to human health and environment.

This thesis focuses on information and methods which are applicable to chemical and process industries: gas and oil processing, petrochemicals, refining, paper production, chemical production, pharmaceuticals, power generation, drink and food industry, plastic production, mining, wastewater purification and water production. Additionally, even though nuclear energy sector can be placed under process industry category (power generation), nuclear sector has its own specific methods which might not be applicable to all chemical and process industry sectors. Therefore, methods that are specifically targeted to nuclear power sector are excluded. The purpose was to find information and methods that are beneficial for an HSE engineer. Testing new methods in co-operation with a client was done for a chemical production facility in Finland. Geographical area of the literary review was more economically developed countries. HSE team service product portfolio extension was the pursued outcome of the thesis. Also aim was to test some methods in practice to gain useful initial experience and to do basic research about the subject to gain valuable information as a basis for further development projects in the company. The boundaries and research questions are presented in Figure 1.

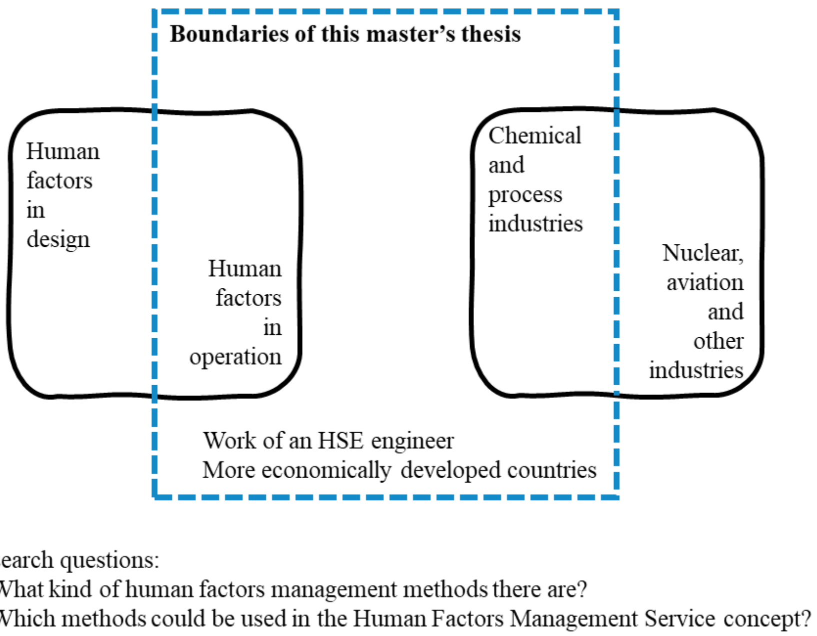


Figure 1 The boundaries and the research questions

The approaches of examining human factors within the work system can be roughly divided into two different points of view: human factors in operation or in design. The design point of view examines improving human performance by designing effective equipment, tools, workspaces and tasks. The operational point of view examines how human performance can be improved by enhancing operation-related aspects such as safety culture, procedures, shift systems and safety critical communications. This thesis focuses on the operational point of view (Figure 1). (Edmonds, et al., 2016, 11, 14.)

Human factor management methods include a wide range of approaches with variable attributes. There are qualitative and quantitative methods, some more comprehensive and detailed than others. There is also synergy with traditional safety engineering approaches. Simpler human factor management approaches merely add set of human factors prompts to a process safety method, for example human HAZOP (Hazard and Operability Study). More developed approaches (for example second and third generation human reliability analyses) examine potential human errors and the conditions which produce errors in a holistic manner. There are long traditions of examining human within a work system (see Chapter 2.1) therefore it is a widely researched subject. The relationship of this thesis to the previous studies is, that from the multitude of sources the mission was to find relevant and usable methods that health and safety engineers could use in their work.

1.3 Research methodology and the structure of the thesis

This master's thesis contains two parts. First part is a qualitative research based on literature. The second part is service design in which the results of the part one are utilized, a service concept constructed, and a pilot conducted.

In this thesis a literature review was conducted by doing qualitative content analysis. According to Sarajärvi & Tuomi (2018, 81) the qualitative research report should explain exactly how the subjects have been selected, how the material has been collected and how it has been analyzed. The course of the study is described in stages: when, where and how was it done? The exact progress of the analysis should be written open clearly, logically and consistently so that the reader can follow the path by which the results have been achieved. The researcher should show all the processes and theoretical structures by which the researcher has end up with the results.

The goal of the literature study was to find a selection of potential human factors management/ assessment methods which could be used in chemical and process industries. This was done by examining a book, e-books and scientific articles about human factors management methods. The materials for analysis were found from LUT Finna portal, which is LUT Academic Library's electronic interface of material search. Categorizing and analysing the methods were based on criteria arising from the materials (common denominators, suitability for a certain purpose, pros and cons) and criteria arising from the HSE team context (suitability for HSE engineering work, suitability to a schedule).

In the applied section of the thesis the results of the literature review were utilized. A service design concept was built, and a pilot conducted. The human factor management service concept was built utilizing knowledge about typical HSE client cases (see Chapter 4.4). It includes Human Error Identification, Human Reliability Analysis and Safety Culture Analysis. The pilot includes three human factor management methods, Action Error Analysis (AEA), Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) and a bowtie diagram (see Chapter 4.5).

Action Error Analysis was conducted at the facility of a client. The role of the author in this evaluation session was expert of the analysis and a scribe. The responsibilities of the scribe are recording the results and the main findings to the assessment sheet and producing the attachments for the evaluation report. SPAR-H was tested while conducting Action Error Analysis at the client's facility. Bowtie diagrams were conducted based on results of Action Error Analysis. The goal was to gain preliminary knowledge about the implementation and usability of these methods.

2 BACKGROUND

Traditionally the work of a health and safety engineer has focused on identifying and minimizing technical process risks. In the 70s loss prevention engineers started to consider non-technical issues in process plants. In the 80s nuclear power community started to identify human error as a type of failure worth paying attention to. Since then numerous methods and approaches to human factors evaluation and management have been proposed. (Pasman, 2015, 82.) Brief history of human factors is presented in Chapter 2.1.

Term “human factors” (HFs) refers to human interactions within a work system. It is a system which has a specific purpose and goals and to reach those various actions are done and resources utilized. For example, oil refinery or any other workplace is a work system. Within that system humans interact with each other and with various elements such as organizational and environmental context, work tools, equipment and tasks. Human factors influence the system during its whole lifecycle from design to operating and decommissioning. Humans have their personal limitations and varied capabilities, which should be considered otherwise safety and performance may be jeopardized. (Edmonds, et al., 2016, 4-5, 11.) Human factor aspects in chemical and process industries and common concepts of human error are introduced in Chapters 2.2 and 2.3.

Structured human factors assessment and management approaches decrease the possibility of accidents. Since human factors have contribution to 80% of accidents in the chemical and process industries (Edmonds, et al., 2016, 37), examining them is reasonable and brings value to the company by preventing damage to the human health or equipment and preventing standstills in the production. The benefits of human factor management are summarized in Chapter 2.4.

2.1 Brief history of human factors and ergonomics

Before the research and applications of human factors aspects, the study of humans in work systems was called ergonomics. A polish scientist called Jastrzebowski introduced the term (Hendrickson Parker, 2015, 390; Karwowski, 2001, 21) in 1857. He published a treatise called “An outline of Ergonomics, or the Science of Work Based Upon the Truths Drawn from the Science of Nature” (Karwowski, 2001, 21). With the early applications of ergonomics, the focus was on physical work and human interactions within it. Early research stated that industrial workers might face unnecessary safety hazards in work or might not be maximally productive because of incongruity between human capabilities and the work design. (Hendrickson Parker, 2015, 390- 391.)

In the early nineteen-hundreds industrial engineers Lillian and Frank Gilbreth were trying to reduce human error in medicine, specifically mistakes in the operating room with the use of callbacks. The surgeon and the assistant communicated by verifying actions. Surgeon requested scalpel and the assistant repeated “scalpel” when handed it over. Similar verification is in use in aviation nowadays. (FAA Safety Team Central Florida, 2012.)

Albeit originally the study of humans within a work system was focused on improving human performance related to physical work, the nature of work has changed and nowadays the focus is broader. There is a wide variety of computer technology and automation equipment within work systems. Nevertheless, even nowadays there are physical ergonomists which focus on the work design and how it relates to aspects such as physical strains, slips and falls. Beside ergonomics, nowadays there is study of human factors. The focus is on aspects such as cognitive functions, social conditions, social dynamics and context of work related to human performance. (Hendrickson Parker, 2015, 391.)

The research interest regarding human factors originates around the time of the First World War. Military leaders hired psychologist to develop tests which could assign soldiers to tasks which fit their qualities. Industrialists such as Frederick Winslow Taylor also considered human factors. He realized that the end-user must be considered when designing complex products such as cars. During the World War two the US military started to research ways to decrease human errors in their operations. (Hendrickson Parker, 2015, 391.) The military in multiple countries started to realize that many operational and training accidents happened because of human errors. For example, in the air force the mistakes were often caused by a poor cock-pit layout, controls and displays. These were not standardized therefore there was variability in design. Maintenance aspects were also neglected in the design. This resulted in poor maintainability. (FAA Safety Team Central Florida, 2012.)

Certain disastrous accidents have shifted the onlook and gained huge attention to human factors in industry (Hendrickson Parker, 2015, 391- 392). Multiple serious industrial accidents happened during the 1970s and 1980s. One common factor between those accidents was that people were doing something they should not have done, non-intentionally or intentionally. Safety critical industries started to become aware that to support safety management, behavioral and cultural aspects should be considered. (Edmonds, et al., 2016, 27.)

One widely known safety incident was Tree Mile Island (Pennsylvania) nuclear power plant accident in 1979 (Hendrickson Parker, 2015, 391- 392). The power plant had partial meltdown resulting in leakage of iodine and radioactive gases to the environment. This caused health risks to the local residents. The incident was a result of technical and human failures. A relief valve got stuck which allowed coolant to escape. The staff failed to diagnose the technical failure due to ambiguous control room display, which falsely indicated that the valve was closed. At a later phase, the operators had a tunnel vision, which caused them to ignore all the information which indicated that their assumption on the valve position was wrong. Automatic cooling system set off but was overridden by the operators. The personnel of the next shift were able to correctly diagnose the situation, but it was too late to prevent the meltdown. (Edmonds, et al., 2016, 29.)

Several human factor issues were identified, such as: unsafe supervision, poor control room design, complexity issues related to critical control loops (Hendrickson Parker, 2015, 391-392), insufficient training and deficiency in procedures (Edmonds, et al., 2016, 33). Even though a huge catastrophe did not happen, the incident altered the perception regarding the impact of human factors in nuclear safety. Before mentioned human factor aspects were considered when new nuclear power plants were designed after the accident. (Hendrickson Parker, 2015, 392.)

A more recent, infamous and thoroughly studied industrial accident happened in BP Texas City refinery in March 2005. There was an explosion during the start-up of an isomerization unit. 15 people died and 180 others were injured. The accident also caused a markable damage to the plant and the surroundings. Overfilling the raffinate splitter tower started the incorrect action sequence which caused the accident. Operators decided to open pressure vessels and by doing that they released flammable liquid from a flareless blowdown stack. The flammable liquid formed a hydrocarbon vapor cloud which exploded. The operators were fixated on pressure release and failed to consider why there was a pressure spike in the first place. In other words, they focused on the symptom, and failed to diagnose the reason. (Edmonds, et al., 2016, 30, 111.)

The BP Texan refinery case involved an alarming number of human factors. The operators were very fatigued since some of them had worked up to 30 days in 12-hour shifts. The control room indicators were insufficient. There were no clear indication of fluid flows and the level transmitter was not calibrated. The field operators could not visually observe the level of liquid since the seeing glass was dirty. There was lack of supervision at the time since the duty supervisor decided to leave the site at the morning of the accident and there was no substitute. This was a violation or rules since BP had a requirement that duty supervisor must be at the site during start-ups. The site had poor procedures and lack of training which was a contributing factor on why the operators failed to recover the situation. The real hazards of the start-ups were not understood. There had been changes in the organization and the management of change was poor. As a result of too drastic staffing cuts there was excessive workload for the remaining staff. Additionally, there was poor safety culture and leadership at higher level of the organization. (Edmonds, et al., 2016, 111, 138.)

2.2 Human factors in chemical and process industries

Chemical and process industries include petrochemicals, paper production, refining, chemical production, gas and oil processing, pharmaceuticals, plastic production, power generation, mining, drink and food industry, wastewater purification and water production (Edmonds, et al., 2016, 13).

Work systems in before mentioned industries handle large quantities of potentially dangerous chemicals and materials, which go through processes that include physical changes and chemical reactions. These industrial processes have predictable and emergent properties (unpredictable). Failures in operations can have life-altering or even catastrophic consequences. The most common injury a worker gets is musculoskeletal disorder such as strains and back injuries. They account for 30-46% work injuries in European Union area. Mental health related disorders such as anxiety and sleeping disorders are the second most common category of work-related impairment (caused by excess stress). (Edmonds, et al., 2016, 13-14, 36.)

Safety hazards and risk factors within these industries include:

- Mechanical hazards (such as moving machine parts, danger of crushing/ clinging)
- Biological, chemical, and radiation hazards (risk of causing contagion, cancer, death)
- Different atmospheric pressures and altitudes
- Outdoor climate conditions
- Extreme temperatures
- Lack of oxygen (for example in certain process tanks)
- Toxic, explosive and flammable substances
- Motion and vibration
- Noise (causing hearing impairment)
- Psychosocial hazards (fatigue, stress, unfriendly working environment)
- Repetition, duration, force (for example rotation motions, lifting heavy objects) and posture related strain (stationary working position, unergonomic working positions). (Edmonds, et al., 2016, 35-36)

The United Kingdom's Health and Safety Executive have defined HSE's top 10 relevant human factors issues within high hazard industries. This list includes topics which are presented in the Figure 2. (Edmonds, et al., 2016, 62.)

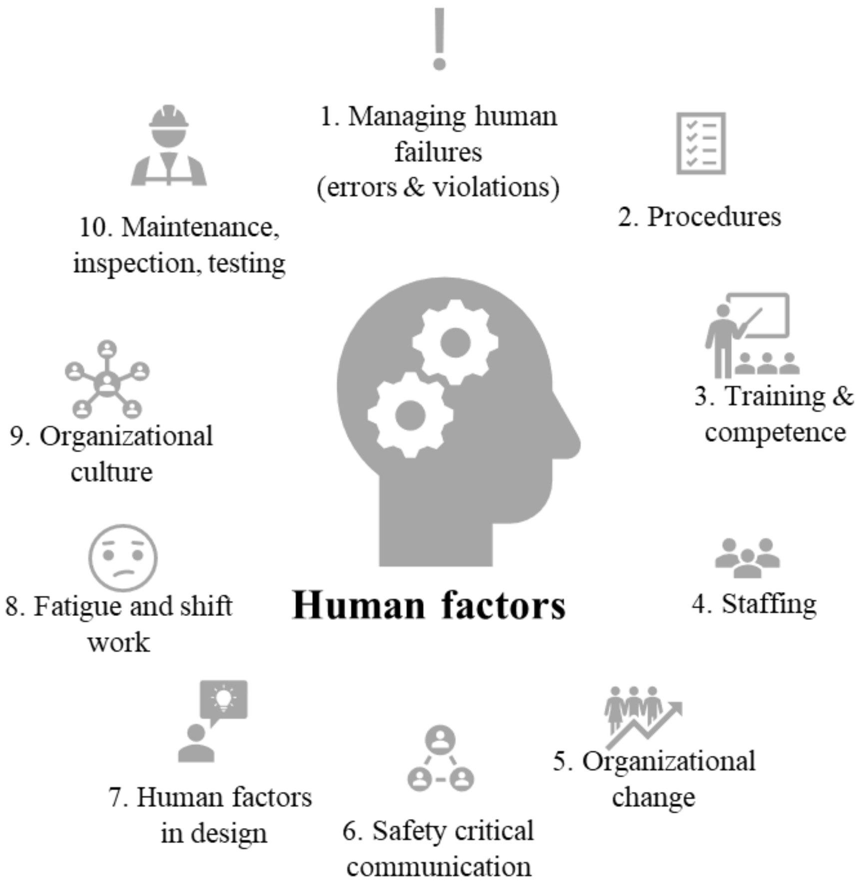


Figure 2 HSE's Top 10 human factor aspects in high hazard industries (modified Edmonds, et al., 2016, 63)

The top 10 human factors aspects are:

1 Structured examination of human failures in risk assessment, design and incident investigation.

2 Making sure procedures are user-friendly to avoid human errors.

3 Staff and contractors should be competent and well trained so they can perform up to standards/ requirements.

4 Staffing should be well managed to ensure that: there is right amount of competent staff and contractors performing work tasks, the workload of staff is manageable and there are right number of competent supervisors.

5 Human aspects of organizational change should be addressed appropriately to ensure safety in operations.

6 It is important to make sure safety critical communication is done effectively and adequately within the organization for example during shift and task handovers.

7 Considering the effects of human factors should be integral part of design processes. Designers should consider ergonomic design of control rooms, alarm systems, control systems and the working environment.
8 Fatigue Risk Management prevents fatigue-related impairment, mitigates the effects and reduces the likelihood of human errors.
9 Organizational culture is an important aspect to consider. Within an organization themes such as behavioral safety and learning organization should be reinforced. There are behavioral based programs which target critical behaviors. Within the organization a “chronic unease” should exist. In other words, there should be always goals to improve, learn and detect areas of improvement.
10 There should be structured approach to manage maintenance, inspection and testing to decrease the likelihood of human errors occurring. (Edmonds, et al., 2016, 63.)

2.3 Common concepts about human failures

As stated in chapter 2.2, human factors include multiple aspects. Human failures are only one part of the whole, but since many evaluation methods investigate them, some basic concepts have been described in this chapter.

Errors are unintentional failures. Person wants to do the right thing but makes an error of judgement. Certain factors/ conditions increase the possibility that humans make errors (performance shaping factors (PSFs)). PSFs are factors that disturb conducting a task and increase the likelihood of errors. PSFs are for example fatigue, poor lighting, rush, stress, lack or training, poor ergonomics, personal factors or poor quality of teamwork. Even though performance shaping factors affect the person’s performance, the root cause of the failure originates from cognitive functions (a person fails to make the correct judgment of the situation). (Edmonds, et al., 2016, 95.)

Intentional noncompliance means that a person breaks the rules knowingly. There are exceptional, situational, routine and malicious violations. Exceptional violation is for example when a person conducts a noncompliant act to save a situation or co-worker under exceptional circumstances. Situational noncompliance occurs when a person believes he/ she cannot obey the rules in the current situation and perform well. For example, the person might take away some mandatory safety gear to work faster. Routine violation is in question when people break the rules because it has become a habit in the work community. In most cases people did not expect any adverse impacts to themselves, co-workers or the workplace as a result of the violations. There is one exception: sabotage (also called as malicious violation). Acts of sabotage mean that an individual chooses to disobey rules while knowing that his/her actions causes damage. The motivation to do violations can be to gain personal benefit (for example doing work task faster without the proper safety gear) or organizational benefit (for example helping to keep production on target). (Edmonds, et al., 2016, 95-96.)

Jens Rasmussen developed a Skill-Rule-Knowledge (SRK) framework in 1983. According to that framework various tasks require different levels of cognitive effort. A person operates in a skills-based performance mode when she/ he is completing well-exercised physical actions in familiar environment or situation. Only little cognitive effort is needed. These actions require only little concentration and are conducted subconsciously (for example turning a valve). Skill-based errors potentially occur when the worker becomes overconfident and complacent of the task and the risks that are involved. The errors a person makes when performing in a skill-based mode are lapses in memory (failing to remember correct sequence to push buttons), slips of action (for example pushing a wrong button), and failures sensing basic information (for example failure to detect an important label). (Edmonds, et al., 2016, 98-99.)

A person works in a rules-based performance mode when she/ he needs to apply rules (memorized or written) to manage a situation which includes familiar problems. In this operation mode more complex cognitive processing is needed than in the skill-based mode. The situation is handled based on know-how of which procedures should be used. The errors in this mode can be due misinterpretation or cognitive bias. The operator/ worker makes and incorrect decision about which rules to apply or misunderstands the rules. Cognitive bias occurs when a person restricts the information based on which they will make decisions. For example, a person might rely too heavily on some “strong rules” that were helpful in the past. (Edmonds, et al., 2016, 99, 106.)

Work tasks that require knowledge-based performance mode are conducted being completely conscious. The tasks are not simple routine tasks but complex, require expertise or are unfamiliar. The highest level of cognitive effort is needed. A person is operating in a knowledge-based mode when he/ she starts to conduct an unfamiliar work task or experienced employees are working with a complex task and unplanned situations occur. A person must put high level of attention to what he/ she is doing and if there is excess stress, the performance is very likely negatively affected. The types of typical errors are: memory error such as failing to recall previous situation correctly; decision error such as failing to make the wright decision on how to handle a situation due to incomplete information or lack of knowledge; and sensory error such as failing to read and important equipment label. (Edmonds, et al., 2016, 99, 106.)

Performance, which requires high levels of cognitive processing are vulnerable to cognitive biases called confirmation and availability bias. Availability bias means that person only regards the information of which he/ she has the most vivid memories and do not consider all necessary aspects. Confirmation bias makes a person to utilize only the pieces of information that fit his/ her pattern of thinking and disregards the information which might indicate that the decision is a wrong one. (Edmonds, et al., 2016, 110.)

2.4 The benefits of human factors management in a nutshell

Human factors are significant contributing factors in unsafe operation therefore managing them is an important means to preventing accidents (Xie & Guo, 2018, 1). Approximately 80% of all incidents in chemical and process industries include human failures (Edmonds, et al., 2016, 37). Managing human factor aspects within an organization reduces errors and improves communication, reduces work related injuries and sick leaves (lower medical costs), increases employee satisfaction and ensures balanced workloads. Human factor management aims to ensure that the work procedures and policies of the organization are compatible with human capabilities, training is sufficient, the workforce is competent and there is enough spare capacity to deal with emergency situations. The overall productivity and quality of work will likely rise, absenteeism and labour turnover will decrease. (Gallimore, 2014, 6, 47.) Efficient safety management including the consideration of human factors can save the company money, preserve a good company image and allows continued existence (authorities will not have to intervene). (UK Health and Safety Executive, 2020.)

3 HUMAN FACTOR MANAGEMENT METHOD REVIEW

In this chapter the literary review of human factor management methods is presented (qualitative content analysis of selected references). The following are described: The phases of the analysis (chapter 3.1), the process of the materials search (chapter 3.2), categorizing human factors management methods (chapter 3.3), introducing the selected method categories and promising methods within them (chapters 3.4-3.10). There is further analysis regarding human factor management methods in the service design section, in Chapters 4.3 and 4.4. Summary table of thirty selected methods is in Appendix II.

3.1 The phases of the analysis

The main goals of this thesis were to map out human factor management methods and find suitable ones for HSE engineering work. The process of the method review is described below.

1) The first step in the qualitative analysis process was finding suitable materials (see chapter 3.2).

2) Second step in the analysis was to answer the research question 1: What kind of human factors management methods there are? This was done by going through the selected references and gathering all the methods into a table (Appendix I).

3) Third step was to find common denominators and similarities within the materials and categorizing the methods. The results can be seen from Appendix I and chapter 3.3.

4) After the step 2 there were abundant number of methods gathered so the amount had to be decreased. Thirty methods were selected to be examined more closely. At this point the emphasis was on methods which evaluate human error/ failure in industrial process tasks, safety culture, well-being and human factors in occupational safety. Basic descriptions of the selected methods categories were written (Chapters 3.4-3.10), a summary table (Appendix II: Table 18) was made and illustrative figures were created (Appendix II: Figure 18 and Figure 19).

3.2 The process of material search

The preliminary timeframe of the material search was 2010-2019. The timeframe had to be extended for physical book search to 2000-2019 because of scarcity of result. 2000-2019 resulted in three eligible books of which one was chosen to be analyzed. The timeframe for e-book and e-article search had to be narrowed down to 2015-2019 because there was plentitude of search results within the original timeframe. As a result of the e-material search four relevant e-books and seven relevant scientific articles were chosen for the analysis.

Books and e-books were searched from the LUT Finna Academic Library's collections and e-articles were searched from LUT Finna international e-materials. The relevancy of the source was first examined reading the title, abstract and table of contents. Additional elimination was done based on further examination of the material (skimming the whole text).

The search phrases for book, e-book and scientific article search are presented in Table 1. Search term for e-book and book search was "any field" and for e-articles it was "title". The initial search of e-articles with the nine search phrases using term "any field" resulted in too much search results for manual examination (over 2 million) so the search had to be narrowed down to "title". Additionally, e-article search had terms "whole text available" and "peer reviewed".

Table 1 Search phrases

No	Search phrase
1	Human factors
2	Human factors engineering
3	Human factors risk assessment
4	Human factors safety
5	Human factors evaluation
6	Human factors management methods
7	Human factors safety management
8	Human factors chemical process industry
9	Health and safety human factors

E-book search with the search words resulted in total of 1072 electronic books, of which 8 were preliminary evaluated to be relevant based on title, abstract or contents. These books were related to HSE engineering work (process safety) and included mentions of human factors management. Further elimination was done based on skimming the whole text. The e-book should contain descriptions of human factors management methods that are related to occupational safety and can be applied to chemical and process industries. Based on closer examination four e-books were chosen for analysis (Table 2). In Table 2 e-book titles are presented in the column which is third from the left. Left column expresses an individual code for each reference. The right column presents search phrases which resulted in this specific e-book. Many of the search phrases resulted in similar search results.

When searching physical books with the nine search phrases, the result was total of 52 books of which three were relevant regarding the thesis topic and available for lending within reasonable time period. Ultimately only the newest one of these books was chosen for analysis (Table 2: Stanton, et al., 2013) This was because there were plenty of more current material available in electronic form so there was no need for including over 10 years old books to the analysis.

Table 2 Book and e-book search results

Code	Reference	Title	Search phrases
B1	Stanton, et al., 2013	Human Factors Methods: A Practical Guide for Engineering and Design	1, 2
EB1	Edmonds, et al., 2016	Human Factors in the Chemical and Process Industries: Making it Work in Practice	1, 2, 4, 7, 8, 9
EB2	De Felice & Petrillo, 2018	Human Factors and Reliability Engineering for Safety and Security in Critical Infrastructures: Decision Making, Theory, and Practice	1, 2, 3, 4, 7
EB3	Mannan, 2014	Lees' Process Safety Essentials: Hazard Identification, Assessment and Control	1, 2, 3, 4, 7, 8
EB4	Pasman, 2015	Risk Analysis and Control for Industrial Processes - Gas, Oil and Chemicals: A System Perspective for Assessing and Avoiding Low-Probability, High-Consequence Events	1, 2, 3, 4, 5, 6, 7, 8, 9

*B refers to book, EB refers to electronic book

For the electronic scientific article search the search phrase 1 (“human factors”) was too wide and produced 6350 results. This was too much for manual examination, so this search phrase was ruled out. Search phrase 6 (“human factors management methods”) gained zero hits so it was modified to “human factors management”. Phrase 8 (“human factors chemical process industry”) had zero results and it was modified to “human factors chemical”. Other search phrases were in the same form than in Table 1. There were 706 results of which of which 34 were preliminary evaluated to be relevant based on title, abstract or contents. Seven articles were chosen for analysis based on closer examination of the contents (Table 3).

Table 3 Electronic article search

Code	Author, year	Title	Search phrases
EA1	Banick & Wei, 2016	Application of human factors evaluation in engineering design and safe operation of dense phase ethylene treaters	2, 5
EA2	Kaber & Za-habi, 2017	Enhanced Hazard Analysis and Risk Assessment for Human-in-the-Loop Systems	3
EA3	Laumann & Rasmussen, 2016	Suggested improvements to the definitions of Standardized Plant Analysis of Risk-Human Reliability Analysis (SPAR-H) performance shaping factors, their levels and multipliers and the nominal tasks	2, 4
EA4	Mcleod, 2017	Human factors in barrier management: Hard truths and challenges	4, 6, 7
EA5	Naikar, 2017	Cognitive work analysis: An influential legacy extending beyond human factors and engineering	2
EA6	Theophilus, et al., 2017	Human Factors Analysis and Classification System for the Oil and Gas Industry (HFACS-OGI)	2,4
EA7	Xie & Guo, 2018	Human factors risk assessment and management: Process safety in engineering	2, 3, 4, 6, 7

*EA refers to electronic (scientific) article

3.3 Categorizing the methods

The reference materials B1, EB1-EB4 and EA1-EA7 were analyzed and human factors management methods were extracted from the text. All the methods are listed in Appendix I: Table 17. The methods were divided into 19 categories (Figure 3). The categorizing of methods was done partly based on the titles found in the literature (such as “Task Analysis”) and partly based on the characteristics of the methods (for example “Diagrams” and “Novel methods”). Some of the methods could easily fit to several categories based on their characteristics. For example, HF-FMEA is placed in “Novel methods” category, because it is a relatively new approach which has been developed based on established process safety analysis method FMEA. But it could be also placed under “Other Human Reliability Analyses” category.

Figure 3 Human Factor Management method categories

Most promising categories were chosen and within those categories few methods were selected for closer examination. Nine chosen categories were:

- Accident analyses (chapter 3.4)
- Diagrams (chapter 3.5)
- First generation human reliability analyses (HRA) (chapter 3.6)
- Second generation human reliability analyses (HRA) (chapter 3.7)
- Third generation human reliability analyses (HRA) (chapter 3.7)
- Human error identification (chapter 3.8)
- Management of safety culture and well-being (chapter 3.9)
- Task analyses (chapter 3.10)
- Task analyses: cognitive (chapter 3.10)

3.4 Accident analyses

Accident analysis can highlight key issues that need attention within a work system. The method is cost-effective because the data which is needed is already gathered. On the other hand, the quality of the data might vary. It may be incomplete or inconsistent. Accident analysis is often retrospective and, in some cases, does not represent the current safety culture (if the incident under examination happened very long time ago). (Edmonds, et al., 2016, 326-327.) There are numerous methods for accident analysis. In the sub-chapters 3.4.1 and 3.4.2 Human Factors Analysis and Classification System (HFACS-OGI) and Johnson's Management Oversight and Risk Tree (Johnson's MORT) are presented.

3.4.1 Human Factors Analysis and Classification System for Oil and Gas Industry (HFACS-OGI) and Reason's Swiss Cheese model

Reason's Swiss Cheese model is a layered model about causal factors that allow an accident to happen. These failures are active or latent in nature. Different factors are represented as a slice of cheese in which the holes represent permanent or temporary failures. When holes (failures) in different "cheese slices" (causal factors) line up, accident happens (Figure 4). There are active and latent failures. Latent failures rise from organizational preconditions such as too low competence of the workforce (insufficient training), time pressures, design mishaps, fallible decisions of top and line managers or poor working ergonomics. Latent preconditions may go unnoticed for years until it is too late. Active failures can be human unsafe acts such as failing to keep the process within safe operating conditions or physical failures such as sudden burst of a pressurized vessel. Reasons swiss cheese model have been built upon Jens Rasmussen's SRK framework (Skill-, rules- and knowledge-based failures causing slips, lapses and mistakes). (Pasman, 2015, 82.)

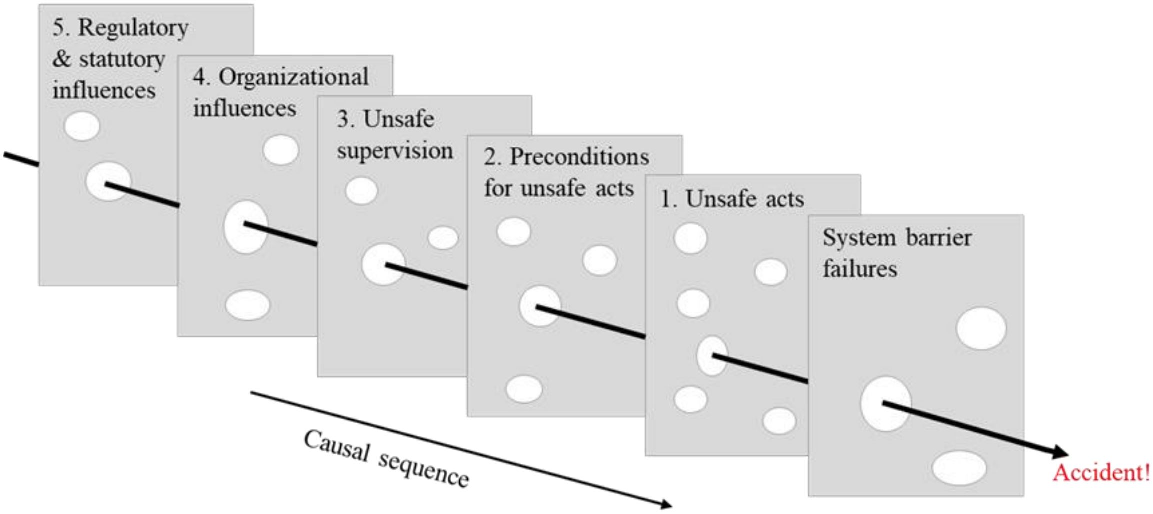


Figure 4 HFACS-OGI based on Reason's Swiss Cheese model (modified Pasman, 2015, 83; Theophilus, et al., 2017, 172-173)

Human Factors Analysis and Classification System is based on the Reason's Swiss Cheese model. Even though HFACS was developed for the aviation sector, with modifications it can be used also in other domains. One example is Human Factors Analysis and Classification System for Oil and Gas Industry (HFAGS-OGI). HFACS is widely used, established method whereas HFACS-OGI is a novel approach suggested by Theophilus, et al. (2017). HFACS can be also applied to maintenance with small modifications, as HFACS-ME (Stanton, et al., 2013, 218). According to Reason, accidents happen as a result of breakdowns in four core system levels: 4) organizational influences/ failures, 3) unsafe supervision, 2) preconditions for unsafe acts and 1) unsafe acts (Stanton, et al., 2013, 218; Theophilus, et al., 2017, 168).

HFACS is system approach which examines and determines deficiencies which have led to accidents. HFACS-OGI framework includes additional level 5, "Regulatory and statutory influences" and additional sub-categories compared to HFACS (marked with grey background in Table 4). The levels and categories which have white background in Table 4 are the ones which are included in the original aviation HFACS framework.

Table 4 HFACS-OGI levels and their sub-categories (modified Theophilus et al., 2017, 172-173)

Level	5. Regulatory & statutory influences	4. Organizational influences	3. Unsafe supervision	2. Preconditions for unsafe acts	1. Unsafe acts
Sub-categories	Industry standards	Organizational climate	Supervisory violations	Crew resource management	Perceptual errors
	National regulatory framework	Organizational process	Failed to correct a known problem	Physical/ mental limitations	Decision errors
		Resource management	Inadequate supervision	Adverse mental states	Skill-based errors
		Process safety culture	Planned inappropriate operations	Adverse physiological states	Routine violations
		Management of change		Technological environment	Exceptional violations
				Physical environment	Acts of sabotage
				Personal readiness	
				Contractor environment	

* The levels and categories which have a white background are included the original aviation HFACS framework.

**HFACS-OGI includes all the categories which are included in the original HFACS framework and also the categories which are marked with a grey background.

The analysis process starts with defining the task under examination (task analysis). The next phase is to collect data to gain understanding of the accident scenario. For example, relevant documents are gathered, and selected members of personnel are interviewed. After the task analysis and data collection the analysis process proceeds from level 1 to 4 in HFACS and from level 1 to 5 in HFACS-OGI. Unsafe acts are identified based on the gathered data (level 1). (Stanton, et al., 2013, 218-219.) Unsafe acts can be defined as any acts that deviate from safe practices and increase the likelihood of accident. The unsafe acts can be non-intentional or intentional. HFACS-OGI includes the sub-category “act of sabotage” which could for example be destroying equipment, contaminating fuel tanks on purpose or working unnecessarily slow with intent of decreasing the production. Sabotage is intentional act with purpose to make harm; violation is intentional deviation from procedure but there is no intent of making harm; and human errors are non-intentional slips, lapses or mistakes. (Theophilus, et al., 2017, 169.)

After the unsafe acts are determined, the analyst should categorize the failures that are preconditions for the unsafe acts (level 2). These preconditions include for example the physical and mental limitations of people, technological & physical environment in the workplace and mental states (Table 4). Additional sub-category on level 2 in HFACS-OGI compared to the original version of HFACS is contractor environment. The original HFACS only examines the technological and physical environmental factors in a single company but HFACS-OGI also examines the contractors of the before mentioned company. (Theophilus, et al., 2017, 170, 173.)

After the preconditions for the unsafe acts are identified, the erroneous actions in supervising are identified (level 3), the organizational failures (level 4) are determined and finally the analysis continues to the level 5 to determine related regulatory and statutory influences. Organizational failures are examined for example regarding resource management and organizational climate. Compared to original HFACS, the HFACS-OGI contains two additional sub-categories in level 4: "process safety culture" and "management of change". The management of change is for example related to changes in procedures, equipment or facility. The changes should be managed and communicated effectively to avoid increasing the likelihood of accidents. Process safety focuses potential on explosions, fires and leaks which could cause incidents. Companies that have specific process safety management system in use decrease the possibility of catastrophic accidents. (Theophilus, et al., 2017, 170-173.)

The advantages of HFACS are that it is relatively simple to use, it provides failure taxonomies for each analysis level, the taxonomy is comprehensive and considers all levels within a system and the framework is built on scientific theory of human error. There are also disadvantages. HFACS analysis is limited by the available data. Accident reports are often imperfect regarding detailed data and it limits the comprehensiveness of HFACS analysis. The definitions of the error taxonomy might cause misinterpretation, more specific definitions would be needed and the HFACS framework does not include the context of error. (Stanton, et al., 2013, 220.)

3.4.2 Johnson’s Management Oversight and Risk Tree (Johnson’s MORT)

Johnson’s Management Oversight and Risk Tree is an established, older (1975), method for accident analysis. It is comprehensive and detailed fault tree type of a method. The fault tree structure branches down from the top event all the way to the bottom until the basic fault events are reached. The aim of the method is to find failing mechanisms and controls which are leading to accidents. (Pasman, 2015, 94.)

The analysis includes examination of components which are less than adequate (LTA) and potentially allow accident to develop: organizational and technical management oversights, potentially harmful environmental conditions or energy flows, insufficient controls and barriers and exposure of vulnerable object and peoples. A complete Johnson’s MORT fault tree is large, often more than one square meter of paper is needed. There are parts of a Johnson’s MORT in Figure 5 and Figure 6. Figure 5 presents the top part which includes how management could have minimized risks. In Figure 6 there is the fault tree section which branches downwards from accident event (SA1). The same accident event (SA1) box is in the lower left corner of Figure 5. (Pasman, 2015, 94.)

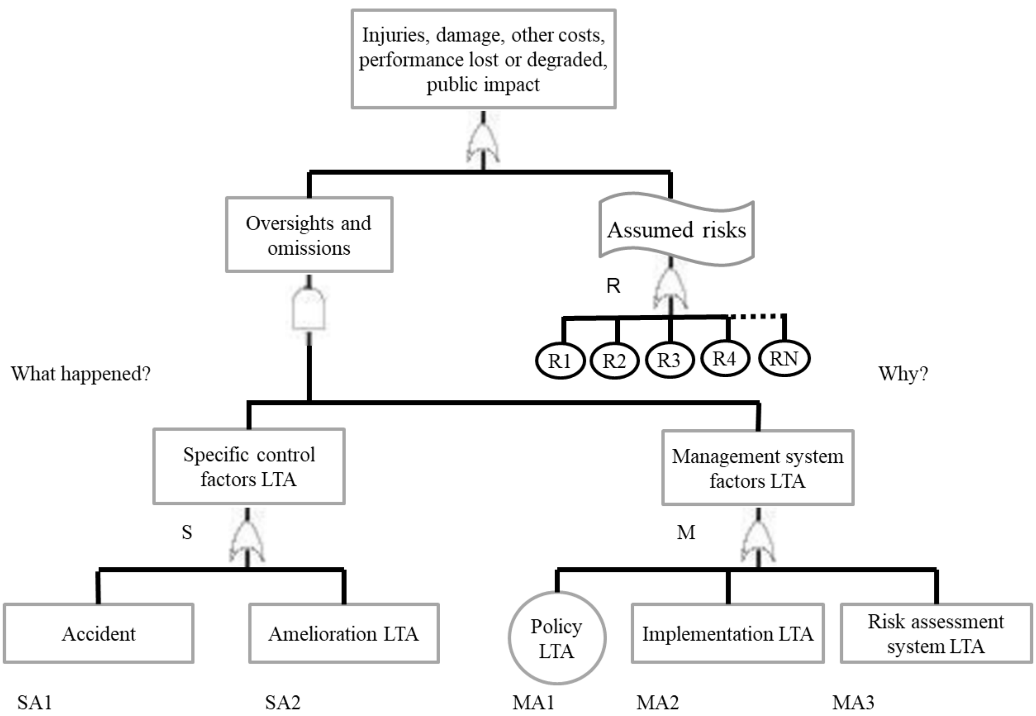


Figure 5 Top part of Johnson's MORT: management section (modified Pasman, 2015, 95)

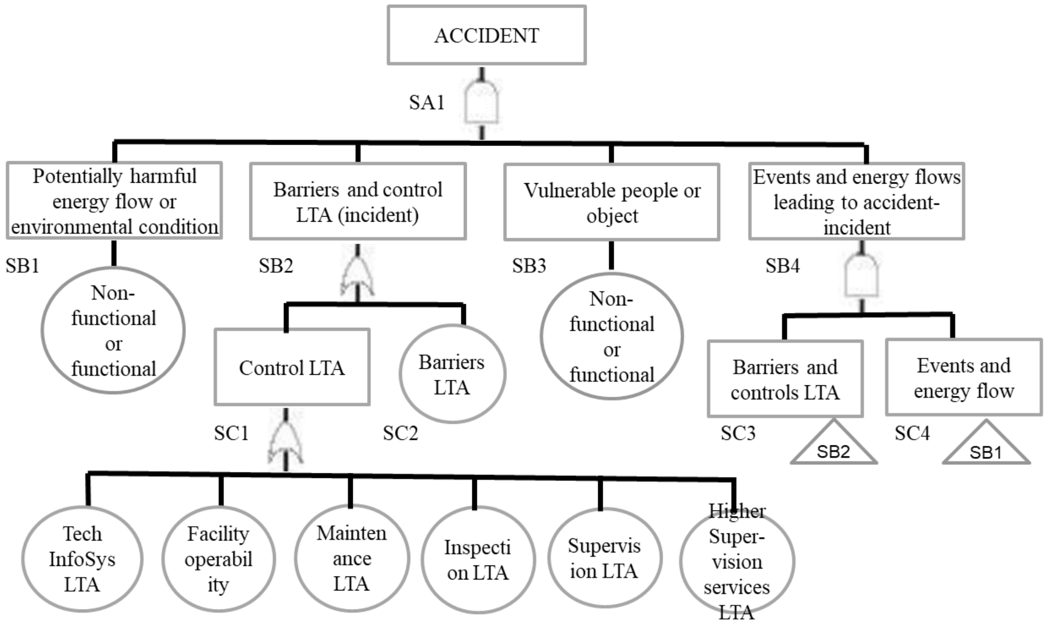


Figure 6 Johnson's MORT lower part: accident section (modified Pasman, 2015, 95)

MORT is an advanced approach for determining mechanisms that lead to accidents and identifying failing controls (Pasman, 2015, 94). MORT is a more detailed approach than a simple fault tree and it can be as a basis for a complete safety system (Mannan, 2014, 11). On the other hand, completing detailed MORT takes time and requires a large area of paper (minimum of one square meter). It can be difficult to showcase MORT results electronically because of the large size. If quick assessments are needed, a simpler fault tree approach would be more fitting. (Pasman, 2015, 94-95.)

3.5 Diagrams

Diagrams can be used to visualize processes or activities such as task sequences, task components and requirements. With diagrams the interrelations and different actions of humans and technical system elements within a work system can be analysed and presented. (Stanton, et al., 2013, 117.) In the sub-chapters 3.5.1-3.5.3 Bowtie diagram, Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) are introduced.

3.5.1 Bowtie diagram

In bowtie diagram a critical event is shown at the center of the diagram, the causes (threats) are shown at the left side (fault tree) and consequences at the right side (event tree) (Figure 7) (Edmonds, et al., 2016, 87). The fault tree identifies plausible causes to formation of the critical event. The event tree describes the events that may unfold after the critical event. (Mannan, 2014, 86.) Preventive and mitigating barriers can be included to the diagram (see Figure 7). Also, the potential failures of the preventive and mitigation barrier can be added. Human factors can be assessed with bowtie by determining the diagram components (controls, threats, barriers) from a human factor assessment perspective. (Edmonds, et al., 2016, 87-88.)

Bowties can become uncontrollable if too many details are considered. Additional task analysis is needed to further analyze specific aspects in detail. (Edmonds, et al., 2016, 86-87.) The bowtie diagram can be used to revise cause of accidents, building accident scenarios, identifying critical events and studying the effectiveness of the safety barriers (Mannan, 2014, 86).

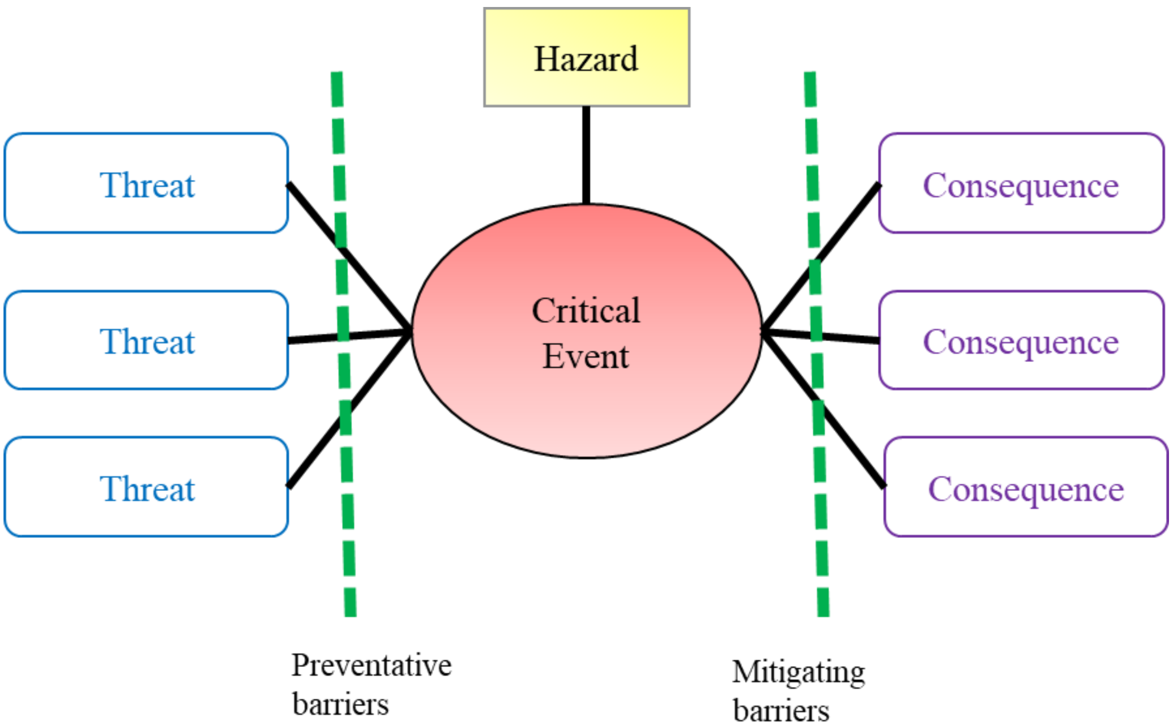


Figure 7 Bowtie diagram (modified Edmonds, et al., 2016, 87)

3.5.2 Event Tree Analysis (ETA)

Event Tree Analysis (ETA) is a tree-diagram which follows inductive logic (Pasman, 2015, 123). It is a task analysis technique. Certain task is taken under examination. Related operator task steps (nodes) and the outcomes (consequences) are determined and presented in the branches of the event tree. The outcomes can be divided into two categories: failure and success outcomes. ETA can be applied to consider human actions and their consequences. The analysis is conducted in six steps: 1) Define the scenario, 2) collect relevant data, 3) define all the task steps/ nodes, 4) define the possible actions for each step, 5) consider consequences for each action, 6) create the event tree diagram based on the information acquired during steps 1-5. (Stanton, et al., 2013, 130.)

Some benefits of this method are: ETA illustrates task sequences and their consequences; it pinpoints error paths and error potential in the system; ETA is relatively easy to use; it can be used in any phase of a project; and when conducted correctly, ETA can potentially predict anything that might cause problems in the system. There are also downsides such as: The method in impractical to use for analysis of complex system because it will become too resource intensive; and the method requires subjective judgements from the analyst. (Stanton, et al., 2013, 131.)

3.5.3 Fault Tree Analysis (FTA)

Fault tree is a tree-like diagram which illustrates failures and the causes of them within a system. Top failure event is placed on top of the fault tree. The diagram branches downwards and presents contributing events. FTA can be used in any stage of the system lifecycle, predicting or retrospectively examining failure events. FTA structure has AND and OR gates. The AND gate is used when multiple events cause a failure (all the linked causes must be on action). OR gate is used when there are multiple possible causes and failure happens if any one of them is on action. FTA has four phases: 1) top failure event definition, 2) failure event cause determination, 3) OR/ AND classification, 4) constructing the fault tree diagram. (Stanton, et al., 2013, 136-138.)

The advantages of the method are: the technique can be applied to any domain since it is generic; FTA can reveal weaknesses in a system and its design; the method can illustrate dynamic behavior of the system; the method can be used retrospectively and predictively; fault trees can be useful especially when examining failure events which have multiple causes. Some disadvantages are: The FTA method can become too resource-intensive if very large and complicated systems are examined; high level of training is needed to use the method quantitatively; there is not much evidence of their use outside nuclear domain. (Stanton, et al., 2013, 140.)

3.6 First generation human reliability analyses (HRA)

Human reliability analysis (HRA) examines the probability of a human to perform a task regarding the requirements. The common theoretical basis for most HRA first generation methods includes: SRK model, PSFs and error classification based on omission-commission model. Omission means failure to conduct an action. Commission means an unplanned or unintended action. First generation methods examine task components (each step needed to perform a work task) and changing factors such as stress and equipment design. Disadvantage of first-generation methods is that they do not consider the organisational factors, context and failures in commission. There are approximately 35-40 first-generation HRA methods, of which many are variations on a certain method. (De Felice & Petrillo, 2018, 20-22, 113.) Regarding De Felice & Petrillo (2018, 32), for example Empirical Technique to Estimate Operator's Error (TESEO) (Chapter 3.6.1) and Human Error Assessment and Reduction Technique (HEART) (Chapter 3.6.2) are applicable to chemical industry.

3.6.1 Empirical Technique to Estimate Operator's Error (TESEO)

Empirical Technique to Estimate Operator's Error (TESEO) is relatively straightforward method. With TESEO a numerical human error probability value can be estimated. This value is calculated for a certain task. Human error probability is determined through five factors: K1) the task type, K2) available to time do the task, K3) the level of experience and features of the operator, K4) the frame of mind of the operator and K5) ergonomic and environmental factors (Table 5). These five factors describe quantified performance shaping factors. HEP is calculated by multiplying all the determined factors: K1*K2*K3*K4*K5. (De Felice & Petrillo, 2018, 27-28.)

TESEO is a quick method compared to other HRA tools. It can also be used in sensitivity analysis, to recognize the effects of improving human factors. This method can be applied to many different kinds of procedures and control room designs. The method on the other hand does not give exhaustive results, since the level of detail is low. (De Felice & Petrillo, 2018, 28.)

Table 5 TESEO factors (modified De Felice & Petrillo, 2018, 29)

Factor	Description	Detail		Value
K1	Typological factor of the activity	Routine, sample		0.001
		Routine but requires attention		0.01
		Non-routine		0.1
K2	Available time	Activities which are routine	>20 s	0.5
			>10 s	1
			>2 s	10
		Activities which are non-routine	>60 s	0.1
			>45 s	0.3
			>30 s	1
			>3 s	10
K3	The qualities of the operator	Carefully selected, well trained, expert		0.5
		Average training and knowledge		1
		Poorly trained, little knowledge		3
K4	State of operator anxiety	Grave emergency		3
		Potential emergency		2
		Normal operation		1
K5	Environmental ergonomics factors	Excellent interface and microclimate		0.7
		Good interface and microclimate		1
		Discrete interface and microclimate		3
		Discrete microclimate, poor interface		7
		Worse microclimate, poor interface		11

3.6.2 Human Error Assessment and Reduction Technique (HEART)

Human Error Assessment and Reduction Technique (HEART) is a quantitative method which utilizes ergonomics literature-based error probabilities and 38 error producing conditions. There method divides operator tasks into eight categories: 1) Totally unfamiliar, 2) task related to system recovery or shift of state performed without supervision or procedures, 3) complicated task which demands high skill and comprehension levels, 4) relatively simple task which is conducted fast or given only low level of attention, 5) routine task which is well practised, 6) restoring a system according control procedures, 7) routine task which is well designed, well-practised and totally familiar and 8) operator gives a correct response to system commands even when there is an augmented or automated supervisory system. (De Felice & Petrillo, 2018, 32; Stanton, et al., 2013, 203-204.)

In HEART quantifying factors are used. The HEART evaluation process has five quantification elements: 1) tasks which are needed to do in order to complete the whole task are classified to one of the before mentioned general operator task categories, 2) human error probability value is assigned for the tasks, 3) the analyst considers which performance shaping factors potentially impact reliable performance of the task, 4) consider the proportion of the impact, 5) calculate human error probability for the whole task. (De Felice & Petrillo, 2018, 32-33.)

HEART has its positive sides, such as: it simplistic and quick approach; minimal training is needed to apply the technique; HEART gives an quantitative output; error producing conditions (EPCs) have remedial measures associated to them; the technique is less-resource intensive than for example SHERPA; there are validation study literature about the method with encouraging results. There are disadvantages such as: the method is very subjective which reduces its reliability; further validation of the method is still needed; dependency and EPC interaction are not considered in HEART and more instructions would be needed on how to assign performance shaping factors. (Stanton, et al., 2013, 205.)

3.7 Second and third generation human reliability analyses (HRA)

Second-generation HRA methods try to correct some weaknesses of first-generation methods. They extend error classification from binary omission-commission model to recognizing cognitive errors. Second generation methods include probable and possible operator decision paths. These decision paths and mental processes are based on cognitive psychology. Human-machine interactions are considered as dynamic and models of human information processing are included. Second generation methods include cognitive models such as Stimulate-Organism-Reaction (S-O-R) paradigm and cognitive viewpoint. S-O-R paradigm argues that stimulus acts upon organism which produces a reaction. Cognitive viewpoint model argues that cognition is active (not reactive) and cognitive activities are not sequential, they are cyclical. (De Felice & Petrillo, 2018, 32.) Three second generation human reliability assessment methods are presented: A Technique for Human Error Analysis (ATHEANA) (chapter 3.7.1), Cognitive Reliability and Error Analysis (CREAM) (Chapter 3.7.2) and Standardised Plant Analysis Risk–Human Reliability Analysis (SPAR-H) (Chapter 3.7.3).

First- and second-generation human reliability analysis methods are found to a large extent in static task analysis of operational events. Third generation HRA methods include simulation-based approaches of dynamic modelling systems. Dynamic methods can complement older HRA approaches for example by computing performance shaping factor levels to examine human error probability at any given point in time. One of the third-generation frameworks, Systematic Human Error Reduction and Prediction Approach (SHERPA) is presented in Chapter 3.7.4. (De Felice & Petrillo, 2018, 37.)

3.7.1 A Technique for Human Error Analysis (ATHEANA)

A Technique for Human Error Analysis (ATHEANA) can be used for prospective or retrospective analysis. Regarding ATHEANA framework the formation of human error is influenced by combination of performance shaping factors, dependencies and the plant state. The framework considers also organizational and environmental factors. ATHEANA consist following steps (also in Figure 8): 1) Describe and clarify the issue, 2) Set the scope of the analysis, 3) Define the baseline scenario: what is the initiating event, and which norm of operations, procedures and actions are needed, 4) describe the unsafe actions (UAs) and/ or human failure events (HFEs) that might influence the task, 5) evaluate the operator’s knowledge level and his/ her competence of finding potential operational vulnerabilities, 6) examine the base scenario in order to find deviations within which unsafe acts are likely, 7) identify and assess links to performance shaping factors and complicating factors (error forcing conditions EFCs), 8) recovery potential assessment, 9) human factors error probability quantification, 10) Incorporate ATHEANA results into the Probabilistic Risk Assessment (PRA) (De Felice & Petrillo, 2018, 32-33.)

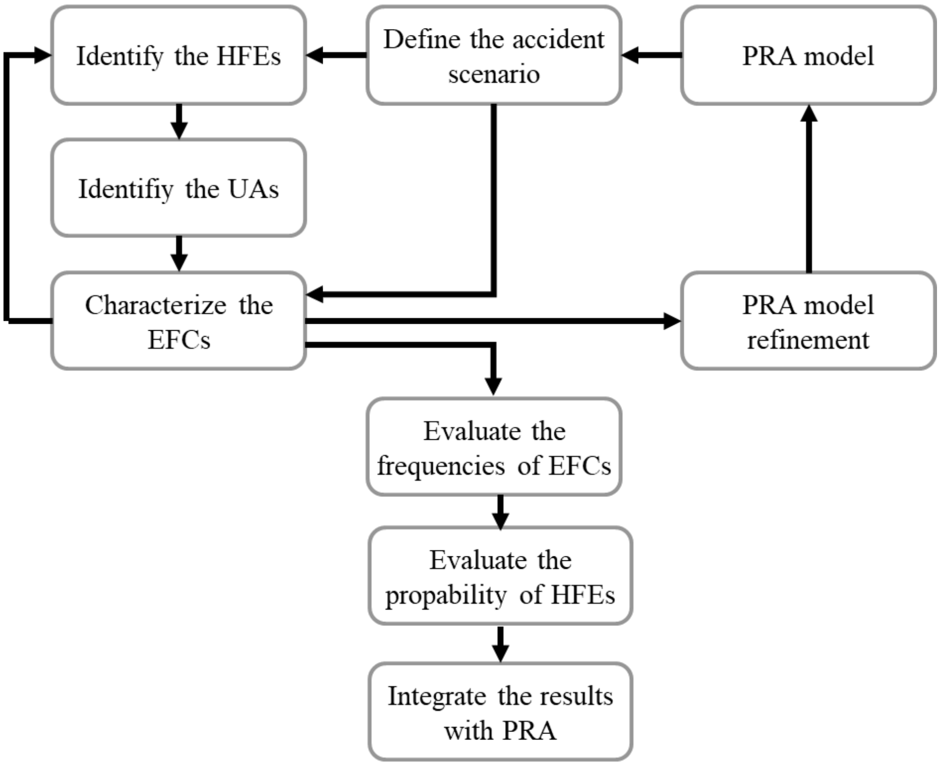


Figure 8 The evaluation process of ATHEANA (modified De Felice & Petrillo, 2018, 34)

This method has certain advantages. Compared to first generation Human Reliability Analysis methods, ATHEANA delivers more complete picture about the human factors which cause incidents. ATHEANA also provides insights about the context. The method considers broad selection of performance shaping factors. The PSFs do not have to be treated as independent, the method aims to identify interactions amongst them. Weighing is done regarding how much certain PSF affects a situation. Some disadvantages: The method is arduous, and the application demands a big team. Reliability of ATHEANA is questionable, since the method is not described detailed enough, there is no certainty that different analyst groups will surely reach the same results. (De Felice & Petrillo, 2018, 3.)

3.7.2 Cognitive Reliability and Error Analysis (CREAM)

Cognitive Reliability and Error Analysis (CREAM) is built on contextual control model “CoCoM” which comprises four cognitive functions from 1) making observations and 2) interpretations to 3) planning an action and 4) executing it. There are two types of errors in this model: 1) non-observational errors (occurs in thought processes) and 2) observational errors (also called as phenotypes, they have external manifestation). Non-observational errors lead to phenotypes through transformation of cause to effect. (De Felice & Petrillo, 2018, 34.)

In addition to phenotypes, there are three different types of genotypes (causes of erroneous actions): individual-related, technology-related and organisation-related. Error modes can be classified as follows: 1) wrong timing: too late/ early, omission 2) too long/ short duration, 3) reversal/ repetition/ intrusion/ commission of sequence, 4) wrong object/ action, 5) too much/ too little force, 6) wrong direction, 7) too short/ far, 8) too fast/ slow. (Stanton, et al., 2013, 207). Third aspect of CoCoM are the CREAM common performance conditions CPCs: 1) organizational sufficiency, 2) the factors related to work environment conditions, 3) sufficiency of operational support and man-machine interface (MMI), 4) the availability of plans and procedures, 5) quantity of concurrent goals, 6) time available for performing a task, 7) what time of the day is at the moment, 8) sufficiency of training, 9) the quality of preparation and staffing. The general steps of CREAM are: 1) conduct a task analysis, 2) determine the context, 3) definition of initiating events, 4) determining controls (Kaber & Zahabi, 2017, 863), 5) error prediction, 6) selection of task steps for quantification and 7) quantitative performance prediction (Stanton, et al, 2013, 209). CREAM method was originally used in the nuclear power sector, but it is possible to apply it to any field of operation which includes dynamic, complex systems (De Felice & Petrillo, 2018, 34-35; Stanton, et al., 2013, 208).

Advantages of CREAM are: it can be used proactively (preventing accidents) and retrospectively (analysing error occurrence); the method is generic (suitable for different domains); context, sociotechnical and environmental aspects are considered; the method has potential to be very thorough; CREAM is clear, systematic and structured method or error identification and quantification. Disadvantages are: the method is resource intensive; to unexperienced analyst the method is complicated to use, considerable amount of time is needed for training the analyst and application of the method, the analyst would require expertise of human factors and cognitive ergonomics. (Stanton, et al., 2013, 208, 210.)

3.7.3 Standardized Plant Analysis Risk–Human Reliability Analysis (SPAR-H)

Standardized Plant Analysis Risk–Human Reliability Analysis (SPAR-H) assesses human cognitive processing during a failure. There are four categories: detection, understanding, making decisions and conducting an action. (De Felice & Petrillo, 2018, 36-37.) SPAR-H is less-detailed derivate of HEART (Pasman, 2015, 255). Human activity is classified into two main task categories: action (operating equipment, starting pumps) and diagnosis (determining appropriate courses of action). SPAR-H framework includes five steps: 1) errors are divided into action and diagnosis failures, 2) consideration of context with relevant PSFs and determining a base-case human error probability with dependency assignment, 3) assigning appropriate value of the PSF by using the previously determined base-case human error probabilities and performance shaping factors, 4) conducting uncertainty analysis with beta distribution, 5) in order to ensure analyst consistency: evaluator uses designated worksheets. (De Felice & Petrillo, 2018, 36.)

There are eight categories of performance shaping factors within SPAR-H theoretical framework: 1) available time, 2) stressors and stress, 3) working experience and training, 4) intricacy of a task, 5) ergonomic factors, 6) procedure-related factors, 7) fitness for work and 8) processes within the work system (De Felice & Petrillo, 2018, 36-37).

The benefit of SPAR-H is that it addresses both the error producing properties and beneficial influences of PSFs. These beneficial influences can in some cases reduce failure rates. Other advantage is that this method has a sound theoretical background. The information processing model of SPAR-H is based on behavioural science research literature. On the downside, the method requires subjective judgement which can affect the reliability. Different analysts might get different results. (De Felice & Petrillo, 2018, 36-37.)

3.7.4 Systematic Human Error Reduction and Prediction Approach (SHERPA)

Systematic Human Error Reduction and Prediction Approach is a human error identification method with error mode taxonomy which is based on behavioural science literature (Stanton, et al., 2013, 151). SHERPA is a qualitative analysis approach (Edmonds, et al., 2016, 77). SHERPA process has eight steps: 1) Hierarchical Task Analysis, 2) Task Classification, 3) Human Error Identification, 4) Consequence Analysis, 5) Recovery Analysis, 6) Ordinal Probability Analysis, 7) Criticality Analysis, 8) Remedy Analysis. SHERPA error taxonomy includes five types of errors: checking, retrieval, action, selection, communication. Each category has several guidewords (Table 6). (Stanton, et al., 2013, 152-153.)

Table 6 SHERPA error mode taxonomy (modified Stanton, et al., 2013, 152)

Error category	Error mode taxonomy
Checking	C1 Omitted check, C2 Incomplete check, C3 Right check on wrong object, C4 Wrong check on right object, C5 Mistimed check, C6 Wrong check on wrong object
Retrieval	R1 Information not obtained, R2 Wrong information obtained, R3 Incomplete information retrieval
Action	A1 Too short/ long operation, A2 Mistimed operation, A3 Operation in wrong direction, A4 Operation too little/ too much, A5 Misalign, A6 Right operation on wrong object, A7 Wrong operation on right object, A8 Omitted operation, A9 Incomplete operation, A10 Wrong operation on wrong object
Selection	S1 Omitted selection, S2 Wrong selection made
Communication	I1 Information not communicated, I2 Wrong information communicated, I3 Incomplete information communication

The advantages of SHERPA: it offers a comprehensive (exhaustive) and structured framework for human error prediction; there is encouraging reliability and validity data available; it can be applied to multiple domains because it is generic; it can be applied using pen and paper (or with usual office software); SHERPA error taxonomy steer the analyst regarding potential errors and the analysis is fairly quick to learn and conduct. There are shortcomings such as: SHERPA becomes resource-intensive to apply for complicated scenarios; it is a subjective method based on analyst’s expertise; and the framework lack the consideration of the organizational errors, contextual factors and the cognitive element of errors. (Stanton, et al., 2013, 153, 156.)

3.8 Human error identification

Human error is a remarkable factor in major portion of incidents which happen in complex systems. Human error identification methods are used to identify human errors within dynamic systems which include human-human and human-machine interactions. The analysis describes the error, contributing factors, the consequences of the errors and recovery remedies. The results of the analysis can be used to propose measures to minimize the possibility of human errors. (Stanton, et al., 2013, 145.) Few examples of human error identification methods are: Action Error Analysis (AEA) and Human Error HAZOP (Chapter 3.8.1), Human Error Identification in Systems Tools (HEIST) (chapter 3.8.2) and System for Predictive Error Analysis and Reduction (SPEAR) (Chapter 3.8.3).

3.8.1 Action Error Analysis (AEA) and Human Error HAZOP

Action Error Analysis (AEA) combines Hazard and Operability Study (HAZOP) with Rasmussen's Skill-Rule-Knowledge (SRK) model (Pasman, 2015, 255). This qualitative method (Kaber & Zahabi, 2017, 863) follows the same procedure and documentation than HAZOP but uses error-cause checklists based on SRK model. Evaluation of latent failures is included in the method and the failures can be tracked by determining event sequences of actions. (Pasman, 2015, 255-256.) There are determined error modes in Action Error Analysis (Table 7):

Table 7 Action Error Analysis error modes regarding Taylor (1979) (modified Pasman, 2015, 256)

Omission	In wrong sequence	Wrong materials
Too little/ much	Wrong substance	Wrong action
Too slow/ fast	Wrong object	Wrong value
Too late/ early	Repetition	Wrong tool
In wrong direction	Other similar wrong choices, such as putting wrong label to a package	
Too slight/ hard	Extraneous action, unrelated but interfering the task	

Examples of errors to be considered: discontinuance of procedure, prematurely executed action (timing error or preconditions not fulfilled); making an extraneous action; inordinate delay in executing an action/ omission of an action; executing action on wrong object, adjusting or reading instruments wrong in a magnitude that is outside tolerance limits; choosing the wrong action when implementing a procedure (Mannan, 2014, 90).

There are also several other approaches of combining HAZOP with human factors consideration. An approach developed by Kirwan and Ainsworth (1992) is called the Human Error HAZOP technique. It was developed for analyzing human error issues. Human Error HAZOP have set of human factors guidewords (Table 8). Some other approaches combine HAZOP with the Failure Modes Effects Analysis, or HAZOP with Fault Tree Analysis or combine Layers of Protection Analysis, Failure Modes Effects Analysis and HAZOP. (Stanton, et al., 2013, 175.) One possibility is to take human factors guidewords from some human factors analysis method and combine it with HAZOP. For example, guidewords from SHERPA could be used. This approach though has the disadvantage that there would be possibly up to 20 guidewords of which some would be ineffectual. (Edmonds, et al., 2016, 86.)

Table 8 Human Error HAZOP guidewords (Stanton, et al., 2013, 176)

Not done	Repeated
Less than	Sooner than
More than	Later than
As well as	Misordered
Other than	Part of

Procedure of Human Error HAZOP proceeds a follows: 1) form a HAZOP team, 2) perform an Hierarchical Task Analysis, 3) consider and determine the appropriate guidewords, 4) describe the errors, 5) Conduct Consequence Analysis (describe the consequences of errors), 6) conduct Cause Analysis (determine causes of the potential errors), 7) determine Recovery Paths, 8) propose error remedies. The recovery paths refer to courses of action that worker/ operator may conduct after detecting an error, aiming to recover the situation and avoid adverse consequences. Error remedies refer to operational or design measures that can be performed to reduce the likelihood of a failure. (Stanton, et al., 2013, 176.)

Benefits of the method are: correctly performed Human Error HAZOP describes all the potential errors that may arise in the work system; since a group of experts conducts the analysis, it is potentially more comprehensive and accurate than single analyst approaches; the technique is easy to apply and learn; the guidewords can be applied to multiple domains and situations because they are generic; the technique is structured, systematic and combines inductive and deductive reasoning. Some downsides include: HAZOP can be time consuming and might take several weeks to be completed; since the team consists several experts such as operators, human factor specialists, engineers, designers it might be a challenge to get everybody to a same place at the same time; there might be personality clashes or other disagreements within the HAZOP team; the human HAZOP guidewords focus on physical errors and overlooks organizational and management factors. (Stanton, et al., 2013, 177.)

3.8.2 Human Error Identification in Systems Tool (HEIST)

Human Error Identification in Systems Tool (HEIST) is a method which can be applied in any domain. The origins of the method are in chemical process industries and nuclear domain. HEIST comprises eight tables which contain pre-defined questions called error identifier prompts. These questions are used to identify potential errors. They are applied to all the tasks within a scenario under examination. Error prompting questions are PSF-based, and each question is related to one of six categories of PSFs: task complexity (C), task organization (O), experience/training (E), procedures (P), Interface (I), time (T). The questions are about external error modes (EEMs), error causes and error reducing guidelines. The error causes are either psychological error mechanisms (PEMs) or system causes. The questions provide a linkage between the types of errors (EEMs) and relevant performance shaping factors (PSFs). After that external error modes are linked to psychological error mechanisms. (Stanton, et al., 2013, 188.)

The theoretical background of HEIST is based on Rasmussen's Skill, Rule and Knowledge framework. The cognitive functions/ behaviors in HEIST are detection/ activation, data collection/ observation, system state identification, interpretation, task definition/ goal selection, procedure selection and execution. HEIST procedure has four phases: 1) Hierarchical Task Analysis, 2) Task Step Classification, 3) Error Analysis, 4) Error Reduction Analysis. The analyst classifies (phase 2) a certain task step under one of the before mentioned HEIST behaviors, then applies error prompting questions and estimates whether any error is credible (phase 3). For credible errors, the analyst determines psychological error mechanisms or system cause, error consequence and error reduction guidelines (phase 4). (Stanton, et al., 2013, 188.)

Some advantages of the technique are: HEIST has potential to be very exhaustive because it utilizes the error prompting checklists which assist the analyst during the process; when a plausible error is determined the prompt aids provide also external error modes, psychological error modes and error reduction guidelines; HEIST is a structured approach which considers performance shaping factors and psychological error modes; the method is easy to learn and apply. Some downsides include: application of the technique requires a lot of time because of the error prompting questions; guidance about error reduction is too generic, thus do not necessarily provide special enough remedies; even though HEIST is said to be easy to learn, the analysis requires human factors or psychologist professionals; there is limited evidence of HEIST applications in scientific literature and there are no validation evidence available; HEIST provides lower error prediction accuracy Human Error HAZOP or SHERPA. (Stanton, et al., 2013, 189.)

3.8.3 System for Predictive Error Analysis and Reduction (SPEAR)

System for Predictive Error Analysis and Reduction (SPEAR) is a qualitative system-taxonomy based approach. The technique includes taxonomies for performance influencing factors and external error modes. PSF taxonomy is used to aid identification of situational or environmental factors which potentially increase the likelihood of erroneous actions. The analyst who conducts this assessment uses subjective judgement to classify each task step regarding SPEAR human error taxonomy. There are five behavioral types: check, selection, action, transmission and retrieval. (Stanton, et al., 2013, 197.)

SPEAR consists five techniques: 1) Task Analysis, 2) Performance Influencing Factor Analysis (defining relevant PSFs associated with each task step), 3) Predictive Human Error Analysis (identifying any credible errors), 4) Consequence Analysis (determining associated consequences), and 5) Error Reduction Analysis (determining error remedies regarding equipment, training and procedures) (Mannan, 2014, 147).

The advantages of SPEAR are: it is simple to learn (requires minimal training) and use; it considers performance shaping/ influencing factors; the method can be used in multiple sectors (even though it originates from chemical and process industries). Disadvantages are: for very complicated tasks SPEAR may become too laborious to conduct; the consistency of SPEAR is questionable; the technique lacks the consideration of the cognitive aspects of human errors and SPEAR seems to be almost like a replica from SHERPA. (Stanton, et al., 2013, 198.)

3.9 Management of safety culture and well-being

Each organization has their shared believes about safety practices, policies and procedures (European Agency for Safety and Health at Work, 2011, 38). There are also certain behavioural standards and requirements of how to act in different situations (Edmonds, et al., 2016, 324). These are all part of the safety culture within an organization. It is possible to improve the safety level of the organization and to prevent accidents by exploring the safety culture through human weaknesses and strengths. There are plenty of methods which can support the improvement of safety culture and well-being within an organization, such as: Antecedent-Behavior-Consequences (ABC) analysis and Stimulate-Organism-Reaction (S-O-R) model (Chapter 3.9.1), Behavior Based Safety (Chapter 3.9.2), Chronic Stress Risk Management (Chapter 3.9.3), Fatigue Risk Management (chapter 3.9.4), Keil Centre Human Factors Maturity® model (Chapter 3.9.5), Safety climate questionnaires, interviews and coaching (Chapter 3.9.6), worker-centric human performance tools (Chapter 3.9.7) and Work Environment Health Risk Analysis (WEHRA) (Chapter 3.9.8).

3.9.1 Antecedent-Behavior-Consequences (ABC) Analysis and Stimulate-Organism-Reaction (S-O-R) model

The ABC Analysis (Antecedent-Behavior-consequences) is an analysis method based on Behavior Based Safety (BBS) and S-O-R (Stimulate-Organism-Reaction) model is a theoretical behavioral framework (Figure 9). Together these can be used to human factors risk management, either prospectively or retrospectively. (Xie & Guo, 2018, 472.)

ABC analysis first determines antecedent conditions that might trigger certain behavior and then defines the consequences which are perceived by the person conducting the behavior. ABC analysis considers intentional behavior. (Edmonds, et al., 2016, 122.) There are individual and organizational reasons for a behavior (antecedents) or a result of interaction between individual and organizational factors. The analyst should determine the types, degree and locations of the risks that potentially arise, and consider predicted damage and monetary losses. Stimulus-Organism-Reaction model may be utilized in risk reduction. This model basically means that when an organism is stimulated it creates a reaction. In practice this means that managers need to choose efficient stimuli (safety measures) based on predicted or observed reactions (deviations from safe behaviors) to improve safety. (Xie & Guo, 2018, 472.)

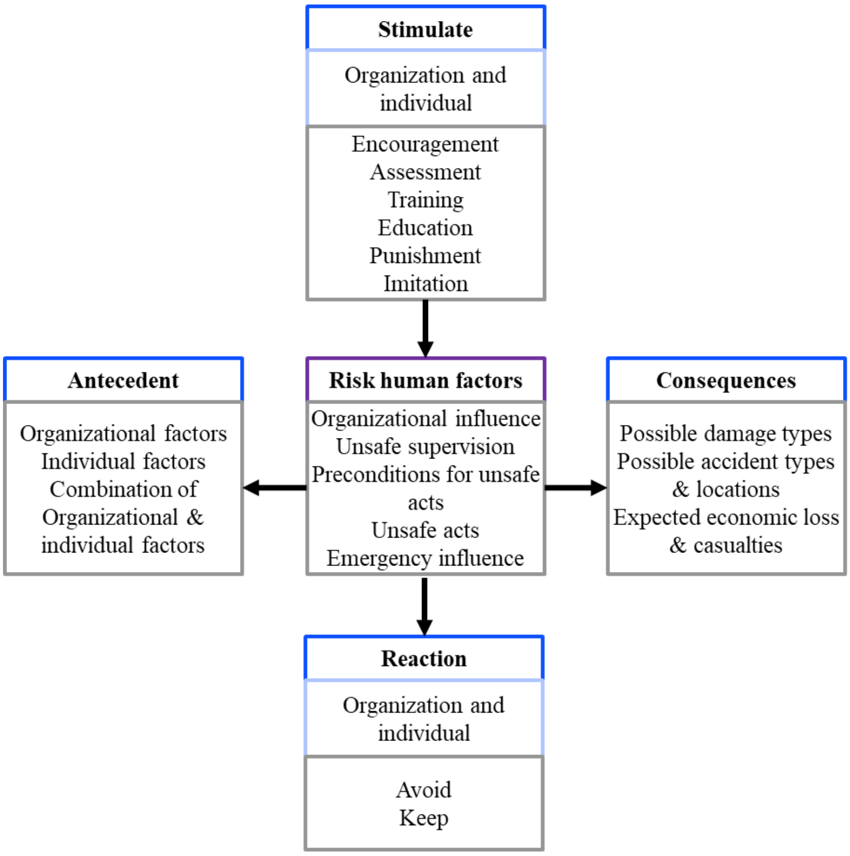


Figure 9 ABC Analysis and Stimulus-Organism-Reaction (S-O-R) model (modified Xie & Guo, 2018, 472)

ABC analysis can be used proactively to encourage positive changes in behavior, or it can be used to analyze accidents. ABC analysis has formed a basis for behavior modification and assessment approaches. This analysis is done from the point of view of the individual who is conducting the task rather than being on a general, objective level. Human performance and abilities vary, so this approach gains specific knowledge on how to improve the behavior of the individuals, who are performing the task under examination. ABC analysis is simple and practical yet systematic tool. (Edmonds, et al., 2016, 122.)

3.9.2 Behavior Based Safety

A Behavior Based Safety Program can be applied to avoid unsafe acts and encourage positive safety behaviors. It is an organizational proactive approach for safety culture improvement and reacting to incidents. The quality of performance should be encouraged rather than the number of observations. (Edmonds, et al., 2016, 128.)

There are certain behavior standards within an organization. Behavioral Gap Analysis examines the perceptions of the workforce about how frequently the demonstrated behaviors are corresponding the behavior standards. Workforce can for example be asked to rate how frequently managers express certain behaviors such as “manager explains safety expectations to the employees.” There are two options for point scales, either zero to four or zero to six. The written range is from never/ seldom (0) to always (4/6). Behavioral Gap Analysis can be executed as a survey (online or hardcopy) or in a workshop or focus group setting. When the analysis is conducted as discussion based (such as workshop, focus group) the event must be well planned and structured to avoid wasting time discussing irrelevant topics. (Edmonds, et al., 2016, 323-324.)

Behavioral Gap Analysis can be used to gain specific information about the areas of improvement, to understand why certain behaviors are not being displayed and how to improve the matter. This analysis measures the gap between the behavioral standards and the actual safety behaviors. Among other things it can help the organization decrease the rates of lost work hours due incidents. The advantages of Behavioral Gap Analysis: the results of the analysis can be utilized for improving safety behaviors and safety culture, and when the analysis is done as a workshop, it can also be used to educate the people about safety. The downsides are that the method is time consuming and the analyst must be experienced facilitator. (Edmonds, et al., 2016, 324, 327.)

3.9.3 Chronic Stress Risk Management

Chronic stress can be defined as a strain experienced by mind and body under excessive/ extended pressure. A three-tier framework (Figure 10) can be used to manage chronic stress and pressures at work. First tier of intervention is stress prevention, second tier of intervention is improving an individual’s management of stress and the third tier or intervention is treating individuals which suffer from stress currently. The frameworks can be utilized in identifying gap areas where is room for improvement and to identify and improve the current interventions. (Edmonds, et al, 2016, 462, 465.)

Primary level methods for identifying potential psychosocial hazards and sources of stress are for example stress risk assessments, surveys, focus groups, action plans and reviews. It is important that staff is involved in assessments and action-planning. The results of assessments should be integrated with finding from the organizational data such as absence rates, engagement surveys and accident rates. Organizational interventions such as improving communications, managing workload and/ or work redesign should be applied. (Edmonds, et al, 2016, 462-463.)

Second tier interventions promote awareness of stress and its impacts, provide access to stress managing services (relaxation, exercise, massages) and provide education about coping strategies. It can be assumed that some stress is unavoidable or not easily prevented so it is useful to create skills to manage this stress and avoid harmful effects to health and well-being. Increase in physical activity and learning cognitive coping tactics have positive impacts on well-being. (Edmonds, et al., 2016, 464.)

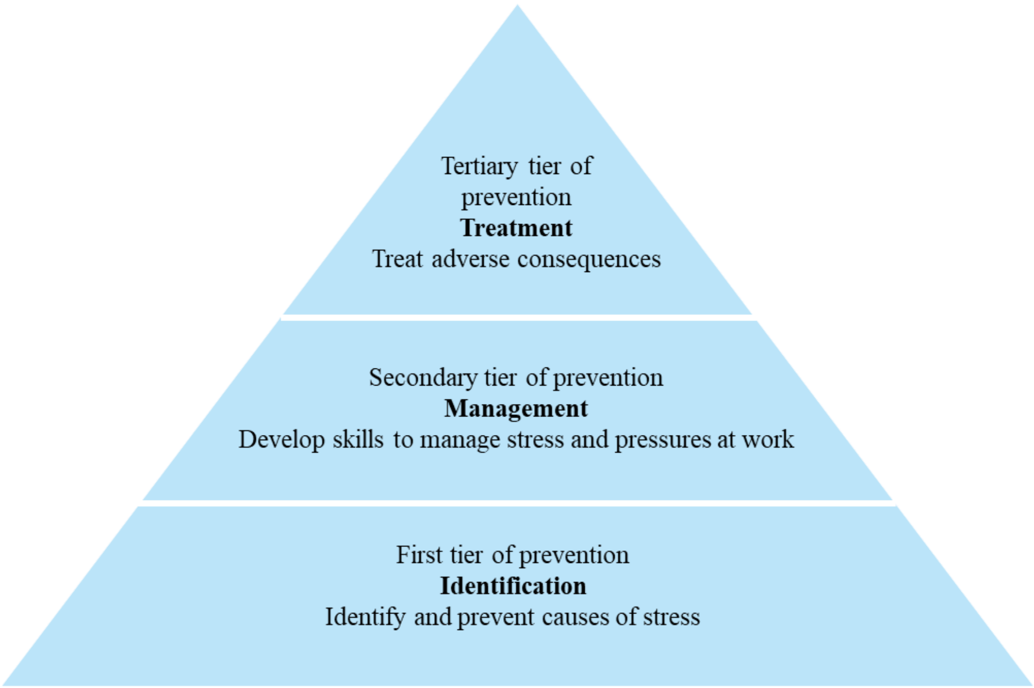


Figure 10 Tiers of prevention in Chronic Stress Risk Management (modified Edmonds, et al., 2016, 463)

Tertiary prevention level can be referred as treatment. These intervention methods are provided to those individuals who are experiencing significant stress-related difficulties. The employees should have access to appropriate professionals such as doctors, occupational health nurses or psychologists. A policy and process for managing stress-related absence should be developed. There should be effective communication between all the people which support the individual. There should be balance between supporting the individual and the desired outcomes for the organization (returning to work). This management system is comprehensive therefore resource intensive. (Edmonds, et al, 2016, 464-465.)

3.9.4 Fatigue Risk Management

Fatigue can act as threat in a sense that it can make hazards more likely to be realized. Fatigue rarely is a direct cause for incidents, but it can cause other hazards to permeate many safety barriers. An employee experiencing fatigue has increased risk to fail and cause an incident. In other words, fatigue itself is not seen as hazard in a traditional way but it is a threat. For example: a scenario where an employee is driving a forklift and falls asleep which results in collision to a warehouse shelf. The hazard is “moving a vehicle”, fatigue is threat that increases the possibility of an incident and the incident is the collision. (Edmonds, et al, 2016, 438.)

It is possible to manage fatigue in a structured way using risk-based approach. While evaluating fatigue risks the workgroup needs to consider the following: the likelihood of impairment caused by fatigue and risks related to the performance of tasks. Fatigue Risk Assessment approach includes a Fatigue Likelihood Analysis, Human Reliability Analysis and based on those two: further analysis of fatigue-related impairment, determining thresholds and applying Fatigue Risk Management controls and monitoring. A Fatigue Likelihood Analysis includes the evaluation of minimum sleep requirements, work hour limitations and behavioral symptoms indicating fatigue. The aim is to minimize the likelihood of fatigue-caused impairment and identify those who are impaired. Human Reliability Analysis is conducted to analyze safety critical tasks. Fatigue Risk Management controls include for example: ensure that work shifts are planned in a way which ensures adequate sleeping opportunities; record actual work hours and compare them to the planned ones to ensure they do not deviate remarkably; determine minimum sleep expectations and define symptoms which indicate that an individual is experiencing fatigue. (Edmonds, et al, 2016, 439-440.)

There are several fatigue proofing strategies to make performing work tasks more resilient to fatigue-related errors. Some tasks might be forbidden from employees which have exceeded the rostered hours. Work tasks can be scored regarding the vulnerability to fatigue-related risks. Some work tasks can be forbidden from employees which have been awake for longer than 18 hours or have been sleeping less than 6 hours within 24 hours. Fatigue proofing should be implemented and documented when it is observed that employee is too fatigued or when the employee himself/ herself states that. Generic fatigue proofing strategies include also: coworker or supervisor monitoring; checklists/ double-checklists; task rotation and re-allocation; self-selected rest times (employee can rest when it is needed rather than at scheduled times); stopping the work until fit to continue; possibility to nap before continuing the work task. It is very important to educate the managers and the workforce about fatigue-related risks, the causes of fatigue and the importance of ensuring sufficient sleeping. Fatigue management improves the safety level by decreasing the likelihood of error, yet it takes effort to maintain the fatigue management system. (Edmonds, et al, 2016, 444-446.)

3.9.5 Keil Centre's Human Factors Maturity® model

The Keil Centre Human Factors Maturity® model measures the level of maturity on how the organization manages human factors aspects. The model also identifies where to focus future improvement efforts. Human Factors Maturity® model has five levels: 1) emerging, 2) transitional, 3) planned, 4) proactive and 5) leading (Figure 11). At higher levels, the human factors management is planned and conducted in a systematic way. At lower levels, the approaches are not planned nor have set procedures or policies. (Edmonds, et al., 2016, 63, 65.)

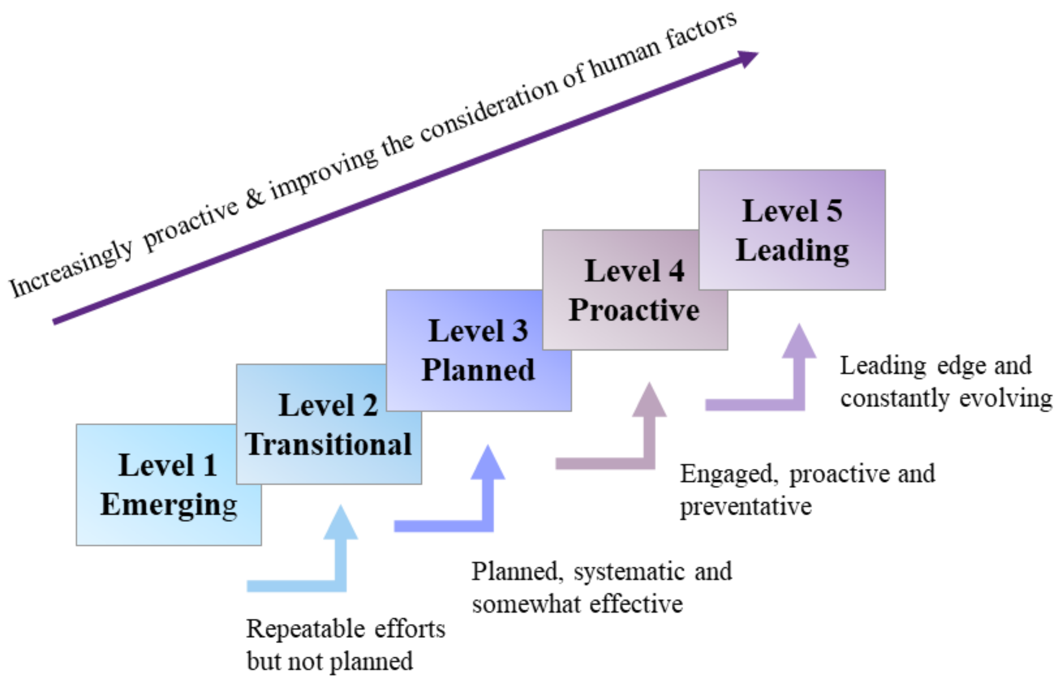


Figure 11 Keil Centre's Human Factors Maturity® model (modified Edmonds, et al., 2016, 65)

The levels of capabilities are determined by examining the organization’s procedures, processes, feedback systems, planning and whether they are following the best practices. The assessment is based on set of human factors issues (can be modified case specifically). The topics of these sets are: 1) management of human failure, 2) procedures, 3) competence and training, 4) staffing, 5) organizational change, 6) safety critical communications, 7) human factors in design, 8) fatigue and shift work, 9) organizational culture, 10) maintenance, inspection and testing. (Edmonds, et al., 2016, 63, 65.)

3.9.6 Safety climate questionnaires, interviews and coaching

Safety climate can be defined as the shared perceptions regarding safety related practices, procedures and policies within an organization (European Agency for Safety and Health at Work, 2011, 38). Standardized safety culture surveys can be used to assess the safety culture of an organization. Surveys can provide insights about the perceptions of safety-related aspects by asking questions such as “is there sometimes pressures to neglect safety instructions?” The answers are assessed on a scale from “strongly agree” to “strongly disagree”. The results are numerical and can be statistically analysed. The respond rate should be at least 50% so that the results can be adequately extrapolated to represent the whole workforce. There are multitude of questionnaires available. (Edmonds, et al., 2016, 322-323.)

European Agency for Safety and Health at Work has published a working paper titled: “Occupational Safety and Health culture assessment – A review of main approaches and selected tools” (2011, 23). A list of questionnaires ant tools is included in the paper, for example the HSL Safety Climate tool (SCT) and the Loughborough Safety Climate Assessment Toolkit (LSCT).

The advantages of safety questionnaires are: they are quick to complete, confidential and standardized; questionnaires can produce quantitative data which is easy to compare over time; online surveys minimize the manual work related to handling the answers; there is potential to examine large samples. Some disadvantages are: there is no opportunity to clarify the meaning of the questions/ statements (compared to an interview); people may answer in a way which they think is socially favourable; questionnaires are impersonal, directed to large samples; there might be difficulties to turn results into safety improvement actions;

there is usually need for setting up workshops to clarify the results. (Edmonds, et al., 2016, 326.)

Interviews can also be used for safety culture evaluation. With an interview it is possible to gain in depth information about all aspects of safety culture. The interviewees should be carefully selected, and the interview should be well planned and structured. Employees from different organisation levels (managers, workers) and positions (newly hired, senior) should be selected for interviews because they might have differences in perception. It is also beneficial to interview employees that are new to the company but have been working for the same field of operation. They have the expertise about the field but “fresh eyes” regarding company policies. Interviews can be used to complement other assessment methods whenever more detailed information is needed. The benefits of interviews are that they can provide detailed picture about safety culture and can be useful when discussing complex or sensitive issues. On the other hand, interviewing and analysing the results is time consuming and it is not easy to make comparisons over time or between sites. (Edmonds, et al., 2016, 325, 327.)

Safety culture can be assessed by an external expert coach, who is skilled health and safety professional with understanding of human factors issues. This external expert observes the operative functions with “fresh eyes”. The expert observes how the work is done, ask questions, attends activities and meeting and interviews people to gain understanding of policies, procedures and practices. The coach spends a specified amount of time in the organisation or site and at the end of the process makes recommendations about improvement and gives feedback. Other option is to use behaviour observation programmes within the company. In a systematic and structured manner, the workforce, supervisors and managers are observed while they do their daily work tasks. This observation can be done by someone within the company who is from the different part of the business, or it can be done by an external person. (Edmonds, et. al, 2016, 325-326.)

The advantage of expert coaching and observing is that the data is collected in real time and the examination can be tailored to target specific areas of interest. The expert coach provides expertise of the assessment of safety culture. Some disadvantages are that observations are time consuming and the observer is susceptible to biases. The observer can be seen as an intruder and people might be reserved to open up. Also, it might be difficult to repeat the analysis or compare the results over time. (Edmonds, et. al, 2016, 327.)

3.9.7 Worker-centric human performance tools

Safe working habits can be improved and fortified with worker-centric human performance tools. These tools have numerous advantages such as: these tools remind the workers to be aware of their surroundings, think throughout the work task that what they are doing, to detect deviations and recover from erroneous situations and to get a second opinion when unsure. In Figure 12 a sample of human performance tools is presented. The application of these tools potentially reduces the probability of human errors. On the other hand, the organization needs to make clear guidelines about which human performance strategies the workforce should use, otherwise the workers might get overwhelmed about what they should do. (Edmonds, et al., 2016, 113-115.)

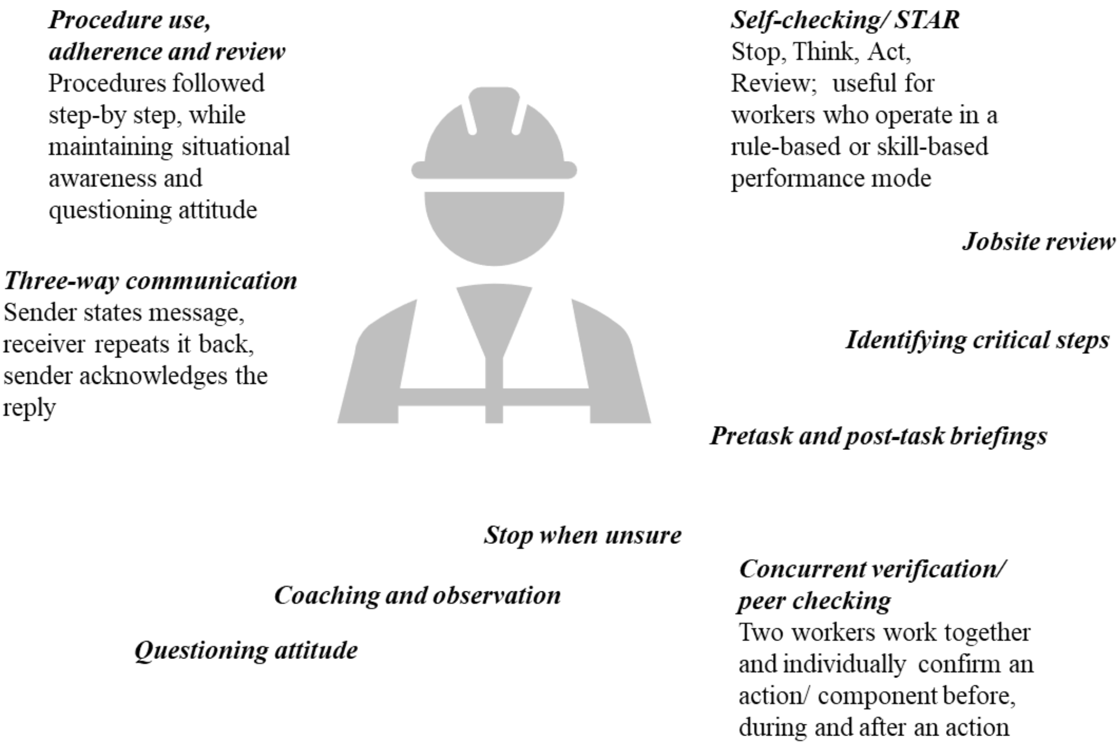


Figure 12 Worker-centric human performance tools (modified Edmonds, et al., 2016, 113-114)

3.9.8 Work Environment Health Risk Analysis (WEHRA)

During Work Environment Health Risk Analysis (WEHRA) inherent system hazards related to environmental ergonomics (and other) factors are evaluated. WEHRA has broader approach compared to typical environmental ergonomics scope. It brings together multiple aspects which may potentially have remarkable adverse effects on human health, safety and performance. The evaluation is done regarding chemical, biological, radiation and mechanical hazards; demanding work; noise; psychosocial hazards and fatigue; lighting; altitude/ atmospheric pressure; motion/ vibration; space arrangement and layout; indoor climate and outdoor climate. WEHRA combines quantitative and qualitative tactics. The quantitative tactics might include using prediction modelling, taking measurements and reflecting the findings against regulations or standards. Qualitative information can be obtained from the workforce by conducting surveys, questionnaires and interviews. The method is comprehensive therefore it is relatively recourse intensive. (Edmonds, et al., 2016, 182, 272.)

3.10 Task analyses

Task analysis methods can be applied to describe human and system performance during a specific work task. In other words, it can be described as study about what operator(s) should do to achieve system goals (and what can go wrong). The analysis includes identification of tasks and their subtasks, collecting data and analyzing it to gain understanding about the potential task steps where human errors might occur. The Chapters 3.10.1-3.10.5 introduce task analysis methods called Cognitive Work Analysis (CWA), Hierarchical Task Analysis (HTA), Operational Task Analysis (OTA), Safety Critical Task Screening/ Analysis (SCTA) and Tabular Task Analysis (TTA). (Stanton, et al., 2013, 39, 152, 176.)

3.10.1 Cognitive Work Analysis (CWA)

Cognitive Work Analysis (CWA) is a framework that can be used to model, (Stanton, et al., 2013, 73) analyse, evaluate and design (Naikar, 2017, 528) complex socio-technological systems (Naikar, 2017, 528; Stanton, et al., 2013, 73). CWA models different kinds of constraints that affect the work system (Stanton, et al., 2013, 73). These constraints limit the number of available actions that could be taken by the operator/ actor (Naikar, 2017, 528). CWA framework is collection of tools that can be chosen depending on analysis needs. There are eight general steps: 1) clearly specify the nature of the analysis (purpose of the study and desired outputs), 2) carefully select the most appropriate CWA methods and phases, 3) a

Work Domain Analysis, 4) Activity Analysis in Work Domain terms, 5) Activity Analysis in Decision-Making terms, 6) Strategies Analysis, 7) Social Organization and Cooperation Analysis, 8) Worker competencies Analysis. (Stanton, et al., 2013, 73-77.)

Work Domain Analysis examines the cultural, social and physical environmental constraints placed upon workers. This includes system's functions and physical resources, purposes, priorities and values. Activity Analysis describes the activities within the system that are needed to fulfil the system's purposes, priorities, values and functions. Strategies Analysis examines the constraints placed upon the actor by cognitive strategies which are used for conducting necessary activities within the system. Social Organization and Cooperation Analysis evaluates the constraints originated from the ways of work allocation, coordination and distribution within the work system. Worker Competencies Analysis evaluates how the demands of the work system can be met while leveraging the cognitive and personal abilities of humans and considering their limitations. (Naikar, 2017, 528.)

The advantages of CWA: the method is flexible and build upon solid theoretical framework; CWA is exhaustive method for analysis and design of complicated work systems; the method is generic and therefore can be used in multiple purposes. There are also disadvantages such as: because the framework is complex, considerable amount of training is needed to master the evaluation; CWA is time-consuming to apply; some methods within the CWA framework are yet not fully described; CWA outputs are extensive and arduous to explain; and the reliability of the method is not strong. (Stanton, et al., 2013, 80.)

3.10.2 Hierarchical Task Analysis (HTA)

In Hierarchical Task Analysis (HTA) method a certain task is divided into hierarchy of task elements (Mannan, 2014, 146). These elements include goals and their sub-goals which are needed to fulfill the task; and plans and operations which are necessary to obtain the goals (Mannan, 2014, 146: Stanton, et al., 2013, 40). HTA examines the basic structure and purpose of a certain task (Edmonds, et al., 2016, 79). HTA is the most popular task analysis technique. The technique was developed for the demands of power generation and chemical processing sectors, but it is generic in nature, so it can be used in multiple sectors. The technique has six steps: 1) task definition, 2) collecting data (regarding the task), 3) determining the general goal of the task, 4) sub-goal determination, 5) decomposition of sub-goals until appropriate operation is reached, 6) analyzation of the plans which consider how the goals will be achieved. Example of plan analysis is in Table 9. (Stanton, et al., 2013, 40, 41-43.)

Table 9 HTA Plans (Stanton, et al., 2013, 43)

Plans	Examples
Simultaneous	First do 1, then 2 and 3 at the same time
Non-linear	Do 1, 2 and 3 in any order
Linear	First do 1, then 2, then 3
Selection	First do 1, then 2 or 3
Cyclical	First do 1, then 2, then 3 and repeat until X
Branching	Do 1; if X present, then do 2 then 3, but if X is not present, then EXIT

Hierarchical task analysis has numerous advantages: The application of the technique is easy and quick; HTA is flexible to use and only minimum training is needed; the result of the HTA is an extensive depiction of the task; the results of HTA are useful in many human factors analyses; the method can be applied to variety of purposes in any domain and depending on the purpose, the level of detail of the analysis can be varied. There are also disadvantages: The results of HTA are not quite analytical, they are descriptive; the technique lacks consideration of the cognitive task components; HTA might become time-consuming and laborious for complex tasks; data collection phase is resource intensive; multiple human factor techniques are needed such as questionnaires, interviews and observations; the method requires considerable level of subjective judgement, therefore the reliability may be questionable and even though the technique is easy to implement, much practice is needed that analyst becomes proficient. (Stanton, et al., 2013, 43-44.)

3.10.3 Operational Task Analysis (OTA)

During Operational Task Analysis the tasks implemented by a certain operator are analyzed. This evaluation is usually done when introducing new equipment or a new system. First a task inventory is set up to determine associated tasks with each work role. Next the standards, operational performance and conditions related to activities performed within task(s) are determined. These can be referred as competence requirements (Table 10). Operational Task Analysis can be used as a tool in competence management and training. (Edmonds, et al., 2016, 389-390.)

Table 10 OTA competence requirements (Edmonds, et al., 2016, 390)

Requirement	Description
Standards	Define how well operator must perform to reach competency. Standards include requirements for accuracy, frequency, amount and so on.
Operational performance	Specify what activities the operator must manage to do.
Conditions	Determine how the operator must perform. For example, how to: do the task, to use the equipment, to follow the procedures.

3.10.4 Safety Critical Task Screening/ Analysis (SCTA)

Different tasks have varying vulnerabilities to human error. Before analyzing the impacts of human factors, it is reasonable to screen the tasks and find the most critical ones (establish a priority list). This is done to avoid further analysis process to become too laborious. Safety Critical Task Screening is done through five questions. Table 11 presents questions which are designed for the gas and oil industry. The questions might have to be modified to fit different domains. The questions have three-point scale from low (1 point) to high (3 points). Not applicable has value 0. After the questions are answered and scaled, the numerical values are summated. The result is between 0 and 15. The criticality based on results is: high (9-15 points), medium (5-8 points) or low (1-4 points). (Edmonds, et al., 2016, 78-79.)

Table 11 Safety Critical Task Screening questions (modified Edmonds, et al., 2016, 79)

Question	Low	Medium	High	N/A*
1. The intrinsic hazards related to the task (regarding conditions, energies or substances)	1	2	3	0
2. The degree to which ignition sources are deployed by the performance of the task	1	2	3	0
3. The requirement to bypass/ invalidate the safety protection systems as part of the task	1	2	3	0
4. The degree of damage to the system to which incorrect performance of the task can result in	1	2	3	0
5. The degree to which the task requires changes to the system configuration	1	2	3	0

*N/A= not applicable

After the Safety Critical Task Screening the high priority tasks can be analyzed for example using human reliability analysis methods, human error identification methods or task analysis such as Tabular Task Analysis or Hierarchical Task Analysis.

3.10.5 Tabular Task Analysis (TTA)

Tabular Task Analysis (TTA) can be conducted to increase the level of detail after Hierarchical Task Analysis. Further details about each task step are examined, such as necessary equipment, which persons do the activities, hazards, potential errors, communications, operational performance standards and conditions. (Edmonds, et al., 2016, 79, 297.) The process of executing TTA can be described with six steps, of which the first three cover conducting HTA. The steps are: 1) define the tasks to be analyzed, 2) data collection (about the tasks), 3) Hierarchical Task Analysis, 4) convert HTA to tabular form, 5) choose categories for task analysis, 6) fill in the TTA table. (Stanton, 2013, et al., 64-65.) There is an example extract of blank TTA table in Table 12.

Table 12 TTA table (modified Stanton, 2013, et al., 65)

Number of the task	Description of the task	Displays and controls	The action which is required	System feedback	Potential errors	Consequences of error	Remedies for errors

Tabular Task Analysis has advantages such as: it is flexible – any factors associated to tasks can be assessed (the analyst has control over determining the categories); TTA can provide exhaustive analysis of a specific scenario or task if the right categories are used; the method is generic, thus can be applied to any domain; it is easy to learn and use; TTA provides much more detailed analysis than traditional approaches such as HTA. There are also downsides associated with the method: because TTA is exhaustive it is also time-consuming; there are limited data in literature about the validity and reliability of TTA; in most cases HTA is detailed enough and there is no need for TTA. (Stanton, et al., 2013, 66.)

4 SERVICE DESIGN

Service design specializes in human-centered development of services, customer and employee experiences and service business. The designed service should meet both customer needs and business goals. In this section first the theoretical background of service design is briefly presented (Chapters 4.1 and 4.2). The Chapter 4.3 includes comparisons about potential human factor management methods, based on the results of the literary review. Human Factor Management Service concept is introduced in Chapter 4.4 and the results of a pilot are presented in Chapter 4.5.

4.1 Service design and client expectations in general

The share of services in the structure of the national economy is constantly increasing in Western countries. Services account for about 70 per cent of GDP in Finland. The industry sector has begun to talk about business servitization. It is a process of change, in which the company moves from mere product development to service delivery. (Koivisto, et al., 2019, 17.)

A strong customer focus is a prerequisite for success. It is important to consider what kind of goals your customers want the services to achieve. The purpose is to provide the customer with a broader solution and more value than just a product. Service design specializes in human-centered development of services, service business and experiences of customers and employees. The key objective of service design is that the service meets both customer needs and business goals. (Koivisto, et al., 2019, 18-19, 34.)

What customers expect from the services they are offered? The services should provide them added value and benefits otherwise it will not be worth their time and money. Clients also expect the service to be understandable, easily accessible and easy to use. The technical end-result and the benefit are important but so is the user experience. Customers expect customized experiences, personalized benefits and offers, appreciation of customer relationships, and remembering their past performance. (Koivisto, et al., 2019, 22-23.)

4.2 Theoretical background of service design

Service design is based on "design thinking", an ideology introduced by Tim Brown and David M. Kelley of the IDEO Design Office and Professor Roger Martin of the University of Toronto around ten years ago. Design thinking is a human-centered innovation process that seeks to meet the needs of people with solutions which are technically and economically feasible. The design thinking includes eight principles:

1. Human-orientation: People are at the center of interest. Customer needs must be identified and recognized. Design thinking seeks empathic and profound understanding of users of services and products. The methods for gaining this understanding could be for example interviews and observations.
2. Solving the right problem: It is important to first find out what really is the user's problem, instead of relying on assumptions. It is important to create the right solution to the right problem. This phase can be called the fuzzy-front end of innovation and it is very open in nature. At the start of the development work the ultimate end-result is not yet precisely known.
3. Exploratory: This principle refers to investigative and experimental development approach and challenging existing policies and solutions. In addition to recognizing conscious needs, latent or unconscious customer needs are addressed, prototypes are being built and creative problem solving is utilized to create revolutionary innovations.
4. Iterative: Innovation progresses iteratively, repeating the work phases until a desirable, technologically, and economically feasible solution is reached. During these iterations, the innovator builds prototypes and tests different solutions while considering the client's needs. Iterative development is based on an idea that innovation process is also a learning process and it is possible to go back to previous phases.
5. The dialogue between divergent and convergent thinking: Convergent thinking refers to analytical reasoning which aims to narrow down the available information and options to find the right solutions. Divergent thinking creates new ideas and is based on innovative open-ended combining of relevant factors. In a development process based on design thinking these approaches alternate.
6. Prototyping and testing: Prototypes and testing are used to provide insight into the functionality and desirability of designs. Prototyping decreases the probability of failures since it offers a possibility to refine an idea or to change plans based on

feedback, if necessary. Prototypes visualize a concept of a service or a product. They should be done early enough in the process and they should be as simple and cost-effective as possible.

7 Co-development: It is beneficial to create solutions in co-operation with co-workers and the users of the service or product. Co-development aims at better meeting and engaging with the needs of the target group. Co-development methods include for example online communities and workshops.

8 Multidisciplinary: Innovating requires expertise in many different areas of specialization. Development work must combine people's needs, business objectives, and technological capabilities in an effective way. Multidisciplinary development teams are favored in design thinking. These teams may include for example engineers, people with business degree and industrial designers. (Koivisto, et al., 2019, 35-41.)

4.3 Potential human factor management methods

This chapter contains comparisons made on the basis of the results of the literature review (Chapters 3.4-3.10 and Appendix II). Based on the results of the literature review, ten of the most promising methods were selected as possible methods of the service concept. This was done to answer the research question 2: Which methods could be used in the Human Factors Management Service concept? The qualities of these selected methods are:

- Generic in nature
- Can be applied to work systems in chemical and process industries
- Relatively quick to learn (training time is from low to medium)
- Can be applied without high level of expertise about human factors
- Are not excessively laborious or time-consuming and fit the usual HSE project timespan (application time is from low to medium)
- It should be possible to conduct the method without specific computerized programs (other than usual Microsoft Office applications)
- The level of detail was also analysed

The ten most promising methods which were chosen are in Table 13. Potential methods which were chosen to be compared were from the categories of human reliability analysis (first, second and third generation), human error identification, diagrams, task analysis and management of safety culture and well-being. These categories are the most closely related to the work of the HSE engineer at AFRY Finland Oy.

Table 13 Summary of ten potential methods (modified Edmonds, et al., 2016, 78-79, 87-88, 122, 182, 272, 325-327; De Felice & Petrillo, 2018, 30-31, 36-38 ; Stanton, et al., 2013, 149-153, 175-177, 188-189, 197-198, 201-205)

	Training time*	**Psychologist/ experienced human factor professional necessary**	**Application time**	**Specific computer program necessary**	**Level of detail**	**Qualitative (QL)/ Quantitative (QN)**
Diagrams						
Bowtie diagram	Low	No	Medium	No	Low-medium	QL•
Human reliability analyses (first, second and third generation)						
HEART	Low•	No	Medium•	No•	Medium	QN•
SHERPA	Low•	No	Medium•	No•	High•	QL•
SPAR-H	Low	No	Medium	No	Medium	QN•
Human error identification						
AEA/ Human HAZOP	Low•	No	Medium•	No•	Medium	QL•
SPEAR	Low•	No	Medium•	No•	High	QL•
Management of safety culture and well-being						
Coaching	Medium	No	Medium	No	High	QL
Questionnaires/ surveys	Low	No	Medium	Yes/ No**•	Medium	QL/ QN
WEHRA	Medium	No	High•	No	High•	QL/ QN•
Task analysis						
SCTA	Low	No	Low	No	Low	QN•

*training a technical professional

**can be conducted as online survey or as paper copy survey

•Ranking mentioned directly in the reference literature (other rankings are subjective evaluations based on the descriptions of the methods in the reference materials)

Bowtie diagram must not be highly detailed otherwise it becomes tedious to conduct. Bowtie can be beneficial method when certain critical events must be examined more thoroughly after other human factor or safety evaluations. (Chapter 3.5.1) Other supportive method which could be useful is Safety Critical Task Analysis/ Screening. On the contrary to bowtie, it would be used before human factor evaluations, to recognize the tasks which should be analysed. This helps to avoid the human factor analysis process becoming too tedious. (Chapter 3.10.4)

Human Error Assessment and Reduction Technique (HEART) is less detailed analysis than Systematic Human Error Reduction and Prediction Approach (SHERPA). Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) is simplified derivate of HEART. SHERPA is said to be relatively quick to learn and apply but with very complex tasks it becomes laborious to conduct. The industrial process tasks tend to be quite complex. However, it can provide comprehensive information and in some client cases it could be a useful method. HEART and SPAR-H consider performance shaping factors (also called as error producing conditions), SHERPA does not. HEART has thirty-eight categories of error producing conditions and SPAR-H has eight categories of performance shaping factors. (Chapters 3.6.2, 3.7.3, 3.7.4.) SPAR-H was selected to be tested in the service design phase, because it is simple enough to fit the HSE project context yet potentially provide detailed enough information about the task under analysis (more information in Chapter 4.5.2).

Action Error Analysis (AEA) procedure is based on an established process safety analysis, HAZOP and human factor related theoretical knowledge, Rasmussen's Skill-Rule-Knowledge (SRK) model. (Chapter 3.8.1). System for Predictive Error Analysis and Reduction (SPEAR) is a qualitative system-taxonomy -based approach which was specifically developed as a human factors analysis. (Chapter 3.8.3). In SPEAR task steps are first categorized in five different types of behavior types. Then each behavior is linked with external error mode, such as action incomplete or omission. In Action Error Analyses there is no classification of behaviors, but task steps are similarly analyzed with error modes such as omission or right action to wrong object. SPEAR considers performance shaping factors, Action Error Analysis does not. Bot includes task analysis, error analysis, consequence analysis and error reduction analysis. Action Error Analysis does not contain PSF analysis or task classification. SPEAR could potentially provide more comprehensive knowledge than Action Error Analysis. However, since comprehensiveness is higher the SPEAR is more time-consuming than AEA. SPEAR considers situational and (working) environmental factors but lacks the consideration of cognitive components of error. (Chapters 3.8.1 and 3.8.3.)

SHERPA is a comprehensive method which can be applied to multiple different domains and there are reliability and validity studies available with encouraging results. SHERPA uses guidewords (error modes) to identify human errors within processes. (Chapter 3.7.4) It could potentially be used instead of Action Error Analysis. Regarding very complex tasks it might get too tedious to conduct and in that case Action Error Analysis is more reasonable choice.

With coaching it is possible to diversely observe the safety practices and policies within an organization and correct them by teaching the staff. The coaching is done by an experienced health and safety professional. It is a conversational method in which the client and the coach co-operates. Sometimes though the external observer is seen as an intruder which might negatively affect to finding out all improvement areas. Questionnaires or surveys can provide anonymous information about safety concerns and therefore people might be more willing to openly pinpoint them. However, this method is unilateral, and it might be just easy to ignore a survey link to an e-mail. These two methods could be used as complementary methods. (Chapter 3.9.6.) Work Environment Health Risk Analysis (WEHRA) can be used to examine working environment, to ensure the well-being of employees. It considers factors in the working environment which potentially have adverse effect on health, safety and performance of employees. WEHRA has broader approach compared to typical environmental ergonomics scope and it uses qualitative (interviews, surveys) and quantitative tactics (prediction modelling, measurements). (Chapter 3.9.8)

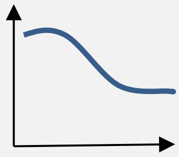
4.4 Human Factor Management Service concept

This concept was developed based on the needs of a theoretical client. The client has industrial production facilities which have had frequent accidents. The client has been trying to solve this problem by paying attention to occupational safety. The situation has improved because measures have been made but the progress has halted to a certain level. There is a need for new perspectives and the client wants that human factors and the safety attitudes of the people are assessed. The concept is described in Figure 13.

Name of the concept: Human Factor Management Service

Customer problem:
•Accident frequency at an unacceptable level
•Measures have been made but
the progress has halted to a certain level
•Need for new perspectives

Metrics



How does it work? The level of safety is increased by identifying and addressing human factors which contribute to the occurrence of accidents.

Value to the end-user:
•Smaller Lost Time Incident Frequency
•Less economic losses
•Improved safety and health of employees
•Improved company image

What differentiates it from other solutions to the same problem?
Holistic approach to accident prevention. Extending the investigation beyond traditional process safety assessments.

Value to our business?
•Expanding the service portfolio
•Business growth and profit gains
•Developing the operation with our existing clients
•Gaining new clients

Written value proposition:
Increasing the level of safety, decreasing accident frequency and cutting economic losses with human factor management.

Main elements:
1 Gathering existing data
2 Identifying critical functions
3 Human error identification
4 Human reliability analysis
5 Safety culture evaluation

Figure 13 Human Factor Management Service concept definition (modified Futurice, 2017)

First the analyst should consider gathering relevant information about previous analyses (for example HAZOP or accident reports). Information should be also gathered with other suitable means, for example by interviewing key personnel. This information can be utilized in identifying critical functions which should be further assessed with human factors assessment methods. There are also methods for identifying critical functions, such as Safety Critical Task Analysis (SCTA). By using that method tasks can be screened and answering a set of questions their criticality can be assessed (Chapter 3.10.4).

As there have been several accidents at the plant, accident reports have been made. Accident/ incident investigation reports can be examined to understand safety culture and improve management practices. The evaluator aims to identify positive behaviors that helped to minimize the consequences and negative behaviors and failures that contributed to development of the accident scenario. Examining the failures reveals vulnerabilities in the work system. (Edmonds, et al., 2016, 326, 327.)

After the critical functions have been identified, human error identification is conducted to the selected operations. There are several human error identification methods. Currently Action Error Analysis (AEA) is used in HSE team. It has been found to be functional by AFRY Finland Oy and therefore it is included in this concept. The Action Error Analysis is conducted as a workshop in cooperation with representatives of the client and AFRY professionals. There is a list of task functions which are analyzed by going through specific keyword list and searching for the potential human errors. The list and the evaluation process in described in detail in Chapters 3.8.1 and 4.5.1. Action Error Analysis provides qualitative results. A potential method for replacing Action Error Analysis in some customer cases could be System for Predictive Error Analysis and Reduction (SPEAR) It contains the consideration of performance shaping factors, which could provide additional information about the aspects that affects the possibility of a human error. (Chapters 3.8.3 and 4.3). Systematic Human Error Reduction and Prediction Approach (SHERPA) could also potentially be used instead of Action Error Analysis when more comprehensive results are needed (Chapters 3.7.4 and 4.3).

After human error identification human reliability analysis shall be conducted if more comprehensive information is needed about the reasons why accidents are likely to happen. There are qualitative and quantitative methods available. In this case the quantitative methods are of interest because there is already a qualitative human factors management method (AEA) in use at AFRY. Possible methods are Human Error Assessment and Reduction Technique (HEART) and Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) because they are quick to learn and relatively straightforward to apply, can be applied to chemical and process industries and do not need any specific computerized programs. They are also generic methods which can be applied in various scenarios. (See Chapters 3.6.2 and 3.7.3).

If after conducting human error identification and reliability analysis there still a need for expanding the scope of inspecting human factors, safety culture evaluation should be conducted. Alternatively, safety culture evaluations can be conducted as a stand-alone assessment. Safety culture and management of well-being are very important aspects in the safe operation of an organization. With coaching it is possible to thoroughly and diversely examine the practices and procedures within the organization to pinpoint any adverse functions in the safety culture. The coach provides an external view, “a set of fresh eyes”. This is beneficial because within an organization, certain mindsets take roots. Possibly even tasks are done in an unsafe manner and it becomes the norm for the people. External observer can pinpoint these defects and coach the staff to function better. Questionnaires/ surveys can be used to collect anonymous information about the safety culture. Chapter 3.9.6.) Instead of safety culture analysis, a bowtie diagram could be conducted is there is a need to examine certain potential critical events within a task and related barriers (Chapters 3.5.1 and 4.5.3).

4.5 Pilot: Human factor assessments for a chemical production facility

The human factor analyses of this chapter were implemented related to a start-up phase of a chemical production facility. Action Error Analysis was done at client facility (Chapter 4.5.1). During the Action Error Analysis information about performance shaping factors was also gathered to be utilized in Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) (Chapter 4.5.2). Bowtie diagrams were done to visualize two selected critical events during the start-up phase (Chapter 4.5.3). They were conducted to demonstrate how the bowtie diagram is done and what benefits it brings to the safety analysis and reporting.

4.5.1 Action Error Analysis for the chemical production process start-up

The Action Error Analysis was conducted at a client facility in 11th of March 2020. The evaluation session lasted one whole working day. There were two AFRY professionals present, a leader of analysis and a scribe. Client had three representatives from different organizational positions: a plant manager, a process engineer, and a process operator. During Action Error Analysis the task steps were analysed one by one using a list of guidewords (Table 14).

Table 14 Action Error Analysis guidewords

Guidewords			
1	Omission	**6**	Excess action
2	Too late	**7**	Wrong order
3	Too soon	**8**	Too much, too long, too quick
4	Wrong or insufficient	**9**	Too little, too short, too slow
5	Action done to wrong object		

A PHA-Pro worksheet was used in the Action Error analysis (Table 15). PHA-Pro is a software tool for conducting Process Hazard Analysis and HAZOP (Sphera, 2020). The worksheet is a table which was filled during the analysis workshop. The name of the task step is on the first column (deviation), the next one includes the reasons why the error happens (using the guidewords) and the third column includes the consequences. The analysis also includes risk matrix columns, which includes the evaluation of severity (S) and probability (P) of the risk.

Table 15 Extract of an Action Error Analysis worksheet

Deviations	Causes	Consequences	Risk matrix 1			Precautions	Risk matrix 2			Proposal of measures			Comments	Residual risk		
			S	P	RR		S	P	RR	Measures	Responsible	Due Date		S	P	RR
18. Open manual chemical x valve	Omission	Process line pressurizes --> possible pressure oscillation in the chemical network --> Process failure								Check if the pressure oscillation affects the equipment	XX	XX				
19. Reset relay (first voltage off, then voltage on)	Omission	Process sequence does not continue --> process failure														
20. Ensure correct process conditions by filling the system with substance y	Omission	Incorrect mixture in start-up phase --> danger of explosion	C	4	2	Work instructions Process equipment rupture disc Personal protective gear Sensory evaluation	C	3	2	Consider adding flow measurement which stops the operating sequence below the lower limit	XX	XX				
21. Close the chemical x valve which was opened in the phase 1	Omission	Too much chemical x during start-up phase--> air + excess chemical x --> danger of explosion	D	4	4	Flow measurement	D	3	2							

There are three kinds of risk matrix columns. Risk matrix 1 considers the risk without precautions, risk matrix 2 considers the risk with precautions and residual risk matrix considers the risk after measures have been applied. The precautions are listed for each task function. Last step of the analysis is to do proposals for measures which aim to reduce the risk to acceptable level and assign a person who is responsible to take the matter forward. The risk matrixes are filled in a case that the consequences cause a risk of harm or danger to people, environment or equipment. If the risk is too high to accept after the precautions, measures should be proposed.

There were altogether forty-eight deviations (task steps) which were examined. During the evaluation, the following were identified (potential events): twenty-two process failures, fifteen personal injuries, four environmental damages, eleven economic damages. Thirteen measures were determined. The most significant potential event was explosion which can cause personal injuries or economic damage. Some events were identified in which it is possible that chemicals leak to the atmosphere. The measures included for example adding certain flow and temperature measurements, adding local displays of information for the process operator in addition to which are in the control room and doing refinements to work instructions.

4.5.2 Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) for the chemical production process start-up

In this chapter SPAR-H evaluation remarks are presented. The chemical production process is covered in a manner which ensures the confidentiality of the client. The main chemicals which are present in the process are named as chemical x, y and z. Standardized Plant Analysis of Risk-Human Reliability Analysis (SPAR-H) includes first task analysis; the tasks (and possibly subtasks) are determined. There are eight categories of performance shaping factors (PSFs) which influence performing the tasks:

1. Available time
2. Stress/ stressors:
3. Complexity
4. Experience/ training
5. Procedures
6. Ergonomics/ Human-Machine Interface (HMI)
7. Fitness for duty
8. Work Processes (Whaley, et al, 2011, 2-12.)

Information for SPAR-H was collected during Action Error Analysis (in 11th of March) by asking the client that do some of the performance shaping factors affect certain task steps. During action Error Analysis the tasks were analyzed step by step. These remarks were utilized to calculate human error probability (HEP). The calculations are presented latter in this chapter. Additionally, after the analysis session clients were also asked to freely tell their thoughts about the eight PSFs in relation to the task under analysis. Qualitative remarks from the interview are as follows:

1. Available time: Available time depends on the situation at the factory. If a lot happens at the same time, for example, multiple events need attention, then you may be in a hurry. Generally speaking, shortage of time is not a problem. The job is stopped and continued at better time if necessary, rather than being hurried. Available time is at a nominal level.

2. Stress/ stressors: Stress level is relative, depends on the person doing the task. The start-up can be a challenging task for someone who does not often do it. Start-up 3 is different from the other start-ups in the facility. It has a lot of manual work, while the other ones have a higher degree of automation. Some stress present throughout the start-up process. There is a higher stress levels in chemical z feed. This is because incorrect substance ratios can cause explosion if air and flame are present. Local measurement does not show low levels of chemical z. Chemical x should be supplied with an estimate and an excess of certainty to ensure the correct ratio. There is nominal stress at other points.

3. Complexity: The start-up process is moderately complex, with dozens of points in the guide, requires knowledge. Specifically, the chemical z and x supply phases are more complex. Experience needs to be comprehensive in these. Complexity is at a nominal level regarding other points.

4. Experience level: The operator staff are trained but might not often do the start-up. It may be that there is not a qualified person due to the adequacy of the crew, in which case the task will not be done. An attempt is made to take a person from the shift, but sometimes they must be assigned from a day shift. The regulars from the shift knows how to do it, but the substitute staff may not. Day shift usually does maintenance. Shift includes control room staff and process operators. Experience level is overall nominal.

5. Procedures: There is some room for interpretation in the work instructions, one must always think about what one is doing rather than blindly following them. There is a mistake in instruction of two of the procedure steps. These are already known and are being corrected. The mistakes are related to valves. There is an instruction to use a specific valve for chemical z supply and other in chemical x supply, but those are too small for creating adequate flow. Other valves need to be used.

6. Ergonomics / HMI: Replacement air valve is in non-ergonomic position. Operator needs walk to a different storey and sometimes in the corridor there are auxiliary items along the passage. The valve is overhead, so the position is not the most ergonomic. There is a certain chemical y auto-valve, which needs to be in an ignition position (operated from control room), otherwise it does not open (when operator needs to further the process). This would be good to know in advance. HMI is not good in this case because the meter is far away, you need to go see the valve position yourself. It would also be good to see certain readings from the field. Chemical z measurement does not show accurate readings (does not show low flow) therefore it is a little at random to set the chemical z flow. Hence chemical x flow must be set approximately so high that right ratio of chemicals is ensured. It is sometimes a bit difficult to visually observe the visible change in the process (this is required in certain task) behind the sight glass. Other aspects are at a nominal level.

7. Fitness for Work: Working at night can make you tired. Some level of tiredness can be a part of shift work. During night shift, it is especially difficult moment to mentally orientate oneself to failure situations in the early hours of the morning (at the end of the shift). Worker must pull oneself together for a moment. The health and the fitness for duty of the staff is monitored by medical examinations. If vision or hearing is poor, then suitability for the job is assessed. Fitness for work is overall at a nominal level, no unfit personnel conduct the start-up.

8. Work Processes: The aim is to give the work shift a peace of mind so they can do the job without interruptions. Even though there is an aim to provide uninterrupted state to do the job, the phone does ring at times. During a shift handover, you might miss something if you have had a lot of events and have not remembered to write down something. That is, forgetting can happen, but as a rule, workers try to tell everything. Communication is done between the control room and the operation by radio telephones during the ignition process. If, for some reason, communication fails, the operating side will not start the process, but will wait for the connection to work again. The procedures are designed to maintain critical security functions. Work processes are at a nominal level.

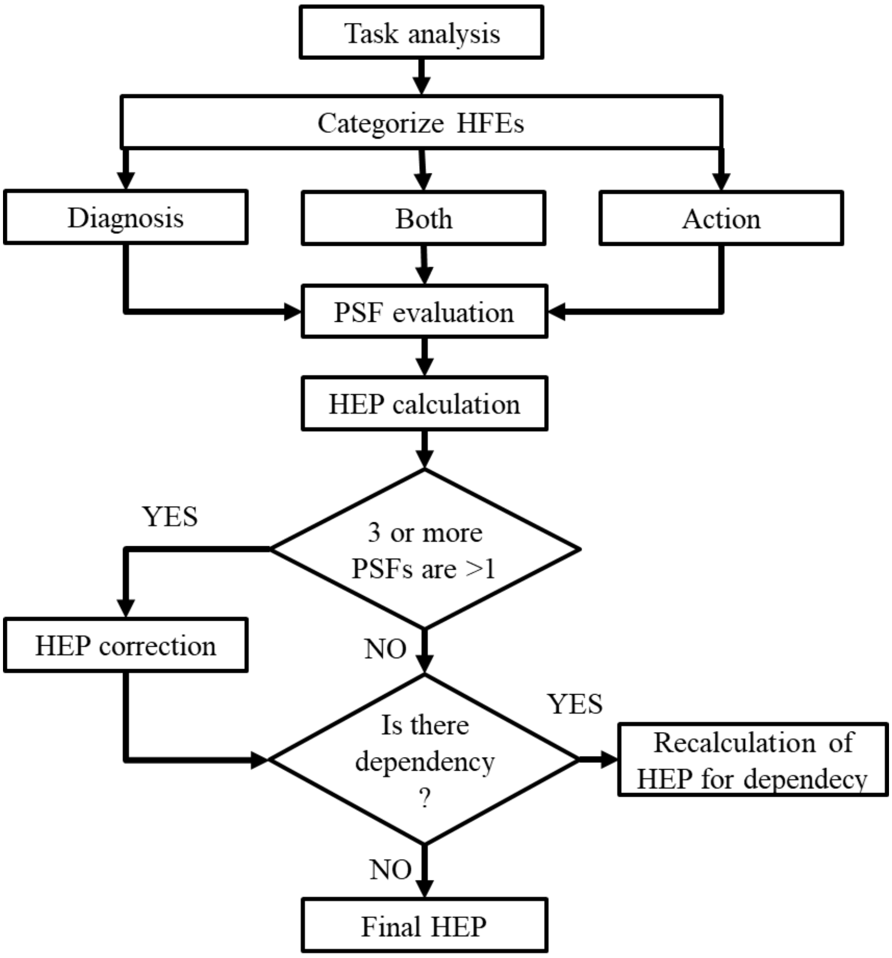


Figure 14 SPAR-H process chart (modified Jahangiri, et al., 2016, 7)

Quantitative evaluation of the human error probability according to SPAR-H includes the phases presented in Figure 14 (Jahangiri, et al., 2016, 7). First the tasks are identified. Each task has a certain human error probability (HEP), a change that human failure event (HFE) takes place. Human failure events are categorized either as action based, diagnosis based or both. Diagnosis refers to more complex tasks that require cognitive processing. Action refers to simpler execution tasks such as turning a valve. Action tasks have a nominal human error probability (NHEP) value 0,001 and diagnosis tasks have value 0,01. (Aliabadi, et al., 2019, 5.) After HFEs are categorized, the levels of performance shaping factors are established regarding the SPAR-H worksheet in Appendix III: Table 19. Each of those eight performance shaping factors have their independent effect to the final human error probability. (Aliabadi, et al, 2019, 5.) The human error probability is calculated with Equation 1 (Jahangiri, et al., 2016, 8). This equation was used for chemical z supply HEP calculations for tasks 1, 3,4 and 5 (Table 16).

$$HEP = NHEP * PSF_C \quad (1)$$

If there are three or more PSFs which affect negatively (value is higher than 1), HEP value needs to be corrected. In that case the HEP is calculated with Equation 2. (Jahangiri, et al., 2016, 9.) This equation was used for chemical z supply task 2 (Table 16).

$$HEP = \frac{(NHEP * PSF_C)}{NHEP\ (PSF_C - 1) + 1} \quad (2)$$

Performance shaping factor composite (PSF_C) value, which is needed in the human error probability calculation, is calculated with Equation 3 (modified Aliabadi, et al., 2019, 5).

$$\prod_{1}^{8} PSF_C = PSF_1 * PSF_2 * PSF_3 \ldots * PSF_8 \quad (3)$$

The last phase is to determine is there a dependency between tasks. If not, then the final HEP is achieved. If there is, then the HEP needs to be re-calculated for dependency using a specific worksheet (Appendix III: Table 20). (Jahangiri, et al., 2016, 9-10.) There is dependency between events if the existence of one event impacts the possibility of another event. Human factor event related dependency is connected to the mindset of the operator. The operator has a persistent, wrong mental model about the situation on hand. (Whaley, et al., 2011, 14, 16.)

The levels of dependency in SPAR-H are: zero, low, moderate, high and complete. The levels are determined by looking into factors: absence/ presence of additional cues, same/ different location, close in time /not close in time, same/ different crew. Additional cues (for example information from alarms or other instruments, from co-workers) can help to break out from the wrong mental mode. They can help the operator to readjust their thinking pattern. The possibility of incorrect mindset forming is increased when the same crew or person always works with the same task. If tasks are not immediately close in time, it enables the working memory to empty. Tasks in different locations can cause disturbance to the script and new information may emerge. (Whaley, et al., 2011, 15, 17.)

When the procedures are well-working and the situation is normal (not an emergency), highly likely there is no dependency. Analyst still should examine the operations and consider is there a possibility that incorrect state of mind could develop and are there some factors which aid breaking that mindset to erase dependency. (Whaley, et al., 2011, 17.) Regarding chemical z supply calculations, it is assumed that there is no dependency in normal conditions, since it was established that the procedure is in nominal level and no compelling reasons for dependency were found.

If any final HEPs are 1, the probability of failure is 1, which means that failure will happen. Human Error Probability was calculated for chemical z supply (Table 16). This phase was identified as critical during the meeting with the client.

Average of HEPs for chemical z supply was 0.04 (Table 16). The biggest possibility to human error (0.2) is in the task 2. It requires cognitive processing (diagnosis task) and the ergonomics/ human-machine interface is poor (it is sometimes difficult to visually observe the change in process through seeing glass). The phase includes evaluating the situation with incomplete information (the local flow measurements do not show low flows). If the valve is opened too much, there is a risk of chemical leakage which causes a danger of personal injury. This elevates the stress level, which is also performance shaping factor. In this instance the operator is experienced (non-qualified personnel are not allowed to perform the task) which affects positively to the human error probability (decreases HEP).

Table 16 Calculating human error probability in chemical z supply according to SPAR-H (modified Jahangiri, et al., 2016, 8-9)

Chemical z supply tasks	1. Open valve xxx to a start-up position from the control room	2. Open chemical z manual valve until a visible change in process occurs	3. Close the air valve approximately halfway	4. Continue closing the air valve and at the same time open chemical z supply valve for one round	5. Open the ejector by-pass valve
Operator	Control room personnel	Process operator	Process operator	Process operator	Process operator
Available time	1	1	1	1	1
Stress/ stressors	1	2	2	2	2
Complexity	1	2	1	2	1
Experience/ training	0.5	0.5	0.5	0.5	0.5
Procedure	1	1	1	1	1
Ergonomics/ human-machine interface	1	10	1	1	10
Fitness for duty	1	1	1	1	1
Work processess	1	1	1	1	1
PSFc= ΠPSFs	0.5	20	1	2	10
Action or diagnosis or both	A	D	A	D	A
NHEP	0.001	0.01	0.001	0.01	0.001
HEP	**0.0005**	**0.2**	**0.001**	**0.02**	**0.01**

The probability of error could be decreased by adding more sensitive local measurement and aiding the visual observation. By improving ergonomics/ human-machine interface to a nominal level (multiplier 1), HEP of task 2 could be decreased from 0.2 to 0.02.

Task 4 had the second biggest human error probability. If the chemical z valve is opened too much, the ratio of chemicals in the chemical production chamber will potentially be incorrect, which could lead to an explosion. This elevates the stress level. Task 4 is a diagnosis task since it includes multiple simultaneous actions and requires cognitive processing.

4.5.3 Bowtie diagrams of critical events in the chemical production process start-up

The Human Factor Management Service concept (see Chapter 4.4) includes human error identification, human reliability analysis and safety culture assessment. Since there was interest to further examine and visualize certain critical events, bowties were conducted instead of a safety culture evaluation. A bowtie diagram can be used to illustrate critical events and related barriers in a process. After critical events are identified during previous process safety and/ or human factors evaluations, bowties are done for each of the critical events to visualize threats, consequences, and barriers. The bowties in Figure 15 and Figure 16 were conducted based on the results of Action Error Analysis (see Chapter 4.5.1. Detailed results of AEA are not available due to confidentiality).

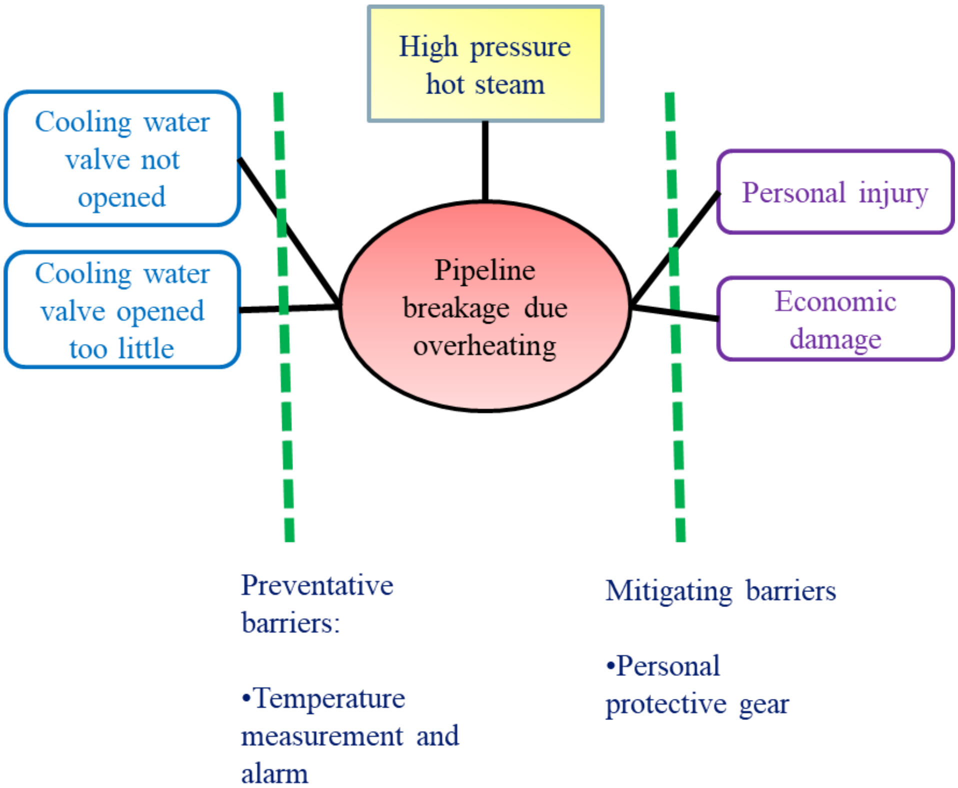


Figure 15 Bowtie diagram of opening ejector cooling water valve

There is a bowtie diagram for opening cooling water valve in Figure 15. If the cooling water valve is not opened or it is opened too little, there will not be adequate water flow to the ejector cooling system and the pipeline heats up. This can result to pipeline breakage. If the pipeline breaks, hot steam ejects to the factory hall. This causes a danger of personal injury to the nearby workers. Economic losses are also caused due to standstill in the production and damage to the equipment. It is possible to try to prevent the pipeline breakage using temperature measurement and alarm. When the alarm sets off, the process operator can apply corrective actions to recover the situation before the critical events happens. If the preventative barriers fail and the critical event happens, it is possible to try to lessen the consequences with mitigating barriers. In this case with personal protective gear the severity of injuries can be decreased.

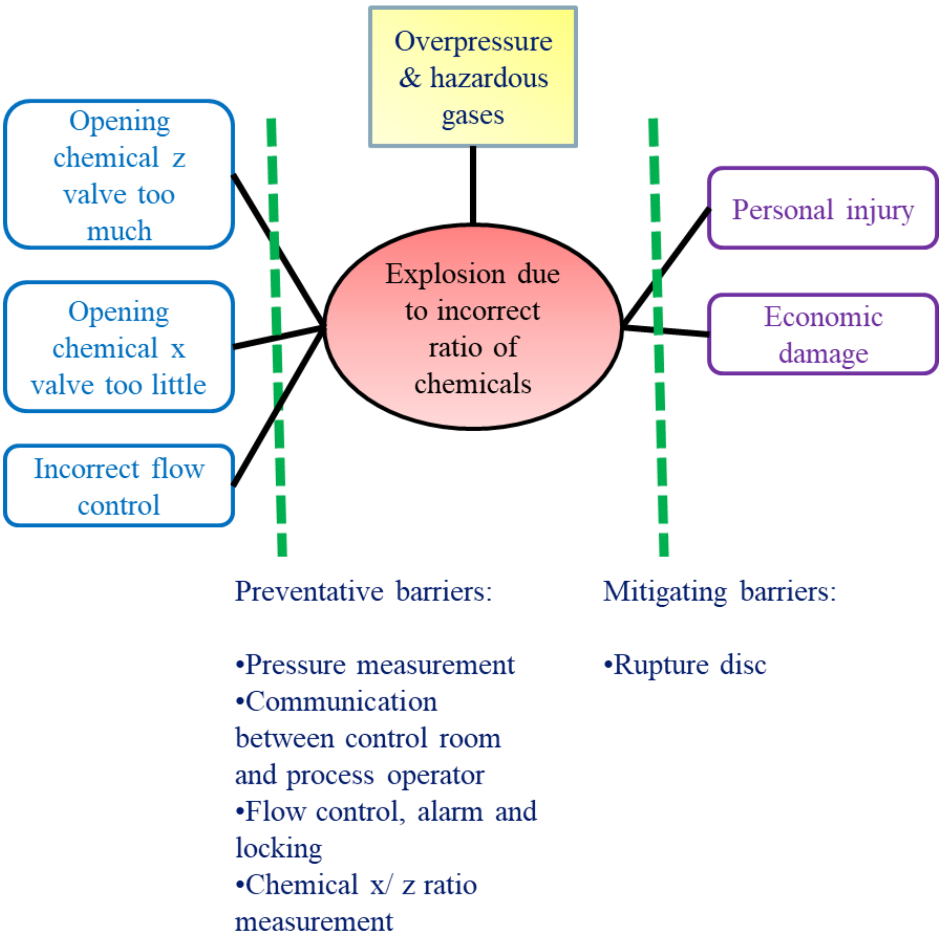


Figure 16 Bowtie diagram for supply flows in chemical production

Bowtie diagram for chemical production is presented in Figure 16. Correct ratio of chemicals is important. If the chemical z valve is opened too much or the chemical x valve is opened too little, there is a risk that the ratio will be incorrect. There are also some automatic flow controls. If chemical x flow control is not put on automatic, the flow does not follow chemical z flow and there will potentially be incorrect ratio of chemicals. There are several preventative barriers. While doing the task the control room personnel and process operator keeps in contact with radiotelephone. Chemical x/ z ratio measurement aims to prevent incorrect ratio which could lead to explosion. Pressure measurement aims to detect undesirable changes so that the personnel could apply corrective actions. Chemical x flow control aims to ensure that there is enough flow and if not, the automatic system will alarm and goes to lock-down. If the explosion happens nevertheless, there will be economic damage and risk of personal injury. As a mitigating barrier the chemical production equipment has a rupture disc. When the pressure rises, it breaks to release the pressure so that the explosion is more controlled.

5 CONCLUSIONS AND DISCUSSION

Within an organization human factors should be considered within all phases of operational lifecycle to ensure safe operations. This thesis provided basic knowledge about human factor management in chemical and process industries and acts as a starting point for further development work within the company. The applied section about service design provides a concept and a pilot which can be utilized later when human factor management service is tested at client facilities.

Action Error Analysis is currently in use at AFRY. Potential methods to be used instead of Action Error Analysis could be SPEAR or SHERPA in cases when more comprehensive information is needed. Action Error Analysis does not consider performance shaping factors, unlike SPEAR. SPEAR has external error mode taxonomy considering errors such as omission or action incomplete (similar with Action Error Analysis). But in addition to that it has performance shaping factors taxonomy which consider environmental or situational factors. SHERPA has extensive error mode taxonomy with 25 error modes. When they are gone through, a profound picture of human error is obtained. In comparison, Action Error Analysis has 11 error modes. It must be thought through which level of comprehensiveness is needed or applicable within the project timeline.

SPAR-H was tested during the thesis and the usability seems promising. There are eight categories of performance shaping factors that might influence the task steps. It is relatively simple list to go through. But since the list is simple, there might be some other performance shaping factors that influence the formation of human errors, but they are not considered. HEART has 38 different human performance shaping factors. It offers a bigger possibility to detect the relevant factors. Other difference between SPAR-H and HEART is that SPAR-H includes dependency evaluation between task steps and HEART does not. If there is no need or interest to do the dependency calculations, HEART can be used. There is reassuring validity data available about the HEART method. Based on the experience gained from the pilot, a separate evaluation day with the client would be needed to thoroughly examine all the potential error producing conditions which could affect the task under examination. It is not possible (or it is very difficult) to conduct a thorough performance shaping factor evaluation in midst of other analysis.

The results of Action Error Analysis can be utilized to identify areas of improvement and to improve the work processes and working instructions. SPAR-H can provide information about the conditions which can lead to an accident. These conditions are related to human capabilities (fitness for duty, level of experience), to the qualities of the task (complexity, stressors), to the work environment (ergonomics/ HMI) and to the operation (the quality of the procedures and work processes). By reducing or improving those factors it is possible to increase the safety level. This is especially beneficial in a situation where new perspectives are needed to eliminate or decrease the amount of error producing conditions. In comparison, action Error Analysis focuses on the questions of what is likely happen and what are the consequences (human error identification). SPAR-H focuses on why the incidents are likely to happen and what is the numerical possibility of a human failure. Therefore SPAR-H complements Action Error Analysis by offering new kind of information about the same situation.

SPAR-H can be used for example to compare the human error probability of different operators doing a same task or used in sensitivity analysis to examine the effect of changing the performance shaping factors for the better. Quantitative methods can be also used to support investment decisions by showing the concrete numbers of safety improvement. The numerical HEP result points out the tasks in which the possibility of a failure is greater than in other tasks. This helps to focus improvement actions. A bowtie diagram can be used to illustrate critical events and related barriers in a process. Bowties could be useful if certain events and their protective barriers needs to be visualized and examined further after human error identification or other safety analyses.

In addition to human error identification and human reliability analysis it would be beneficial to examine the safety culture and management of well-being within the company in order to thoroughly examine all the relevant human factor issues. Several methods could be combined to gain comprehensive picture of the situation. WEHRA combines qualitative and quantitative tactics to examine environmental ergonomics factors. Coaching could be used to get observation data, to utilize conversations and teaching methods to pinpoint and improve human factor related safety concerns. With questionnaires it is possible to gather the kind of information that the employees do not dare to reveal because of social pressures.

Further studies could be to research and experiment with human factors management method categories which were not examined closely in this thesis, for example design methods. Other interesting area of research could be examining the most common reasons for human error in a specific field of industry (for example pulp and paper industry) and based on the results developing a tailored list or guidewords (error modes) for error identification and/ or developing a check-list for human factors consideration.

The thesis topic was very interesting and a new field of study for me. This, on the other hand, was a benefit since I could look into the topic with "fresh pair of eyes", without entrenched preconceptions. However, because of the novelty a plenty of work was needed in getting to know and in orientation to the topic. It was a surprise that the management of human factors has a very long tradition of research and, also the fact that there is a great deal of research information and abundance of management methods and techniques. Other surprising element was that despite the fact that research data and methods are so abundant and the benefits to safety level improvement are widely researched, still the means of controlling human factors are not routinely (systematically) used in industry in Finland and often the main emphasis is on the technical aspects of process safety.

Depending on the work communities there may be indifference and unsafe attitudes at any level of the organization, and human risk or well-being factors may not be valued as highly as they should be. Managing organizational change and improving the safety culture can often be challenging due to complex social issues. There may be positive improvement in the organization, but in the end, even good ideas can fail, against the opposition of certain key people. Improving safety level in an organization requires commitment from all of the organizational levels. Even good methods will fail if their benefits/ results are not implemented properly in the organization.

A work system is a complex entity formed by human-machine and human-human interactions. The challenge with assessment methods is obtaining the right kind of correct information. Firstly, a person does not always talk directly about the problem area for many different reasons (person does not want to tell on a co-worker or fears a backlash from the work community). Secondly, one does not always fully understand one's own actions and their causes. There may be certain practices in the work communities that are wrong, but the members of the community are used to the fact that this is always the case here. A new member of the work community may for a moment be able to wonder, even rebel or try to improve things but very soon after realizing this is useless, adapts to one's destiny and becomes blind to the problem areas.

In this thesis the research focus was in the chemical and process industry and methods suitable for a safety engineer. However, some of these methods can be used more widely in the industrial settings, either directly or after modification. Many of the methods for managing human factors are such that, although they have been developed for a particular industry (such as aviation), they can also be used to evaluate other industries with complex and dynamic work systems (for example the chemical industry). Aviation and nuclear are the industries that have been at the forefront of human risk assessment, aviation already during World War II and nuclear around the late 70s (especially after accidents such as the Tree Mile Island accident). One example of a simple method which can be used in aviation, in the chemical industry or in nuclear energy production, is three-way communication. It is a worker-centric human performance tool in which sender states a message, receiver repeats it back and sender acknowledges the reply. This is process ensures that the safety critical information is delivered right.

There are dozens of human reliability and error analyzes and they have many similarities. Many have taxonomies for various functions that a person erroneously makes or fails to perform (for example omission or right action to wrong object). Humans are very complex with their cognitive processes and very comprehensive methods have been developed. In these, the challenge is resource intensity. It is possible to gather information more freely without rigid taxonomy constraints by conducting interviews, but they should be structured to find out what is needed. No single method alone gives a complete picture of the overall situation. It would often be useful to use several different methods with different theoretical frameworks, data acquisition methods or objectives. Often, human error and accident situations are affected by a great many different factors that also have synergies. For example, fatigue negatively affects thought processes, and if the employee is also inexperienced or site training is insufficient, the probability of error increases due to the combined effect of the before mentioned factors.

6 SUMMARY

Figure 17 presents the thesis process. There were two research questions: 1) What kind of human factors management methods there are? 2) Which methods could be used in the Human Factors Management Service concept? During literature review (qualitative content analysis) research question 1 was answered. During service design section the research question 2 was answered.

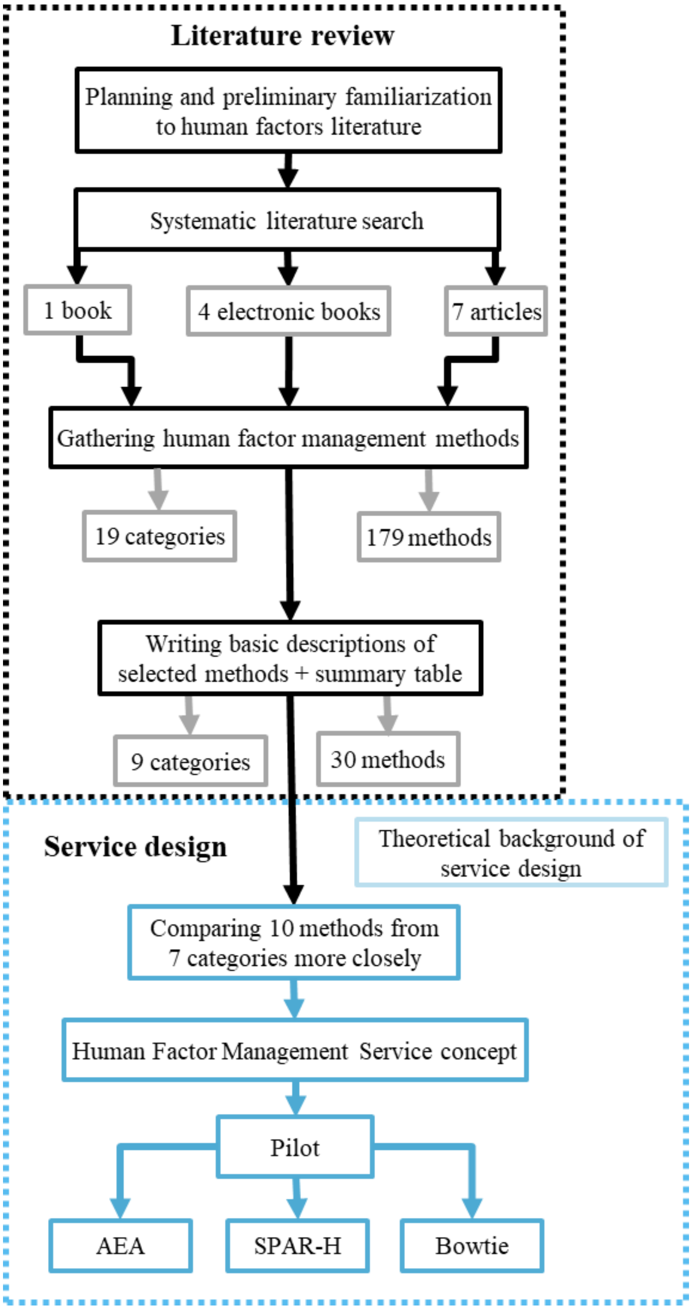


Figure 17 Thesis process

There are hundreds of methods, measures and techniques which can be used to manage human factors in industrial settings. Within this thesis research 179 were extracted from the analyzed materials and divided into nineteen categories. There was such an abundance of methods that elimination needed to be done. The emphasis was put on methods which evaluate human error/ failure in industrial process tasks, human factors in occupational safety and manage safety culture and well-being of employees.

After two elimination rounds ten methods from seven categories were established as promising: Systematic Human Error Reduction and Prediction Approach (SHERPA), System for Predictive Error Analysis and Reduction (SPEAR), Human Error Assessment and Reduction Technique (HEART), Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H), bowtie diagram, Action Error Analysis (AEA), coaching, questionnaires/ surveys, Safety Critical Task Analysis (SCTA) and Work Environment Health Risk Analysis (WEHRA). From the before mentioned Action Error Analysis, Standardized Plant Analysis Risk-Human Reliability Analysis Method and bowtie diagrams were tested in a pilot related to a chemical production plant.

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Table of collected methods

CODEX

- Method category (Category)
- Code of the reference (Code): B= Book, EB= Electronic book, EA= Electronic article

Table 17 Methods collected from the reference materials

Category	Method	Code
Accident analyses	Functional Resonance Accident Model (FRAM)	B1, EB4
	Human Factors Analysis Classification System (HFACS) and Reason's Swiss Cheese	B1, EB4, EA4, EA6, EA7
	Johnson's Management Oversight and Risk Tree (Johnson's MORT)	EB3, EB4
	Root Cause Analysis	EB4
	The Systems Theory Accident Modelling and Process (STAMP)	B1, EB4
	The Safety Occurrence Analysis Methodology (SOAM)	B1
	Why-Because Analysis (WBA)	B1
Diagrams	Bayesian Belief Network (BBN) for Human Reliability Model-ling	EB2
	Bayesian Networks LOPA	EB4
	Bayesian Networks to model human error probability	EB4
	Bowtie diagram	EB1, EB2, EB3, EA4
	Decision Action Diagrams (DADs)	B1
	Event Tree Analysis (ETA)	B1, EB2, EB4, EA2
	Fault Tree Analysis (FTA)	B1, EB2, EB4, EA1, EA2
	Murphy's diagram	B1
	Operation sequence diagrams (OSDs)	B1
	Petri networks	EB4
	Reliability block diagram (RBD)	EB2
	Work Organization Possibilities (WOP) diagram	EA5
Design methods	Allocation of function analysis	B1

	Automated cooling systems	EB1
	Collaborative Analysis of Requirements and Design (CARD)	B1
	Contextual inquiry	B1
	Design with Intent (DwI)	B1
	Emergency planning	EB3
	Emergency shutdown device (ESD)	EB1
	Fire & gas protection systems	EB1
	Focus groups	B1, EB1
	Mission analysis	B1
	Passive engineered safeguards	EB1
	Process design checks	EB3
	Plant equipment checks	EB3
	Rich Pictures	B1
	Scenario-based design	B1
	Storyboards	B1
	The Wizard of Technique	B1
	Task-Centered System Design (TCSD)	B1
	User-Centered Design (UCD)	EB1
	Uninterruptible Power Supply (UPS)	EB1
First generation human reliability analyses (HRA)	Human Cognitive Reliability (HCR)	EB2
	The Human Error Assessment and Reduction Technique (HEART)	B1, EB1, EB2, EB3, EB4, EA3
	Justification of Human Error Data Information (JHEDI)	EB4
	Systematic Human Action Reliability Procedure (SHARP)	EB2
	Success Likelihood Index Method (SLIM)	EB2, EB3, EB4
	Empirical Technique to Estimate Operator's Error (TESEO)	EB2, EB3
	Technique for Human Error Rate Prediction (THERP)	EB2, EB3, EB4, EA2, EA3
	Operator Action Tree (OAT)	EB2
Second generation human reliability analyses (HRA)	A Technique for Human Error Analysis (ATHEANA)	EB2, EB4, EA2, EA3
	Cognitive Reliability and Error Analysis (CREAM)	B1, EB1, EB2, EB4, EA2, EA3

	Standardized Plant Analysis Risk–Human Reliability Analysis (SPAR-H)	EB2, EB4, EA2, EA3
Third generation human reliability analyses (HRA)	Systematic Human Error Reduction and Prediction Approach (SHERPA)	B1, EB1, EB2
	Probabilistic Cognitive Simulator (PROCOS)	EB2
Other human reliability analyses (HRA)	Generic Error Modeling System (GEMS)	EB1
	Human Error and Recovery Assessment (HERA) framework	B1, EB4
	Human Reliability Analysis+ fuzzy data sets (for example CREAM)	EB2, EB4
	Nuclear Action Reliability Assessment (NARA)	EB1
	Technique for Retrospective and Predictive Analysis of Cognitive Errors (TRACEr)	B1, EB1
Human error identification	Action Error Analysis (AEA)/ Human Error HAZOP	B1, EB1, EB3, EB4, EA1, EA2
	Human Error Identification in Systems Tool (HEIST)	B1
	Human Error Template (HET)	B1
	Pattern Search Method	EB3
	Predictive Human Error Analysis (PHEA)	EA3
	System for Predictive Error Analysis and Reduction (SPEAR)	B1, EB3
	Technique for Human Error Assessment (THEA)	B1
Interface analyses	Checklists	B1
	Heuristic Analysis	B1
	Interface Surveys	B1
	Layout Analysis	B1
	Link Analysis	B1, EB1
	Nielson's 10 heuristics	B1
	The Post-Study System Usability Testing Questionnaire (PSSUQ)	B1
	The Purdue Usability Testing Questionnaire (PUTQ)	B1
	The Questionnaire for User Interface Satisfaction (QUIS)	B1
	Repertory Grid Analysis	B1
	Schneiderman's Eight Golden Rules	B1
	The System Usability Scale (SUS)	B1
	Usefulness, Satisfaction and Ease of Use (USE) Questionnaire	B1
	User Trials	B1
	Walkthrough Analysis	B1
Novel methods	Human Factors Failure Modes and Effects Analysis (HF-FMEA)	EB1, EA2

	Blended HAZID (BLHAZID)	EB4
	Enhanced System Hazard Analysis (E-SHA)	EA2
Management of safety culture and well-being	Antecedent-Behavior-Consequences (ABC) Analysis and Stimulate-Organism-Reaction (S-O-R) model	EB1, EA7
	Behavior Based Programs	EB1
	Behavioral Gap Analysis	EB1
	Cultural Progression Assessment	EB1
	Coaching	EB1
	EPSC’s Responsible Care program	EB1
	EU-OSHA Culture Assessment Document	EB1, EB4
	Fatigue Risk Management	EB1
	Feedback from workforce	EB3
	Chronic Stress Risk Assessment	EB1
	Human Factors Integration (HFI) + Early Human Factors Analysis (EHFA)	EB1, EB2
	Human Performance Standard	EA4
	Inspection, maintenance and testing regimes	EB1
	Keil Centre’s Human Factors Maturity® model	EB1, EB4
	Log Out Tag Out System (LOTO)	EB1
	Observations	EB1
	OECD guidance for senior leaders in high hazard industries document	EB1
	Permit-To-Work Systems	EB1
	Psychometric Questionnaire Surveys	EB1
	Safety Climate Questionnaires/ Surveys	EB1
	Shell’s Heart and mind program	EB1
	Software, Hardware, Environment, Liveware (SHELL) Model	EB1
	Shell’s Tripod Delta tool derived from Reason’s Swiss cheese	EB1
	Safety Management System (SMS)	EB1, EB2
	Work Environment Health Risk Analysis (WEHRA)	EB1
	Worker-centric human performance tools	EB1
Performance time prediction	Critical Path Analysis (CPA)	B1
	Key Stroke Level Model (KLM)	B1
	Timeline Analysis	B1
Situational awareness assessments	Propositional Networks	B1
	The Situation Awareness Global Assessment Technique (SAGAT)	B1

	Situational Awareness Requirements Analysis	B1
	The Situation Awareness Rating Technique (SART)	B1
	Situational Awareness Subjective Workload Analysis (SA-SWORD)	B1
	The Situation Present Assessment Method (SPAM)	B1
Task analyses	Goals, Operators, Methods and Selection Rules (GOMS)	B1
	Hierarchical Task Analysis (HTA)	B1, EB1, EB3
	The Sub-Goal Template (SGT)	B1
	Safety Critical Task Screening/ Analysis (SCTA)	EB1
	Task Analysis for Error Identification (TAFEI)	B1, EB2
	Tabular Task Analysis (TTA)	B1, EB1
	Task Decomposition	B1,
	Verbal Protocol Analysis (VPA)	B1
	Operational Task Analysis (OTA)	EB1
Task analyses: cognitive	Applied Cognitive Task Analysis (ACTA)	B1
	The Critical Decision Method (CDM)	B1
	Critical Incident Technique (CIT)	B1
	Collegial Verbalization	B1
	Cognitive Walkthrough	B1
	The Concurrent Observer Narrative Technique (CONT)	B1
	Cognitive Work Analysis (CWA)	B1, EA5
	Object-Oriented Cognitive Task Analysis and Design (OOCTAD)	B1
Team assessments	Behavioral Observation Scales (BOS)	B1
	Coordination Demand Analysis (CDA)	B1
	The Cockpit Management Attitudes Questionnaire (CMAQ)	B1
	The Comms Usage Diagram (CUD)	B1
	The Decision Requirements Exercise (DRX)	B1
	Groupware Task Analysis (GTA)	B1
	Hierarchical Task Analysis for Teams (HTA(T))	B1
	Questionnaires for Distributed Assessment of Team Mutual Awareness	B1
	Social Network Analysis (SNA)	B1
	Targeted Acceptable Responses to Generated Events or Tasks (TARGETs)	B1
	Team Cognitive Task Analysis (TCTA)	B1
	Team Communications Analysis	B1

	Team Workload Assessment	B1
	Team Task Analysis (TTA)	B1
	Task and Training Requirements Analysis Methodology (TTRAM)	B1
Training assessments	Competence management system	EB1
	Training Gap Analysis (TGA)	EB1
	Training Needs Analysis (TNA)	EB1
	Training Options Analysis (TOA)	EB1
Workload and staffing assessments	The Bedford scale	B1
	Cognitive Task Load Analysis (CTLA)	B1
	The DRA Workload Scales (DRAWS)	B1
	Instantaneous Self-Assessment (ISA)	B1
	The Malvern Capacity Estimate (MACE) Technique	B1
	The Modified Cooper Harper Scale (MCH)	B1
	The Mental Workload Index (MWLI)	B1
	The National Aeronautics and Space Administration Task Load Index (NASA-TLX)	B1
	The Projective Workload Assessment Technique (Pro-SWAT)	B1
	The Projective Workload Dominance Technique (Pro-SWORD)	B1
	The Subjective Workload Assessment Technique (SWAT)	B1, EB1
	The Subjective Workload Dominance Technique (SWORD)	B1
	Subjective Workload Assessment	EB1
	Task Performance	EB1
	The Time-Line Analysis and Prediction (TLAP)	EB1
	Visual, Auditory, Cognitive, and Psychomotor (VACP/VCAP)	EB1
	Workload Index (W/INDEX)	EB1
	The workload profile technique	B1, EB1
Other methods	Agent-Based Modeling (ABM)	EB4
	Barrier management	EB4, EA4
	Information, Decision, and Action in Crew Context (IDAC) model for human reliability analysis	EB4
	Monte Carlo Experiment/ Simulation	EA5
	Risk Trend Analysis	EA7
	Set Pair Analysis	EA7
	SPA-Markov Chain Risk Prediction Method	EA7
	What-If Analysis	EB2, EB3

Summary table and visualization of the thirty selected methods

These methods were selected for further examination. Basic descriptions were written in Chapters 3.4-3.10. Additionally, the following aspects were analyzed: training time, application time, type (qualitative or quantitative), level of details, whether a psychologist or experienced human factor specialist is necessary and is a specific computer program necessary (Table 18).

Table 18 Summary of the thirty selected methods (modified Edmonds, et al., 2016, 78-79, 83, 87-88, 113-115, 122, 182, 272, 323-327, 389-390, 462-465; De Felice & Petrillo, 2018, 27-28, 30-38; Mannan, 2014, 11, 86-87 ; Pasman, 2015, 94-95 ; Stanton, et al., 2013, 41-43, 71, 118, 130-131, 136-137, 140, 149-153, 175-177, 188-189, 197-198, 201-205, 207-210, 217-220)

	Training time*	**Psychologist/ experienced human factor professional necessary**	**Application time**	**Specific computer program necessary**	**Level of details**	**Quali-tative (QL)/ Quantita-tive (QN)**
Accident analysis						
HFACS-OGI	Low•	No	Low•	No•	High•	QL•
Johnson’s MORT	Medium	No	High•	No•	High•	QL•
Diagrams						
Bowtie diagram	Low	No	Medium	No	Low-medium	QL•
ETA	Low•	No	Medium•	No•	Low-medium	QL•
FTA	Low•	No	Medium•	No•	Low-medium	QL•
First generation human reliability analyses						
HEART	Low•	No	Medium•	No•	Medium	QN•
TESEO	Low	No	Low•	No	Low•	QN•
Second generation human reliability analyses						
ATHEANA	Medium	No	High•	No	High•	QN•
CREAM	High•	Yes•	High•	No•	High•	QN•
SPAR-H	Low	No	Medium	No	Medium	QN•
Third generation human reliability analyses						

SHERPA	Low•	No	Medium•	No•	High•	QL•
Human error identification						
AEA/ Human HAZOP	Low•	No	Medium•	No•	Medium	QL•
HEIST	Low•	Yes•	Medium•	No•	High•	QL•
SPEAR	Low•	No	Medium•	No•	High	QL•
Management of safety culture and well-being						
ABC analysis	Medium	No	Medium	No	Medium	QL
Behavior Based Programs	High	Yes	High	No	High	QL
Behavioral Gap Analysis	Medium	No	Medium	No	Medium	QN
Chronic Stress Risk Management	High	Yes**•	High	No	High	QL/ QN
Coaching	Medium	No	Medium	No	High	QL
Fatigue Risk Management	High	Yes	High	No	High	QL/ QN
Interviews	Low	No	Medium	No	Medium	QL
Keil Centre's Human Factors Maturity® model	High	Yes	High	No	High	QL
Questionnaires/ surveys	Low	No	Medium	Yes/ No***•	Medium	QL/ QN
WEHRA	Medium	No	High•	No	High•	QL/ QN•
Worker-centric human performance tools	Low-Medium	No	Low-Medium	No	Low-Medium	QL
Task analyses						
HTA	Medium•	No	Medium•	No•	Medium	QL•
SCTA	Low	No	Low	No	Low	QN•
TTA	Low•	No	High•	No•	High•	QL•
OTA	Low	No	Medium	No	Medium	QL•
Task analyses: cognitive						
CWA	High•	Yes	High•	No•	High•	QL•

*training a technical professional, ** psychological evaluations or the expertise of medical professionals might be needed, ***can be conducted as online survey or as paper copy survey, •Ranking mentioned directly in the reference literature (other rankings are subjective evaluations based on the descriptions of the methods in the reference materials)

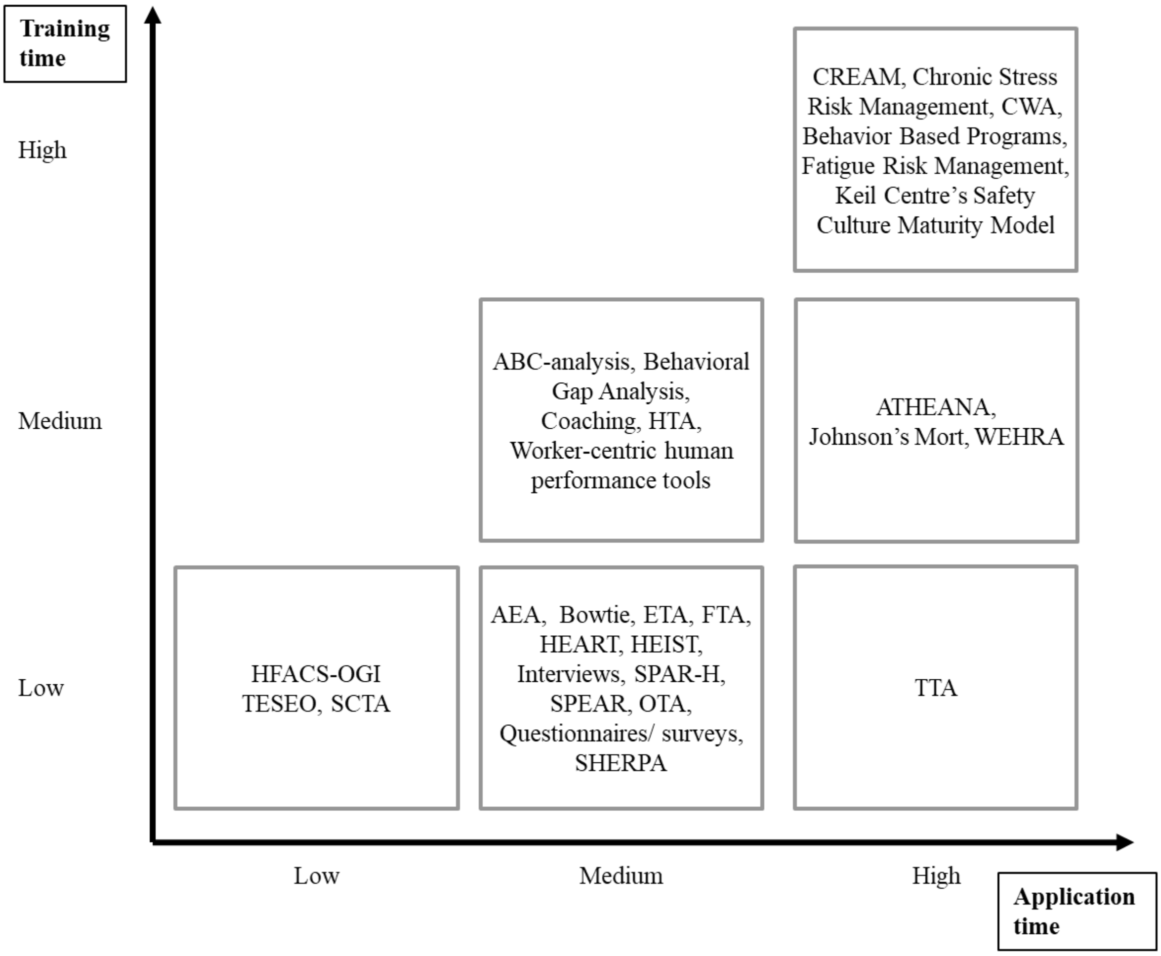

Figure 18 Visualization of the thirty selected methods: Application time and training time

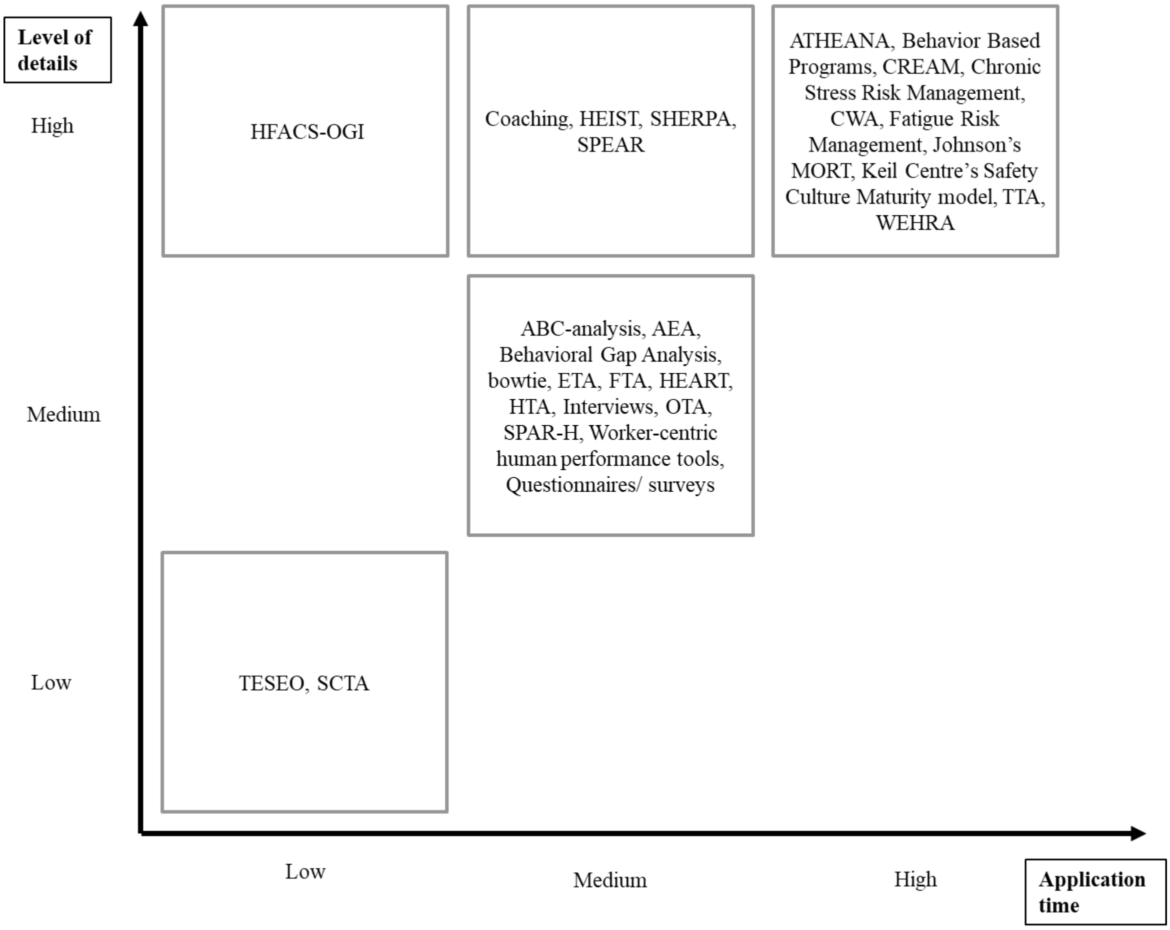

Figure 19 Visualization of the thirty selected methods: Application time and level of details

Worksheets of SPAR-H

Table 19 Multipliers for SPAR-H PSF levels (modified Jahangiri, et al., 2016, 9)

PSF	PSF level	Multiplier
Available time	Inadequate time	P (failure) = 1
	Available time is approximately the time required	10
	Nominal time	1
	Available time is ≥5x the time required	0.1
	Available time is ≥50 x the time required	0.01
Stress/ stressors	Extreme	5
	High	2
	Nominal	1
	Insufficient information	1
Complexity	Highly complex	5
	Moderately complex	2
	Nominal	1
	Insufficient information	1
Experience/ training	Low	3
	Nominal	1
	High	0.5
	Insufficient information	1
Procedure	Not available	50
	Incomplete	20
	Available, but poor	5
	Nominal	1
	Insufficient information	1
Ergonomics	Missing/ misleading	50
	Poor	10
	Nominal	1
	Good	0.5
	Insufficient information	1
Fitness	Unfit	P (failure)= 1
	Degrade fitness	5
	Nominal	1
	Insufficient information	1

Work processes	Poor	5
	Nominal	1
	Good	0.5
	Insufficient information	1

Table 20 SPAR-H dependency worksheet (Jahangiri, et al., 2016, 10)

Condition number	**Crew (same or different)**	**Time (close in time or not close in time)**	**Location (same or different)**	**Cause (additional or not additional)**	**Dependency**	**HEP calculation formula**
1	s	c	s	na	Complete	P (failure)= 1
2				a	Complete	
3			d	na	High	$(1+P_{W/OD})/2$
4				a	High	
5		nc	s	na	High	
6				a	Moderate	$(1+6*P_{W/OD})/7$
7			d	na	Moderate	
8				a	Low	$(1+19*P_{W/OD})/20$
9	d	c	s	na	Moderate	$(1+6*P_{W/OD})/7$
10				a	Moderate	
11			d	na	Moderate	
12				a	Moderate	
13		nc	s	na	Low	$(1+19*P_{W/OD})/20$
14				a	Low	
15			d	na	Low	
16				a	Low	
17					Zero	$P(failure)=P_{W/OD}$