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Report

Measures against hydrocarbon leaks: taxonomy, effect and costs

A literature study of measures against hydrocarbon leaks

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ABSTRACT

This report presents the results from a literature study on measures against hydrocarbon (HC) leaks. The literature study is a part of the project *How to get it right*, initiated and financed by Statoil with the aim of developing a guideline that can help leaders in the company to identify measures that are effective against HC leaks, and the economic costs related to different measures. Four research questions are asked in the literature study. These are: (1) Do there exist previously developed methods to evaluate the effect of measures against HC leaks or other incidents with major accident potential? If this is the case, how are these methods designed? (2) Do there exist previously developed taxonomies to categorize measures against HC leaks or other incidents with major accident potential? If this is the case, how are these taxonomies constructed? (3) According to the literature, which types of preventive measures against HC leaks have been proven effective, which have not and under which conditions are different measures most effective? (4) Which methods have previously been applied in order to categorize and evaluate the costs related to measures after HC leaks or other incidents with major accident potential?

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Executive summary

This report presents the results from a literature study on measures against hydrocarbon (HC) leaks. The literature study is a part of the project *How to get it right*, initiated and financed by Statoil with the aim of developing a guideline that can help leaders in the company to identify measures that are effective against HC leaks, and the economic costs related to different measures. Four research questions are asked in the literature study. These are: (1) Do there exist previously developed methods to evaluate the effect of measures against HC leaks or other incidents with major accident potential? If this is the case, how are these methods designed? (2) Do there exist previously developed taxonomies to categorize measures against HC leaks or other incidents with major accident potential? If this is the case, how are these taxonomies constructed? (3) According to the literature, which types of preventive measures against HC leaks have been proven effective, which have not and under which conditions are different measures most effective? (4) Which methods have previously been applied in order to categorize and evaluate the costs related to measures after HC leaks or other incidents with major accident potential?

Regarding research question 1, the study has identified two methods that have been developed in order to model the effect of proposed risk reducing measures related to HC leaks. These are the BORA-Release method and the Risk OMT model. Furthermore, parts of a method for modelling offshore helicopter safety (the HSS model), largely based on expert judgements, is evaluated as directly relevant for the project. As an alternative to methods designed to model risk, methods designed for process evaluations should be useful. Process evaluations, in contrast to risk modelling, are highly relevant when the goal is to collect information on how a given measure could be implemented successfully and has been recommended within the nuclear power industry as well. No methods for evaluating the *observed* effects of measures has been identified. This is not unexpected since HC leaks are an example of so-called low-probability events. Hence, the frequency of events is too low for statistical measurements of before/after effects on the output variable.

As regards research question 2, the study has identified 7 publications offering literature that is relevant for taxonomies to categorize measures against HC leaks. These are in the form of industry standards, user guidelines and research literature. None of the taxonomies is applicable in the current project without adaptions and rework, but the strengths and weaknesses identified in the existing classification schemes give valuable input to a revised taxonomy.

Research question 3 is the most wide-ranging of the four research questions. Three qualitatively different types of literature have been identified. The first type is related to measures against HC leaks, specifically. The second type focuses on the characteristics of successful measures in general and how they should be determined, formulated and implemented (referred to as the action process). The third type addresses the main causes of HC leaks and how causes should be avoided. This third type is not related to HC leaks in particular, but of a more generic type – relevant across different industries. Together, the three different types of literature should offer a significant contribution to the question of which types of preventive measures against HC leaks have been proven effective.

The literature related to research question 4 indicate that there are several important aspects that need to be taken into consideration when performing economic analysis of measures to prevent HC leaks. The publications identified address both analysis frameworks and discussions of relevant cost components. The examination of the literature, however, indicates that the final choice of method and framework for analysis should be tailor-made to the application at hand and to the available data.

Norsk sammendrag

Foreliggende rapport presenterer resultatene fra et litteraturstudie om tiltak mot hydrokarbonlekkasjer (HC lekkasjer). Studien er en del av prosjektet *How to get it right*. Prosjektet er initiert og finansiert av Statoil med det formål å utvikle en guideline som kan benyttes av ledere i selskapet for å få informasjon om hvilke tiltak som er effektive mot HC lekkasjer, hvilke som ikke er effektive og hvilke kostnader som er forbundet med ulike typer tiltak. Fire forskningsspørsmål er belyst i litteraturstudien: (1) Finnes det allerede utviklede metoder for å evaluere effekten av tiltak mot HC lekkasjer eller andre hendelser med storulykkepotensial? Hvis så, hvordan er disse metodene utformet? (2) Finnes det allerede utviklede taksonomier for å kategorisere tiltak mot HC lekkasjer eller andre hendelser med storulykkepotensial? Hvis så, hvordan er disse taksonomiene utformet? (3) Hvilke typer av preventive tiltak mot HC lekkasjer er, i henhold til relevant litteratur, bevist effektive, hvilke er ikke effektive og under hvilke omstendigheter er ulike typer av tiltak effektive? (4) Hvilke metoder har tidligere blitt anvendt for å kategorisere og evaluere kostnader knyttet til tiltak mot HC lekkasjer eller andre hendelser med storulykkepotensial?

Når det gjelder forskningsspørsmål 1 har studien identifisert to metoder som er utviklet for å predikere effekten av foreslåtte risikoreduserende tiltak. Disse er BORA-Release og Risk OMT-modellen. Videre er deler av en metode for å modellere offshore helikoptersikkerhet (HSS-modellen) vurdert som direkte relevant for prosjektet. Modellen baseres i stor grad på ekspertuttalelser. Som et alternativ til metoder utviklet for å modellere risiko er også metoder utviklet for å evaluere tiltaksprosess vurdert som relevante. Slike prosessevalueringer er, i motsetning til risikomodellering, svært relevante når målet er å oppnå innsikt i hvordan et gitt tiltak kan bli implementert for å oppnå effekt. Slike evalueringer har blant annet blitt anbefalt i kjernekraftindustrien. I studien har det ikke blitt identifisert metoder som evaluerer effekt på bakgrunn av *observert* lekkasjerate. Dette er ikke uforventet da HC lekkasjer er et typisk eksempel på hendelser med lav sannsynlighet. Frekvensen av lekkasjer er dermed for lav til å kunne benyttes som statistisk mål på effekt av tiltak.

For forskningsspørsmål 2 har studien identifisert 7 publikasjoner som er relevante for taksonomier for å kategorisere tiltak mot HC lekkasjer. Disse publikasjonene er industristandarder, guideliner og forskningslitteratur. Ingen av de identifiserte taksonomiene er direkte anvendbare i prosjektet uten tilpasninger og omarbeidinger. De styrker og svakheter vi finner i de foreliggende taksonomiene er allikevel et godt utgangspunkt for en revidert taksonomi.

Forskningsspørsmål 3 er det mest omfattende av forskningsspørsmålene. Tre kvalitativt forskjellige typer litteratur har blitt identifisert. Den første typen er relatert til tiltak mot HC lekkasjer spesifikt. Den andre typen fokuserer på egenskaper ved effektfulle tiltak generelt og hvordan disse skal bli besluttet, formulert og implementert (omtalt som tiltaksprosessen). Den tredje typen litteratur retter seg mot typiske årsaker til HC lekkasjer og hvordan slike årsaker kan forebygges. Denne typen litteratur er ikke relatert til HC lekkasjer spesifikt, men er av mer generell art – relevant på tvers av ulike industrier. Sammen danner de tre typene av litteratur et viktig bidrag i å belyse spørsmålet om hvilke typer av preventive tiltak som er effektive mot HC lekkasjer.

Litteratur knyttet til forskningsspørsmål 4 indikerer at det er flere sentrale aspekter som må tas i betraktning ved utførelse av økonomiske analyser relatert til tiltak mot HC lekkasjer. De identifiserte publikasjonene adresserer både ulike analytiske rammeverk og diskusjoner av relevante kostkomponenter. Litteraturgjennomgangen indikerer også at valg av metode og analytisk rammeverk bør være skreddersydd til formålet og de tilgjengelige data.

1 Introduction

1.1 Background

During the last 15 years, the Norwegian oil and gas industry has achieved a significant reduction in the number of hydrocarbon (HC) leaks. However, most of this reduction was achieved during the first ten years of the period. During the last five years, the reduction rate has stagnated (PSA, 2016). In order for a positive development to progress, there is a need for further steps in terms of identifying and implementing effective preventive measures. In relation to this, it is necessary to achieve additional knowledge by examining the effect of different measures and the economic costs related to the implementation of the measures.

The project *How to get it right* is initiated by Statoil precisely with this as the primary goal. The objective of the project is to develop a guideline that leaders in Statoil can use to identify measures that are effective against HC leaks and the economic costs related to different measures. The guideline shall be technically oriented in the sense that it should offer advices on how to use information extracted from Statoil's SIOP database as assistance in choosing proper preventive measures. As of today, the SIOP database contains information about causes and involved work processes related to 34 HC-leak incidents. In the database, causes are first categorized by work process or barriers in accordance with Statoil management system. Operational errors are further categorized in accordance to the Compliance & Leadership model with corresponding performance influencing factors (PIF). Technical errors are further categorized in accordance with ISO 14224 (ISO, 2016). The SIOP database does not contain information about preventive measures, their effect or costs. Implementing this information is also a part of the project.

The project is divided into nine research activities of which four are empirically oriented towards data collection and data analysis. These four activities include (1) a literature study documenting the state of the art within this research area, (2) a follow-up study of recent HC-leaks, (3) information sharing with other operators, and (4) a retrospective study of installations which have performed differently with respect to HC-leaks and unplanned shutdowns. This report describes the method, data and results from the literature study.

1.2 Objective and research questions

As described above, the primary goal of *How to get it Right* is to examine the effect and the economic costs of different preventive measures initiated after investigated HC-leaks. Empirical findings related to effects and costs will be exported to the SIOP database. In order to make this possible it is necessary to develop a taxonomy (classification scheme) for preventive measures and a method for assignment of potential effects and costs. Furthermore, it is necessary, with the use of different data sources, to examine and estimate the effects and the costs that different measures have. Thus, the objective of the literature study is fourfold; (1) The literature study will examine whether there exists already devised methods to evaluate the effect of measures against HC leaks and/or other incidents with major accident potential. (2) The literature study will examine whether there are already devised taxonomies for categorization of measures against HC leaks and/or other incidents with major accident potential. (3) The literature study will identify preventive measures proven effective. (4) The literature study will examine methods previously used in economic analyses related to costs of preventive measures against HC-leaks and/or other incidents with major accident potential.

The fourfold division of the research objective leads to the following research questions (RQs):

1. Do there exist previously developed methods to evaluate the effect of measures against HC leaks or other incidents with major accident potential? If this is the case, how are these methods designed?
2. Do there exist previously developed taxonomies to categorize measures against HC leaks or other incidents with major accident potential? If this is the case, how are these taxonomies constructed?

3. According to the literature, which types of preventive measures against HC leaks have been proven effective, which have not and under which conditions are different measures most effective?
4. Which methods have previously been applied in order to categorize and evaluate the costs related to measures after HC leaks or other incidents with major accident potential?

With regard to the learning from incidents process as a whole (Figure 1), the four research questions are related to the late phases of the process, i.e. in the phases which follow after the causation analysis (i.e. phase 2-4 in the figure). More specifically, research question 1 is related to phase 4 of the process, which is the evaluation phase. Primarily, the literature study will look at two different types of evaluations; evaluations of effect on the output variable (HC leaks) and evaluations of mechanisms that hinder and facilitate desired intervention outcomes. Research question 2 is related to phase 2, which is the planning phase. In this phase, recommendations and measures are formulated and the research question examines the extent to which previously developed taxonomies for measures are adequate. Research question 3 is related to phase 3 of the process, which is the intervening phase. Primarily, the literature study will look at two different types of literature related to this question: literature, which points directly to measures against HC leaks and literature which points to the more generic characteristics of successful preventive measures and action processes across different incident scenarios and industries. Research question 4 is related both to the planning phase and the intervening phase since costs related to intervention (phase 3) primarily are (or should be) considered in the planning phase (phase 2). Despite the fact that *How to get it right* is a project that focuses on measures, it should be noted that proper measures do not arise in a vacuum. This means that proper measures are, among other things, highly dependent on a proper causation analysis (i.e. phase 1 in the figure). Thus, parts of the early phase will also be reflected upon and mentioned briefly in the replies to the research questions.

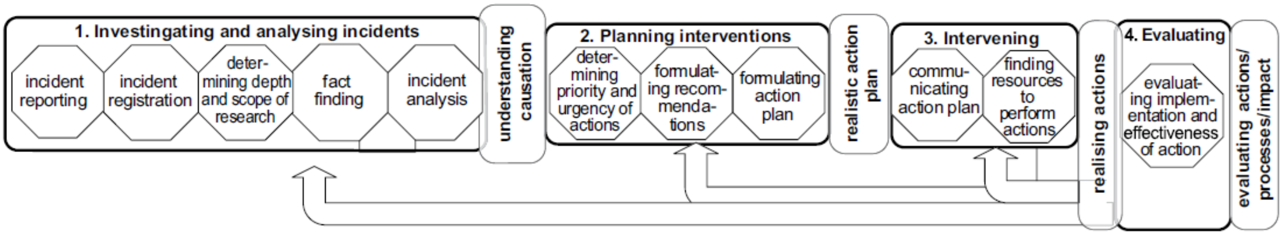

Figure 1 Model of the learning from incidents process (Drupsteen et al., 2013: 65)

Concerning *How to get it right* as a whole (Figure 2), there are clear links between the research questions and the other activities of the project. Hence, the answers of the research questions will be used to adjust the research perspectives within the activities. Research question 1, which deals with previously developed methods to evaluate the effect of measures against HC leaks, is linked primarily to activity 2 (the leadership guideline) and activity 1 (the framework of the guideline). The guideline will consist of advices related to the types of measures that have been effective. Hence, there is a need to know how other researchers have gathered evidence for effect. This knowledge is also necessary for the empirical activities of the project (activity 5, 6 and 8), in which the main objective is to evaluate effect of HC leak measures and the overall action process. Research question 2, which deals with previously developed taxonomies to categorize measures against HC leaks, is linked primarily to activity 3 (categorize and analyse measures after HC leaks). The most fundamental objective of this activity is to develop a group of categories for HC leak measures, hence there is a need to know how others previously have categorised such measures. Appropriate categories are also necessary for activity 1 and 2, in order to structure the guideline around some common threads. Furthermore, a fixed set of categories is advantageous for the organisation of the empirical parts of the project. Research question 3, which deals with preventive measures against HC leaks that have been proven effective, is linked primarily to activity 2 since the guideline largely will consist of advices related to concrete effective measures. Hence, there is a need for an evidence basis. Research question 4, which deals with costs related to measures after HC leaks, is also linked primarily to activity 2. In addition to advices related to measures, the guideline will consist of information related to the economic costs related to implementation of different measures and/or information related to methods to evaluate such costs. In addition, the research question is related to the overall objective of *How to get it right*, as the project, in principle, is addressing a typical multi-criteria decision problem, where economic rationality has to be considered towards nonmonetary perspectives.

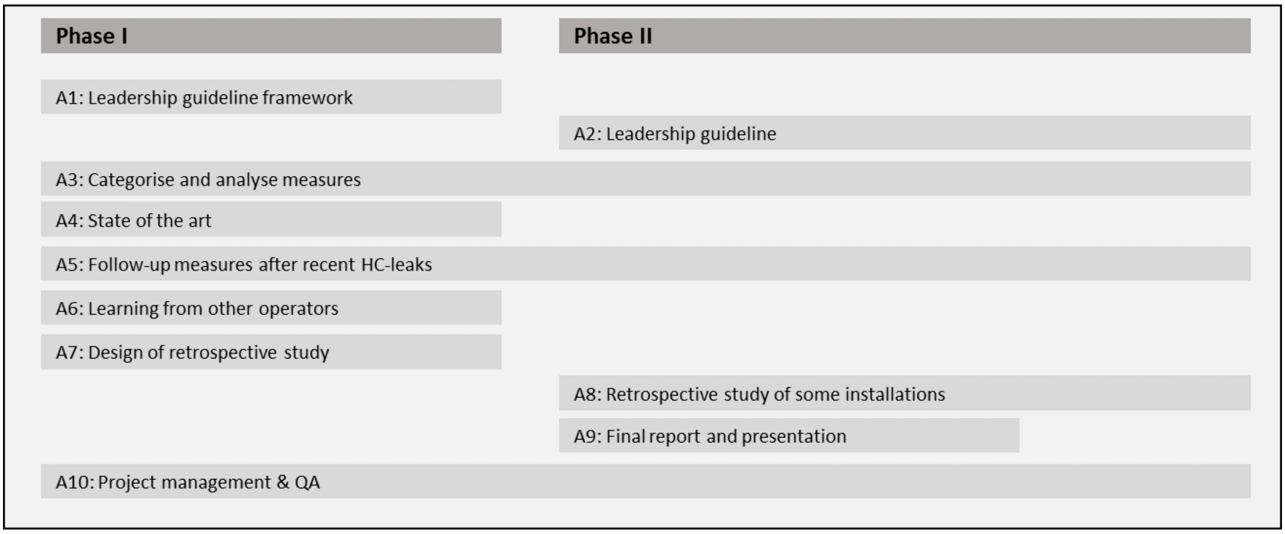

Figure 2 Activities included in *How to get it right*

1.3 The basics of the analysis

In order to answer the research questions, it was first conducted a systematic online search for relevant literature. Different sets of keywords were used for each research question. Thereafter, the search results were screened, reviewed and assessed for relevance with regard to the research questions. A detailed description of the methodology is presented in chapter 2.

To ensure that the literature study fitted the overall needs of the project regular meetings have been conducted with the client throughout the research period. Upon request from Company, significant changes has been made because of these meetings.

1.4 Content of report

The remainder of the report is structured as follows. In chapter 2 a brief description of the review method used is presented. This includes a description of the databases, the search criteria and the search words/strings. In chapter 3 a short quantitative overview of the results is offered in addition to a brief general description of the literature identified. This is followed by the presentation of the study findings in chapter 4. The findings related to each research question is presented separately. A short summary of the key findings is presented in chapter 5, followed by a discussion of the practical implications of the findings and a discussion of strengths and limitations of the study. The conclusion is presented in chapter 6.

1.5 Abbreviations

The following abbreviations are used in the report:

Phrase		Description
ARIS	-	Statoil's management system tool
BBN	-	Bayesian belief network
BORA	-	Barrier and operational risk analysis
CAPP	-	Canadian Association of Petroleum Producers

CBA	-	Cost benefit analysis
EI	-	Energy Institute
ESD	-	Emergency shut down
HAZID	-	Hazard identification
HAZOP	-	Hazard and operability study
HC	-	Hydrocarbon
HRO	-	High reliability organisation
HSE	-	Health and Safety Executive (United Kingdom)
HSS	-	Helicopter safety study
IAEA	-	International Atomic Energy Agency
IRR	-	Internal rate of return
IFE	-	Institute for Energy Technology
ISO	-	International Organization for Standardization
LDAR	-	Leak detection and repair program
MCA	-	Multi criteria analysis
MJS	-	Maximum justifiable spend
MTO	-	Man, technology, organization
NCS	-	Norwegian Continental Shelf
NOK	-	Norwegian krone
NORSOK	-	Norsk sokkels konkurranseposisjon
NPV	-	Net present value
OE	-	Operating experience
OGP	-	International Association of Oil and Gas Producers
OMT	-	Organisation, man, technology
OTS	-	Operational condition safety
PBP	-	Payback period
PEAT	-	Procedural event analysis tool
PIF	-	Performance influencing factor
PSA	-	Petroleum Safety Authority Norway
QRA	-	Quantitative risk analysis
RIF	-	Risk influencing factor
RNNP	-	Risikonivå norsk petroleumsvirksomhet (Trends in risk level in the petroleum activity)
RQ	-	Research question
SCS	-	Step Change in Safety
SIOP	-	Serious Incident One Pager
SMARTER	-	Specific, measurable, achievable, realistic, timely, effective, reviewed
SSIV	-	Subsea isolation valve
UK	-	United Kingdom
VR	-	Virtual reality

2 Data and method

2.1 Databases and websites

The literature search was conducted using Google Scholar and Scopus. Google Scholar was used to ensure a proper width of the data, including both research literature, technical papers and practically oriented papers such as those retrieved via onepetro.org. Scopus, a bibliographic database containing abstracts and citations for roughly 20.000 peer-reviewed academic journals, was used to ensure inclusion of all relevant literature not retrieved by Google Scholar.

In addition to using the two databases, strategic and unstructured literature searches were performed on the websites of the following actors:

- Petroleum Safety Authority Norway, *www.ptil.no*
- The Norwegian Oil and Gas Association, *www.norskoljeoggass.no*
- Step Change in Safety, *www.stepchangeinsafety.net*
- Health and Safety Executive (UK), *www.hse.gov.uk*
- International Association of Oil and Gas Producers, *www.iogp.org*
- SINTEF Safety Research's internal archive database
- Standards Norway, *www.standard.no*
- International Atomic Energy Agency, *www.iaea.org*
- The Energy Institute, *www.energyinst.org*

2.1.1 Google Scholar

Google Scholar provides a way to broadly search across many disciplines. It searches various sources such as articles, books, theses, abstracts, websites, etc. over a number of different databases simultaneously. The search results are sorted by relevance, where the relevance is determined based on the number of quotes, thus it may involve having to go through a large amount of search results to find what you are looking for. Google Scholar includes full text articles when these are available. One can do advanced searches, which makes it simple to include or exclude certain words or phrases, as well as limiting the period. One weakness is that Google Scholar only allows for search strings up to 256 signs, and a search in singular does not necessarily cover the plural and vice versa. It is also a weakness that one does not know what databases have been searched, and that one cannot sort the search results by author, title, year, etc.

2.1.2 Scopus

Scopus is a comprehensive database with content of great scientific width. The database is updated on a daily basis to ensure access to the most recent research within the various fields, and an independent expert group constitute a board/committee that assures the quality of the sources that Scopus includes. Search results cover journals, books, conference papers and articles, patents, etc. and links to full text is given when available. Scopus allows for significantly longer search strings than Google Scholar, and searching for the singular of a term also covers the plural etc. Some of the searches were made searching the whole document, whereas others were made searching the title, abstract and keywords – limiting the number of results to the most relevant ones.

2.1.3 Databases and websites of significant actors

In order to supplement the research literature, searches were performed on the websites of different industry actors. It was expected that this would result in access to more practically oriented literature. The actors selected covered different areas of the industry, such as regulating authorities, standardisation organisations and industry forums. The searches were performed either via search functionality directly on the websites of the actors or via Google's site search functionality.

2.2 Search-limiting criteria

The literature search was conducted with the following search limiting criteria:

- Literature language: English or Norwegian
- Publication period: 2006-2016[1]
- Type of literature: Research articles, conference papers, books, book chapters, guidelines, reports/notes, theses and standards.

2.3 Search words and strings

As described above (cf. chapter 2.1), differences between the various databases and websites imply that different combinations and specifications of search words could be used. Thus, key words related to each of the research questions (i.e. hydrocarbon leaks, measures, effects, methods, taxonomy, cost-benefit, etc.) were combined in various ways. Examples of applied search strings are given in Table 1[2]. Note that synonyms and adjacent words for the term "measure" also were used. These are not cited in the table. Synonyms/adjacent words include "action" and "recommendation".

Table 1: Examples of search strings

RQ no.	Examples of applied search strings:
All	"measures against HC leaks" OR "measures against hydrocarbon leaks" OR "measures against hydro carbon leaks"
	measures AND ("HC leaks" OR "hydrocarbon leaks" or "hydro carbon leaks")
	(reduction OR mitigation) AND ("HC leaks" OR "hydrocarbon leaks" or "hydro carbon leaks")
	"measures against process leaks"
RQ1	leaks AND ("effect of mitigation measures" OR "effect of risk reduction measures" OR "effect of risk reducing measures")
	("method for evaluating" OR "method to evaluate") AND ("effect of mitigation measures" OR "effect of risk reduction measures" OR "effect of risk reducing measures")
	"method to evaluate effect"
	"effect of (safety) measures"
	"evaluate effect" AND leak
	"quantify (the) effect(s) of measures"
	"evaluate/evaluating (the) effect of mitigating actions" OR "evaluate/evaluating (the) effect of preventive actions"
RQ2	("taxonomy" OR "classification") AND ("HC leaks" OR "hydro-carbon leaks" OR "hydrocarbon leaks")
RQ3	"(effective) measures" AND ("HC leaks" OR "hydrocarbon leaks" OR "hydro carbon leaks")
	(effective) measures AND "major accident potential"
	lessons (learned) AND ("HC leaks" OR "hydrocarbon leaks" OR "hydro carbon leaks")
	"measures that have been proven effective" OR "measures that are proven effective"
	"actions that have been proven effective" OR "actions that are proven effective"
RQ4	"cost of measures"
	"cost-benefit" AND ("HC leaks" OR "hydro-carbon leaks" OR "hydrocarbon leaks")
	cost AND (reduction OR mitigation) AND ("HC leaks" OR "hydro carbon leaks" OR "hydrocarbon leaks")
	cost AND measures AND petroleum AND risk

Similar search strings were constructed in Norwegian.

[1] Please note that this period applies to the literature search exclusively. Literature published prior to this period is included when referred to in publications from the search results and considered directly relevant.
[2] Please note that that the search strings in Table 1 applies for the searches in Google Scholar and Scopus. Unstructured searches were conducted on the websites listed in chapter 2.1.

3 Brief overview of results

3.1 Inclusion and exclusion criteria

In addition to the search limiting criteria (chapter 2.2), the overall criteria for a given publication to be included in the findings and the following discussion was that it must address at least one of the four research questions. If none of the RQs were addressed, the publication was excluded. Another inclusion criterion was that the publications had to be available in full-text.

3.2 Search results – overview

After the searches were completed, 42 publications were evaluated as directly relevant for answering the research questions. 23 publications were evaluated as indirectly relevant. This means that they are of some relevance, but that they either are too general, too specific or only *supports* literature that already has been evaluated as directly relevant. When including these, the total number of publications was 65. Six of these were relevant for two research questions and one guideline developed by the International Atomic Energy Agency (IAEA, 2005) was relevant for three research questions. Hence, the total number of publications in Table 2 adds up to 73 (for a detailed summary, see Appendix A).

In addition to literature that was evaluated as directly or indirectly relevant, several publications were used to either support arguments or give examples of further readings. When including these (not presented in Table 2), the total number of publications was 116 (for a full overview, see References).

The majority of the literature is from the oil & gas industry. However, literature from other industries such as the nuclear power industry, the aviation industry, the mining industry and the construction industry is also included. Literature related to other risk scenarios than HC leaks is also included, such as offshore helicopter crashes, offshore service vessel collisions and occupational accidents.

The number of publications evaluated as relevant varied across the four research questions. As regards research question 1, six publications were evaluated as directly relevant and six were evaluated as indirectly relevant. Eight publications were evaluated as relevant for research question 2 and none as indirectly relevant. As regards research question 3, 25 publications were evaluated as directly relevant and nine were evaluated as indirectly relevant. Ten publications were evaluated as directly relevant for research question 4 and nine were evaluated as indirectly relevant.

Table 2: Number of publications of each literature type addressing the research questions directly. Supporting literature evaluated as indirectly relevant in parentheses.

RQ no.	Total	Articles/ conference papers	Books/ book chapters	Guidelines	Reports/notes	Theses	Standards
1	6 (6)	5 (4)	(1)	(1)	1	-	-
2	8 (0)	2	-	2	2	-	2
3	25 (9)	14 (8)	2	5	3 (1)	1	-
4	10 (9)	6 (5)	1 (4)	-	2	1	-

4 Findings

The findings related to each research question are presented below. Each research question is treated separately.

4.1 Methods to evaluate the effect of measures against HC leaks (research question 1)

Based on the identified literature, research question 1 is addressed in this chapter: *Do there exist previously developed methods to evaluate the effect of measures against HC leaks or other incidents with major accident potential? If this is the case, how are these methods designed?*

The literature search has identified 12 publications that are of relevance for the research question, among which six have been evaluated as directly relevant. Three of these are research articles presenting a method called BORA-Release and the fourth is a research article describing Risk OMT, a model derived from BORA-Release. The fifth presents a model for evaluating risk in offshore helicopter transport. The sixth presents a model for process evaluations.

On the initiative of PSA, the Institute for Energy Technology (IFE) has evaluated what types of measures related to various categories of organisational factors companies within the petroleum sector suggest in their investigation reports. They also assessed to what degree it is possible in practice to evaluate the effect of these measures. The review of 20 carefully selected investigation reports revealed no focus on how the effect of the suggested measures is or can be evaluated in practice (Thunem et al., 2009). This finding indicates a lack of focus on the effect of measures in the industry in general, thus underlining the importance of research question 1.

Some of the identified publications argue that specific tools and technology can be used to simulate possible emergency scenarios and to evaluate the effects of mitigating measures. Examples are Hansen et al. (2011) and Kinateder et al. (2013) who discuss the use of VR simulation related to hydrogen release and road tunnel accidents, respectively. Publications such as these will not be discussed further as they represent technical tools rather than evaluation-methods. However, they might be further explored in later stages of the project if considered relevant for concrete measures in the leadership guideline.

4.1.1 BORA-Release and Risk OMT

Generally speaking, the safety literature is rich with respect to describing methods evaluating the effect of measures aiming at reduction in high-probability - low-impact events such as workplace injuries (Porru et al., in press) and road traffic accidents (e.g. Peltola et al., 2013). However, the literature is less rich with respect to describing methods evaluating the effect of measures related to low-probability - high-impact events. As regards HC leaks directly, some of the most relevant literature, at least with respect to modelling the effect of measures, is to be found in the so-called BORA-Release and the OMT methods.

BORA-Release, i.e. barrier and operational risk analysis of hydrocarbon releases, is a method designed with the purpose of modelling the effect of risk reducing measures and risk increasing changes during operations. The method is specifically proposed as a method to be used for qualitative and quantitative analyses of a platform specific hydrocarbon release frequency. The method includes both technical, human, operational and organisational risk elements. However, the focus is on sharp-end elements, whereas blunt-end elements (such as strategic and tactical management decisions) are left out. It is important to emphasize that the method only predicts the effect based on how a certain measure is likely to affect given risk influencing factors (RIFs) (Aven et al., 2006; Sklet et al., 2006; Sklet, 2006).

In part I of their paper, Aven et al. (2006) present a description of the BORA-Release method, which comprises the following main steps:

1. Development of a basic risk model including release scenarios. The purpose is to identify, illustrate, and describe the scenarios that may lead to a hydrocarbon release on a platform. Barrier block diagrams are used to illustrate the basic risk model.
2. Modelling the performance of safety barriers. This is done in order to analyse the plant specific barrier performance when platform specific conditions of human, operational, organisational and technical factors have been taken into consideration. Fault tree analysis is used for analysis of barrier performance in BORA-Release.
3. Assignment of industry average probabilities/frequencies and risk quantification based on these probabilities/frequencies. Several databases are available presenting industry average data.
4. Development of risk influence diagrams, with the purpose of incorporating the effect of the plant specific conditions of human, operational, organisational and technical RIFs on the occurrences (frequencies) of the initiating events and the barrier performance. The framework for identification of RIFs consists of the following main groups of RIFs: personal characteristics; task characteristics; characteristics of the technical system; administrative control; and organisational factors/operational philosophy.
5. Scoring of risk influencing factors from A to F, where score A corresponds to the best standard in the industry, score C corresponds to industry average, and score F corresponds to worst practice in the industry.
6. Weighting of risk influencing factors. This is an assessment of the effect (or importance) the RIFs has on the frequency of occurrence of the basic events. The weights of the RIFs correspond to the relative difference in the frequency of occurrence of an event if the status of the RIF is changed from best standard to worst practice. Expert judgment is used to do the weighting of the RIFs.
7. Adjustment of industry average probabilities/frequencies. The purpose of doing this is to assign platform specific values to the input probabilities/frequencies allowing for platform specific conditions of the RIFs.
8. Recalculation of the risk in order to determine the platform specific risk related to hydrocarbon release.

In part two of their paper on the BORA-Release method, Sklet et al. (2006) present results from a case study that was carried out on an offshore oil and gas production facility where the method was applied and tested. The case study was carried out in order to determine the selected platform specific hydrocarbon release frequencies, but also to assess whether the method is a useful tool to analyse the effect of risk reduction measures and changes that may influence the release frequency. This was done by carrying out several sensitivity analyses. Based on this, they conclude that one of the main application areas of BORA-Release may be to study the effect on the release frequency of risk reducing measures or risk increasing changes.

The Risk OMT, i.e. risk modelling – integration of organisational, human and technical factors, model represents a generalisation and improvement of the BORA-Release model. Work from another project based on BORA, i.e. the Operational Condition Safety (OTS) project has also been utilised in the development of the Risk OMT model. Two important changes were made in the OMT project that the BORA-Release model did not incorporate: Firstly, the RIFs can influence each other and they are structured in two levels, i.e. RIFs "closest" to the basic events and RIFs related to management. The former (RIFs on level 1) have the most direct influence on the failure probabilities, whereas the latter (RIFs on level 2) influence the level 1 RIFs. Secondly, the model distinguishes between "true" underlying values of the RIFs and observed values of the RIFs (Gran et al., 2012).

According to the authors, they have been able to demonstrate that the Risk OMT model provides a good basis for ranking risk reduction measures (Gran et al., 2012). Thus, according to the authors themselves the

Risk OMT model should be a reasonable method to evaluate the effect of measures against HC leaks. It should be noted, however, that the application of the model depends on input of large amounts of data and expert judgements which is not necessarily easily available. Hence, applying the method as a basis to evaluate the effect of measures against HC leaks will be very resource demanding. Furthermore, it should be noted that the OMT approach is based on risk modelling and not on empirical evidence. Hence, the output of the model are predicted values and not observed values.

4.1.2 Learning from studies of offshore helicopter safety

In addition to previous studies which have developed methods to model the effect of risk reducing measures related to HC leaks, there are some studies of other major accident scenarios which should be relevant, in particular the series of studies performed on helicopter safety on the Norwegian Continental Shelf (NCS). Similar to HC leaks, offshore helicopter accidents are an example of low-probability - high-impact events. Hence, they share the same challenge with measuring the output variable. I.e. the observed values (incidents/accidents) are extremely low. This makes the causal chain from preventive measure to observed effect more or less invisible. Thus, studies of helicopter safety have to rely on risk modelling with corresponding predicted effects.

Three offshore helicopter safety studies (HSS) on the NCS have been completed in Norway, the last in 2010 (Herrera et al., 2010). A fourth study is currently in progress. The basics of the risk model applied in the studies is similar across the three studies, but with some improvements to provide a more nuanced understanding of risk. The model applied in the last study (Herrera et al., 2010) is, similar to BORA and OMT, referred to as a RIF-model (risk influencing factors model). The RIF-model is split into one model for predicted frequency and one model for predicted consequence. RIFs are defined as a separate group of conditions that influence the risk associated with offshore helicopter transport. Furthermore, the different RIFs (19 in total) are defined as either operational, organisational or authority/customer related. A given RIF (e.g. customer demands) could influence other RIFs (e.g. maintenance) and the probability of one or more causes of helicopter accidents. A given RIF (e.g. survival equipment) could also influence the consequence of helicopter accidents.

Over time, a given RIF, for example pilot competence, could be stable, turn negative or turn positive. Changes could be a result of preventive measures implemented, other planned factors such as new legal requirements or unplanned factors such as weather conditions. In the model, the impact that such changes have on the frequency and consequence of different accident scenarios is evaluated and quantified by the use of accident statistics and expert opinions. Thus, the output of the model is *predicted* risk – defined as predicted frequency and predicted consequence.

Similar to BORA and OMT, application of the HSS model depends on input of data and expert judgements that is not necessarily easily available. Hence, applying the model as a basis to evaluate the effect of measures against HC leaks will be resource demanding. In addition, to fit the purpose of *How to get it right* the content of the model (in particular the set of RIFs) must be re-built. However, the basic idea of modelling effect of measures based on expert judgements should be useful for and transferable to the *How to get it right*-project, in particular for the interview study and the retrospective study. In the helicopter safety studies expert judgements have been carried out in sessions that include working meetings, telephone meetings, group interviews, individual interviews and e-mail exchanges. In the working meetings the different answers from the experts are discussed in plenary where each expert is given the opportunity to state the reason for their answer, and where the experts also is given the opportunity to a certain degree, to agree on a common answer (Herrera et al., 2010). Similar sessions, with the purpose of evaluating a pre-defined set of measures against HC-leaks could be used in *How to get it right*. However, it should be noted that the validity and reliability of expert judgements is questionable. For a critical discussion of this related to the HSS model, see Rosness (1999).

4.1.3 Learning from high-probability - low-impact events and interventions

As described above, the safety literature is rich with respect to describing methods evaluating the effect of measures aiming at reduction in high-probability - low-impact events, but less rich with respect to describing methods evaluating the effect of measures related to low-probability - high-impact events. The reason for this is that the output variable of high-probability events is far easier to observe, measure and analyse statistically. For example, the number of workplace injuries (a high-probability event compared to HC-leaks) in Norway per year is estimated to 90.000 (Gravseth, 2011). This allows for empirical analyses of the observed output variable. Hence, studies that aim to examine the effect of preventive measures against workplace injuries are easier to design by mapping the output variable. This is also true for studies that aim to examine the effect of preventive measures against road traffic accidents, another type of high-probability - low-impact events (e.g. Gettman and Head, 2003). The statistical analyses included in such studies are not transferable to studies of HC leaks, including *How to get it right*.

However, a particular branch of studies of occupational health and safety interventions could be relevant and transferable. These studies do not focus on the output variable at all. Instead, they focus on process evaluations that include a close examination of the psychological and organizational mechanisms that hinder and facilitate desired intervention outcomes. A directly relevant study within this branch identified in the literature review is a study by Nielsen and Randall (2013). In addition, several other studies are found to be relevant. However, these are labelled as indirectly relevant because they support or largely cover the same basis as Nielsen and Randall (e.g. Biron and Karanika-Murray, 2014; Briner and Walshe, 2015; Randall, 2013. See also IAEA, 2005 for an example of process evaluation of measures related to low-probability events).

In Nielsen and Randall (2013), it is claimed that even for interventions aiming at reducing high-probability events (such as workplace injuries and occupational illness) it is not sufficient in an evaluation to analyse changes in the output variable. Instead, they argue that evaluations should examine directly how and why such interventions bring about change and why they sometimes fail. This, they argue, involves a process evaluation that 'includes a close examination of the psychological and organizational mechanisms that hinder and facilitate desired intervention' (Nielsen and Randall, 2013: 601). Furthermore, they argue that the factors that may have an impact on the outcomes of an intervention can be grouped into three themes. These are: (1) intervention design and implementation, (2) intervention context, and (3) participants' mental models (of the intervention and their work situation). Within each of these three themes, Nielsen and Randall have identified several specific questions that need to be asked about the intervention process. These need to be answered through collection of process evaluation data (e.g. interviews). The themes and questions that Nielsen and Randall address are not relevant to all types of interventions or measures. For example, measures that include technical re-design and the like are not relevant, whereas measures that include organizational change and new work practices are relevant. Examples of questions raised by Nielsen and Randall are as follows:

1. Intervention design and implementation
    a. Who initiated the intervention and for what purpose?
    b. Did the intervention activities target the problems? (How/why/why not?)
    c. Did the intervention reach the target group? (How/why/why not?)
    d. Who were/are the drivers of change?
    e. Did employees participate significantly in decision-making and how many were involved?
    f. What was the role of middle managers, senior managers and consultants?
    g. What kind of information was provided to participants?
2. Intervention context
    a. Which hindering and facilitating factors in the context influenced intervention outcomes?
    b. How did the intervention fit in with the culture and conditions of the intervention group?
    c. What capacity does the organization have to conduct the intervention?

   d. Which events (e.g. conflict/multiple changes) took place during the intervention phase?
3. Participants' mental models
   a. What is the role of participants' mental models (e.g. expectations/agendas) in determining their response to the intervention?
   b. To what degree do participants have shared expectations?
   c. Did the intervention bring about a change in participants' mental models (e.g. attitudes)?

The themes and questions that Nielsen and Randall address are based on previous research related to success criteria of organizational interventions. For example, in relation to question 1e (employee participation), several studies have found that procedure preparation is most effective, in terms of compliance, when the end-user is allowed to influence on the design of new procedures (e.g. Antonsen et al., 2009), and in relation to question 1g (information) several studies have found that the level of information and communication plays an important role in the effect of interventions (e.g. Jimmieson et al. 2004). Hence, mapping such success criteria is, according to Nielsen and Randall (2013), essential when evaluating the effect of organizational interventions. However, the key question is whether and how process evaluation is a relevant method to evaluate the effect of measures against HC leaks?

Both BORA, OMT and HSS focus on the output variable by means of quantitative predictions of how changes in RIFs will influence the output variable in terms of estimated risk increase/decrease. Process evaluations offer an alternative perspective where the mechanisms that hinder and facilitate desired intervention are the prime focus of the analysis. Nielsen and Randall's model is related to occupational health and safety interventions specifically and cannot be transferred to measures against HC leaks directly. However, the notion of evaluating the process per se is highly relevant also for measures against HC leaks, because the measure in itself is quite frequently a process and not an immediate and finite event. Hence, in an exploratory study such as *How to get it right*, an analysis of the mechanisms that hinder and facilitate desired effects should be highly relevant. Such an analysis could have both deductive and inductive elements. This means to examine both the importance of known success/failure mechanisms (e.g. employee participation, information sharing) and the importance of unknown success/failure mechanisms. (For an example of an inductive study of success/failure mechanisms related to resistance to change in the aftermath of accident investigations, see Lundberg et al., 2012).

In a guideline developed by the International Atomic Energy Agency, a particular sort of process evaluations is recommended also for low-probability events (IAEA, 2005). The guideline offers several relevant questions to be asked when evaluating the effectiveness of measures. Similar to Nielsen and Randall (2013), IAEAs approach does not focus on the output variable per se, but on factors that probably will have an influence on the output variable (e.g. actual changes in procedures, understanding of procedures, actual skills upgrading after training etc.). In IAEAs approach the use of qualitative methods, such as interviews, observations and document studies are recommended, whereas predictions of the output variable are not. This illustrates that process evaluations are not only relevant for measures related to high-probability events. IAEA's advices for evaluations are relevant for the empirical parts of *How to get it right*.

4.1.4 Summing up research question 1

No methods for evaluating the *observed* effect of preventive measures against HC leaks or other incidents with major accident potential have been identified in this review. However, it should be stressed that the effect of measures against low-probability events such as HC-leaks are difficult to evaluate due to low event frequencies, and the generally complex relationship between measures and effects. Hence, both the BORA-Release method and the Risk OMT model provide valuable guidance for *modelling* the effect of proposed risk reducing measures related to HC leaks. The OMT model is the most detailed one of the two. Applying the methods, in particular the OMT, as a basis to evaluate the effect of measures against HC leaks will however be resource demanding.

The HSS model (developed for offshore helicopter transport) provides guidance on modelling of both predicted frequency and predicted consequences related to low-probability events. As with BORA and OMT, the full-scale method behind the HSS model is resource demanding. Furthermore, to fit the purpose of *How to get it right*, the content of the model (in particular the set of RIFs) must be re-built. However, the basic idea of modelling effect of measures based on expert judgements should be useful for and transferable to *How to get it right*, in particular for the interview study and the retrospective study. In addition, the methods developed to collect expert judgements should be relevant.

As an alternative to methods designed to model risk (BORA, OMT and HSS), methods designed for process evaluation of occupational health and safety interventions could be useful. Process evaluation, in contrast to risk modelling, is highly relevant when the goal is to collect information on how a given measure could be implemented successfully. Hence, the fundaments of Nielsen and Randall's (2013) model should be useful in order to analyse the mechanisms that hinder and facilitate desired intervention outcomes (see also IAEA, 2005). However, parts of the model must be re-built to fit the purpose of *How to get it right*. Furthermore, the model should to a greater extent build on an inductive approach, since the success/failure mechanisms are largely unknown.

4.2 Taxonomies to categorize measures against HC leaks (research question 2)

Based on the identified literature, research question 2 is addressed in this chapter: *Do there exist previously developed taxonomies to categorize measures against HC leaks or other incidents with major accident potential? If this is the case, how are these taxonomies constructed?*

Whereas several publications present taxonomies that differentiate between different *causes*, *types* and *severities* of HC leaks (e.g. Duguay et al., 2012), the present study have only identified five publications that are relevant for taxonomies to categorize *measures* against HC leaks. In addition, three relevant publications offering literature on categorizing measures in general or within other risk areas are identified. These eight publications are identified in industry standards, user guidelines and research literature. The detailing level of these differ considerably. Hence, their suitability for detailed categorization of measures against HC-leaks vary.

4.2.1 Industry standards

The most basic taxonomies are localized in the two industry standards NORSOK Z-013: 2010 *Risk and emergency preparedness assessment* (NORSOK, 2010) and ISO 13702: 2015 *Petroleum and natural gas industries - Control and mitigation of fires and explosions on offshore production installations - Requirements and guidelines* (ISO, 2015). Roughly, the NORSOK Z-013 standard simply differentiate measures that provide safer design[3], measures that reduce possibility of accidental events occurring and measures that reduce consequences if accidental events should occur. The ISO13702 standard also operate with a tripartite classification. In addition to measures that reduce possibility and measures that reduce consequences, the standard distinguishes these two from measures set to control the incident once it has occurred. It should be noted that both NORSOK and ISO distinguish between different risk reducing measures in general, whether related to HC leaks or not.

The general categories that NORSOK and ISO present are suitable for allocating a category to a given measure in accordance with the end purpose of the measure (e.g. reduce probability) and not in accordance with the actual content of the measure (e.g. technical re-design). However, the lack of details that the standards present makes them inappropriate for an in-depth categorization of measures against HC-leaks.

[3] Safer design may reduce the possibility of accidental events occurring (e.g. increased wall thickness of HC piping) and may also reduce the consequences (e.g. increased fire resistance of passive fire protection). Hence measures that provide safer design are actually a subset of the two next categories.

Also, for the purpose of categorisation, we believe that it is easier to do this with the respect to the nature of the measure (e.g. change a procedure) rather than the end purpose (which requires a further interpretation; e.g. of what is the purpose of changing the procedure).

4.2.2 Guidelines

A second source of information related to taxonomies to categorize measures against HC leaks, are guidelines developed to reduce HC leaks. Similar to the industry standards described above, the primary goal of the guidelines is not to present exhaustive taxonomies that cover any conceivable preventive measure. With regard to research question 2, the most relevant guideline is the *Guidance on Hydrocarbon Reduction Plans* offered by the Step Change in Safety (SCS, 2012) in the UK. The guideline is developed on basis of a review of operating companies' HC leak reduction plans. The review was performed by the SCS in order to identify best practices. The specific advices offered in the SCS guideline are grouped under categories that are more generic. These categories could serve as a starting point for a taxonomy of preventive measures. The generic categories are (1) learning from release incidents (own incidents), (2) proactive learning (learning from others), (3) integrity and maintenance activities, (4) managing operational activities, (5) well integrity, (6) leadership and engagement, (7) resourcing, (8) training and competence, (9) targets and metrics, and (10) practices, monitoring and auditing.

Compared to the industry standards, which present categories defined in accordance with the end purpose of the measure, the SCS guideline present categories defined on basis of the actual content of the measure. Hence, an SCS category could be used to categorize a given measure independent of the end purpose of the measure. For example, measures such as courses, exercises, training and seminars could be grouped under category *8 Training and competence* regardless of whether the end purpose of the measure is to reduce the probability or consequence of an HC leak. A restriction related to the SCS categories is that the categories primarily are oriented towards proactive measures and to a lesser extent towards the reactive ones. Hence, the categories might be somewhat more suitable for continuous measures under normal operating conditions and less suitable for measures initiated as a response to a certain incident.

Another guideline, which offers a taxonomy of measures, is a guideline developed by the International Atomic Energy Agency, IAEA (2005). Similar to the industry standards referred to above, the IAEA taxonomy is simple as it operates with only three different categories. These are labelled immediate corrective actions, interim corrective actions and corrective actions to prevent recurrence. The immediate ones are actions taken to promptly restore normal conditions or eliminate problems. The interim ones are described as short-term actions to reduce the risk of recurrence while awaiting long-term corrective actions, whereas corrective actions to prevent recurrence are described as actions that directly address the root causes with the intention of preventing the problem from ever happening again. Hence, the categories of the IAEA taxonomy simply differs with regard to the time lapse and urgency, and are as such somewhat insufficient to fully categorise measures.

4.2.3 Research literature

The majority of taxonomies presented in the HC leak research literature is related to immediate and underlying causes (e.g. Pratt, 2002; Vinnem and Røed, 2014) and not the measures initiated in the aftermath of an incident. However, a taxonomy which is designed to cover both causes and measures has been developed in an HC leak study performed by SINTEF on behalf of the Petroleum Safety Authority Norway in 2010-2011 (PSA, 2011; see also Mostue et al., 2014). The basis of the taxonomy is the MTO perspective; Man, Technology and Organization. Furthermore, the sub-categories are developed on basis of relevant research literature (e.g. Sklet et al., 2010; Schiefloe et al., 2007). The categories are as follows:

Human	H1 Human error of category slips/lapses
	H2 Cognitive errors (lack of competence and/or poor understanding of risk)

	H3 Human error due to bad/poor design
	H4 Wrong actions stemming from non-observance of prevailing practice/procedures
Organization	O1 Company management, installation management
	O2 Work supervision/management, change management
	O3 Risk assessment/analysis, planning/preparation
	O4 Procedures/documentation
	O5 Work practice
	O6 Workload
	O7 Control/check/verification
	O8 Poor communication/cooperation/-interfaces/conflicting objectives
	O9 Competence/training
Technology	T1 Technical design of the system/process plant, design of tools/mobile equipment, ergonomics/man machine interface
	T2 Technical condition/aging/wear and tear, technical equipment failure

The fact that causes and measures are categorized according to the same taxonomy is obviously favourable for analysis of correspondence between cause and measure. At the same time, however, it is also obvious that some of the categories are more suitable for causes than they are for measures. For example, the wording of H1-H4 is clearly applicable for causes, but it is less obvious that they are applicable for measures. This is evident in the PSA study where the human category was identified as immediate cause in 41% of the leaks, and only in 1% of the measures (PSA, 2011). Another limitation related to using the taxonomy for measures is that it is not clear whether each category is related to the end purpose of a given measure or to the actual content of the measure itself. For example, technical redesign of a control panel (T1) could be a relevant measure if the end purpose is to avoid human error due to bad/poor design (H3). Hence, a given measures could be allocated to at least two different categories. This means that the categories are not mutually exclusive when applied for measures.

A second taxonomy from the research literature is the one applied in a study by Rollenhagen et al. (in press). Their study is not performed within the oil and gas industry, but at nuclear power plants. However, the taxonomy of measures applied in the study is generic and thus potentially applicable independent of industry. Their taxonomy is not related to the end purpose of a given measure, neither to the actual content of the measure itself, but to the type of problem the measure addresses. The categories applied in the taxonomy are (1) human behaviour, (2) information, (3) technology, (4) organisation, (5) combination and (6) no problem. In Rollenhagen et al.'s study of 106 event investigation reports (with a median of six remedial actions per investigation), close to 75% of the remedial actions addressed problems associated with information and organisational factors. Few actions (less than 10%) were placed in the combination category, which could indicate only minor challenges with overlap. However, a challenge with applying the taxonomy in a project such as *How to get it right* could be the limited availability of information related to the actual problem(s) a given measure addresses.

A third taxonomy from the research literature is the one applied Shappell & Wiegmann (2006) in their study of preventive measures within aviation. A limitation with the taxonomy is that it is built on basis of an analysis of measures that target human errors and violations exclusively. Hence, measures that target any other type of error or malfunction is left out of the taxonomy. Anyway, Shappell & Wiegmann's taxonomy is constructed by means of an inductive approach, where two researchers (with different academic backgrounds) independent of each other coded 622 unique safety recommendations without the use of a predefined classification scheme. Hence, a part of the classification process was to independently develop a taxonomy on basis of the data. Given the vagueness of the classification process, there were some differences in the terms used by the two researchers, but also strong similarities. In case of disagreement, the researchers were asked to discuss their coding and to agree on a single classification. In the end, all the recommendations were classified based on their underlying similarities by the two researchers. Initially, this resulted in nine unique categories. This was later clustered into four larger categories with corresponding subcategories as follows:

Administrative/organizational	Rules/regulations/policies
	Information management/communication
	Research/special study
	Human resource management
Mechanical/engineering	Design/repair
	Inspection
Human/crew	Training
Task/mission	Procedures
	Manuals

In Shappell & Wiegmann's study 34% of the measures were within the category of administrative/ organizational measures, whereas 31% were within the category of mechanical/engineering. Furthermore 11% were within the category of human/crew measures, whereas 23% were within the category of task/mission. According to Shappell & Wiegmann, the taxonomy is not only appropriate for categorization of measures per se. It is also well suited for an analysis of how widely a given problem is addressed. For example, if the problem is a decision error, then the goal with such an analysis would be to identify prospective measures within each category. Hence, the framework "could be used proactively to determine which areas an organization has covered and where gaps exist in the current safety program given current trends in the error data" (Shappell & Wiegmann, 2006: 6).

4.2.4 Summing up research question 2

The literature study has identified eight publications offering literature that are relevant for taxonomies to categorize measures against HC leaks. These are in the form of industry standards, user guidelines and research literature. The basic categories that the two industry standards (NORSOK Z-013 and ISO 13702) present are suitable for differing between the most fundamental aspects of a given measures, e.g. is the measure implemented with the purpose of reducing probability or with the purpose of reducing consequence? However, the lack of details that the standards present makes them inappropriate for an in-depth categorization of measures against HC-leaks. This is also true for the taxonomy which the IAEA (2005) offers.

The ten different categories that the SCS guideline operate with could be used to categorize a given measure independent of the end purpose of the measure. This means that a given measure could be placed in a specific category independent of whether the end purpose is to reduce possibility or to reduce consequence. Compared to the industry standards, the SCS guideline also offer far more categories. However, the categories offered by the guideline are primarily oriented towards proactive measures and to a lesser extent towards the reactive ones. This makes the categories more suitable for continuous measures under normal operating conditions and less suitable for measures initiated as a response to a certain incident.

The only taxonomy presented with an explicit purpose of making an in-depth categorization of measures against HC leaks is found in PSA (2011). The same taxonomy is also applied in Mostue et al. (2014). The taxonomy offers 15 different categories, which cover both human, organizational and technical measures. However, the wording of the categories indicate that the taxonomy is more applicable for causes than for measures. Furthermore, the measure categories are not mutually exclusive, i.e. a given measure could be allocated to at least two different categories. Rollenhagen et al.'s (in press) taxonomy applied in the nuclear power industry seems to have less challenges with overlap between categories. However, the taxonomy could be challenging to apply in cases where no information related to the problem a given measure addresses is available. Furthermore, it may be argued that it is generally easier to categorise a measure by its content/nature, rather than by the problem the measure addresses.

The taxonomies identified in the literature review have different strengths and weaknesses. The categories that are identified in the industry standards are, on the one side, relatively clean-cut and easy to apply. On the other side, the lack of details makes them inappropriate for in-depth categorization. The categories identified in the SCS guideline are far more detailed, but lacks sufficient focus on measures initiated as actions directed towards a concrete incident. The categories identified in the PSA study have a suitable level of specificity, but are to some degree more appropriate for causes than for measures. In addition, the categories are not mutually exclusive. Rollenhagen et al.'s taxonomy, which is based on the problems a given measure addresses, could be a possible avenue for in-depth categorization of measures. The taxonomy could also be further developed with sub-categories. However, its application depends on available information regarding the problems a given measure addresses and such information may not always be available and may require further evaluations. In sum then – isolated, none of the taxonomies identified are directly and readily applicable as adequate classifications of preventive measures against HC leaks for the *How to get it right* project. However, they can all serve as a important input of relevant background information to a revised taxonomy. This includes the following:

- A revised taxonomy should include categories that either classifies a given measure in accordance with (a) the end purpose of the measure, (b) the actual content/nature of the measure itself, or (c) the problem the measure addresses. A combination of these three types of categories will result in a taxonomy where a given measure could be classified in accordance with different principles. Hence, it should be better, for the purpose of easier classification, to stick to one of the approaches
- A revised taxonomy should include categories that are suitable for (a) continuous measures under normal operating conditions and for (b) measures initiated as a response to a certain incident.
- A revised taxonomy should include categories that are, as far as possible, mutually exclusive.
- A revised taxonomy should include categories that covers both human, organizational and technical measures.
- A revised taxonomy should be based on information that is readily available.

4.3 Preventive measures against HC leaks (research question 3)

Based on the identified literature, research question 3 is addressed in this chapter: *According to the literature, which types of preventive measures against HC leaks have been proven effective, which have not and under which conditions are different measures most effective?*

In total, the literature search has identified 34 publications that provide relevant input to the development of effective preventive measures against HC leaks. 25 of these either (a) suggest concrete measures/types of measures against HC leaks, (b) discuss attributes of successful measures/attributes of the implementation process, or (c) gives vital input related to prevention of the main causes of HC leaks, and are therefore evaluated as directly relevant. The review thus indicate that there exists a solid literature base relevant for measures against HC leaks. It should be noted, though, that none of the proposed concrete measures in the identified literature has been *proven* effective through evidence-based research. The main reason for this is linked to the fact that HC leaks (at least those with a major accident potential) are examples of low-probability events with a correspondingly low frequency. Hence, empirical evidence (in the form of e.g. repeated statistical hypothesis tests) is hard to obtain – since evidence, in a strict sense, presupposes a certain frequency of events. However, the literature search indicate that some directly relevant guidelines and best practices for preventing HC leaks are prepared, and other publications present examples of measures that according to their modelling will have an expected reduction in the leakage rate. These and other relevant documents are presented in this chapter. As with most research, the literature presented falls in the category of 'best available evidence', rather than in the category of 'evidence-based' (for a thorough discussion of the concept of evidence-based practice, see Mullen and Streiner, 2006).

As regards the indirectly relevant documents, several of them focus on the causes of hydrocarbon leaks (e.g. Vinnem et al., 2010; Li, 2011; Gilroy and Dumolo, 2013; Haugen and Vinnem, 2011; PSA, 2011). Some of these documents suggest that measures or preventive actions should be implemented that are directly aimed at the identified main causes (e.g. Haugen and Vinnem, 2011), but they do not go as far as suggesting *concrete* preventive measures against HC leaks. For this reason, they are not discussed further. The same goes for papers that discuss relations between HC leaks and general organizational factors (e.g. Olsen et al., 2015) or general psychosocial factors (e.g. Bergh et al., 2014).

4.3.1 Advice on appropriate measures by Step Change in Safety

An initiative launched by Step Change in Safety to cut the number of hydrocarbon leaks from installations in the UK continental shelf by 50% was endorsed by the board of Oil & Gas UK in 2010. The board requested operating companies to develop hydrocarbon leak reduction plans. Based on a review of these leak reduction plans, Step Change in Safety later issued a guideline that offers advice on appropriate measures against HC leaks (SCS, 2012). In chapter 4.2.2 we provided a list of list of ten generic categories or components that form a "good" HC leak reduction plan according to this guideline. Table 3 gives an overview of the various categories and related examples from companies' leak reduction plans.

Table 3: Components that form a "good" HC leak reduction plan. Source: SCS (2012)

Component	Sub-component	Examples
Learning from release incidents	Quantity estimation	Verification of leak quantity by a process engineer
	Investigation	Leadership review of leak investigations
	Lessons learned	Leaders check that assets are receiving and acting on the lessons learned
	Analysis	Communicate themes from annual analysis
Proactive learning	Drawing on industry practices	Review of industry practices and gap analyse
	Specific topics	Isolations and reinstatement
	Integrating own practices	Folding learning back into practices
Integrity and maintenance activities	Inspection methodology	Baseline vibrations and fatigue surveys
	Technology	Improved coating options
	Specific surveys and assessments	Valve integrity surveys
	Turnarounds	Leak testing standards
	Specific equipment areas	Revised design and installation practices for instrument tubing
Managing operational activities	Leak searches	Leak searches triggered by maintenance management system
	Management of leak discovery	Weeps and seeps registers
	Technology	Ultrasonic leak detection
	Jointing	Small bore competence
	Other operations activities	Sand removal
Well integrity	Well integrity management system	Describes response to the degradation or failure of well barriers
	Well barriers	Recognition and management of the risks associated with removal of well barriers
	Well design, construction and testing	Well control equipment, procedures and drills specified
	Well commissioning, operation and maintenance	Removal of emergency shutdown systems assessed and mitigations in place when requested
	Well suspension and abandonment	Inspection and maintenance routines in place for suspended wells

Leadership and management	Mindfulness Leadership Engaging broadly Engaging with industry	Clear distinction between process and personal safety Process safety leadership training HC leaks engagement workshops Engagement in Oil & Gas UK and Step Change workgroups
Resourcing	Manpower Improved access Finance	Level of manpower allocated to leak prevention activities Increased POB for maintenance Integrity spend
Training and competence	Management of training and competence Awareness training Operating practices Environmental testing	Focus of training and competence for most relevant for HC release practices Process safety workshop Pressure testing Environmental management
Targets and metrics	Understanding limitations of metrics Management of metrics Leading metrics Lagging metrics	Knowledge of UK benchmarking position Quality assurance of leak quantities Competence refreshers Tiered loss of containment measures
Practices, monitoring and auditing	Practices Monitoring Audit	Practice users workshops and engagement Regular review of HC leak release investigations Audit of HC release practice compliance

Note that the above list of measures is fairly comprehensive and as such has a somewhat limited relevance with respect to targeting *specific* measures against specific causes and problems.

Also published by Step Change in Safety (SCS) is the *Hydrocarbon Release Reduction Toolkit* (SCS, 2009). The Toolkit provides the following collection of good practice guidelines developed by the oil and gas industry to address main leak areas:

- Bolted Joints Guidelines
- Flexible Hose Guidelines
- Small Bore Tubing Guidelines
- Vibration Guidelines
- Corrosion Management Guidelines

SCS argues that a full commitment to these practices will contribute to improvements in major and significant HC releases. It should be noted, that the evidence for this assertion is not based on solid empirical studies, but on a condensed account of leak reduction plans prepared by practical experts within the field, i.e. operating companies on the UK Continental Shelf. Hence, the recommended practices have not been subject for empirical studies or risk modelling.

4.3.2 Risk modelling in BORA-Release and Risk OMT

In contrast to the SCS guideline, which is based on expert judgments, BORA-Release and OMT are methods that aim to predict the probability of HC releases through modelling the effect of a given measure based on its potential ability to affect certain risk influencing factors (RIFs). Effective or relevant measures according to these methods are described below.

Sklet et al. (2006) have demonstrated that BORA-Release is a suitable method for modelling the effect of risk reduction measures on hydrocarbon release frequencies (cf. chapter 4.1.1). In their study of an offshore oil and gas production platform, sensitivity analyses were carried out for three scenarios: A) Release due to valve(s) in wrong position after maintenance; B) release due to incorrect fitting of flanges or bolts during maintenance; and C) release due to internal corrosion. The main results from the sensitivity analyses included the following results for eight different risk-reducing measures:

- Implementation of an additional barrier, i.e. third party control of work
  E.g., third party control of closed valves in scenario A reduces the release frequency from scenarios A and B with 77% by use of industry average data, and 68% by use of revised data.
- Improvement of the scores of all RIFs by one grade
  E.g., this reduces the release frequency from scenarios A and B with 61%.
- Improvement in communication
  E.g., improvement of the score of the RIF Communication RIF from D to C reduces the release frequency from scenarios A and B with 2%.
- Improvement in time pressure
  E.g., improvement of the RIF Time pressure from D to C reduces the release frequency from scenarios A and B with 28%.
- Implementation of condition monitoring by use of corrosion coupons in dead legs
  E.g., this reduces the expected release frequency due to corrosion by 31%.
- Improvement of the efficiency of the inspection program
  E.g., changing from fairly effective to usually or highly effective for corrosion group 1 reduces the expected release frequency by 21% and 35%, respectively. Changing from usually effective to highly effective for corrosion group 2 reduces the release frequency by 52%.
- Improvement in painting, tidiness and cleaning
  E.g., improvement of the status of the RIFs Painting, and Tidiness and cleaning reduces release frequency due to corrosion by 13%.
- Improvement of the probability of detecting minor release
  E.g., changing the probability of failure to detect minor release by system for HC detection from 0.2 to 0.1 reduces the release frequency by 10%.

It is important to note that these risk-reducing measures are related to the three scenarios that were chosen for the analyses. The purpose of the case study was to demonstrate that BORA-Release could be used to model the effect of leak frequencies of risk reducing measures, not to provide an exhaustive list of proven effective measures. Furthermore, it should also be underlined that the results obtained by the BORA-Release method is based on risk modelling and not on empirical evidence. Hence, the quantitative results are based on a number of assumptions and simplifications related to the basic risk model, the weighting of the RIFs, the input probabilities etc. These limitations are also stressed by Sklet et al. (2006) themselves.

Similar to the BORA-Release method, the objective of the Risk OMT model is to provide a basis for ranking risk reduction measures related to HC leaks (Gran et al. 2012). In the OMT project, a dialogue with Statoil resulted in the list of proposed measures that is shown in Table 4. The list represents examples of measures at different levels covering various operational and organisational challenges.

In Gran et al.'s (2012) study, expert judgements were used to assess the effect of each of the proposed risk-reducing measures. The effect value was based on three different inputs: (1) which RIFs the measure would have influence on, (2) the importance of the influence for each RIF (low/medium/high) and (3) additional structural changes to the model. The modelled examples showed that the list of proposed measures not only represented examples, which could be undertaken, but also that it represented measures that would also have an expected reduction in the leakage rate. The overall effects (in terms of risk reduction) of each measure, calculated on basis of Bayesian belief network (BBN), are presented in Table 4. According to the results, the measure with the highest expected effect are measures related to increased focus on the psychosocial work environment through greater degree of involvement across levels and disciplines. However, the effect of each measure varied in relation to different failure scenarios (not shown in Table 3). For example, the OMT model predicted that the effect of measure 6 (improve labelling of process equipment), with an overall effect of 15,0%, actually varied from 8% risk reduction for scenarios caused by error in isolation/blinding/planning, to a 91% risk reduction for scenarios caused by incorrect isolation/blinding.

Table 4 Risk-reducing measures from the Risk OMT project. Source: Gran et al. (2012)

No.	Measure	Risk reduction (BBN)
1a	Work process training: work on normally pressurised equipment	7,0%
1b	Change the procedure for safe job analysis and pre-work dialogue with a greater emphasis on hydrocarbon leaks (major accidents)	1,5%
2	Increase emphasis on leaks (major accident potential) in the training of managers and executives	6,4%
3	Compliance program: conduct training in action compliance	14,2%
4a	Increase focus on the psychosocial work environment through greater degree of involvement across levels and disciplines	25,9%
4b	A subset of 4a is to improve involvement of contractors	5,4%
5	Improve availability and faster updating of technical documentation	5,1%
6	Improve labelling of process equipment, i.e. more uniform labelling in accordance with technical documentation, in combination with improvements of established practice for radio communication	15,0%
7	Improve management of change, especially routines for quality control and the handover from modification projects to operation	15,0%
8	Formalise requirements to the work process 'Work on normally pressurised equipment' in form of new procedures	13,7%
9	Develop procedures for the preparation and use of specific checklists from drainage/sampling	10,1%

In contrast to the guideline presented by the SCS, OMT uses risk modelling to determine the effect of different measures. This allows for contrasting the effect of different measures. The measures evaluated by Gran et al. (2012) do not represent an exhaustive list of measures. Hence, the results are limited to the measures actually evaluated. Furthermore, OMT has the same limitations as BORA-Release with regard to the fact that it is a model and not empirical data. Hence, the validity and reliability of the results depends on the model itself, the assumptions made and the data employed.

4.3.3 Other literature proposing concrete measures against HC leaks

In addition to measures proposed in guidelines and measures proposed on basis of risk modelling, the literature review has also identified empirically based studies that propose relevant measures. Although the measures proposed are empirically based, in the sense that they are based on identified frequent causes of HC leaks, they are not empirically evaluated, in the sense that the effect of the proposed measures are assessed and quantified.

The first example of studies proposing concrete measures is found in Al Mansouri and Alam's (2008) study of leak and spill data from the period 2003-2006 in an upstream petroleum company. The study resulted in an overview of the 22 most common causes related to HC leaks and spills and the preventive actions suggested for each of these (Al Mansouri and Alam, 2008). Table 5 show the complete list of causes and preventive measures.

Table 5: Source of leaks and its preventive measures. Source: Al Mansouri and Alam (2008)

Potential source/cause of leak or spill	Preventive action

Vent / drain / tapping / sampling point may be open	Check and close any open vent / drain / tapping / sampling point
Crude oil carry over to flare due to bypassing of Level Switch High High (LSHH) for the vessel/tank	Normalize the LSHH or keep a continuous watch on the level and take preventive measure accordingly
The isolation valve may be passing	Use positive isolation in case the integrity of the valve is doubtful
The isolation of wrong valve/ equipment / pipeline	Ensure the identity of isolation valve / equipment / pipeline prior to isolating it
Accidental damage of above ground / underground services by heavy equipment during excavation work	Use a metallic detector and make slit trenches to locate the underground services
Missing or improperly tightened studs and bolts on flange joint	Ensure all Studs & Bolts are in place, and tightened properly
Corroded pipes, valves, flanges etc.	Ensure Cathodic Protection, Regular Inspection and maintenance of the pipes and fittings
Displacement of pipe clamps / damaged clamps / corrosion on clamps / damaged hose	Regular inspection of hose, clamps and fittings and immediate replacement of the damaged ones
Blowout / uncontrolled flow from the well	Ensure the availability of Quick Shut Off Valve (correct type and size) matching with tubing configuration at the well site
Overflow from tank, vessels or separator	Check level alarms, level transmitter and level switches function
Overflow from effluent water disposal pits	Do not overload Disposal Pits beyond 60% of its capacity
Poor or improper support of headers, flowlines or pipelines	Regular survey and inspection of headers / flowlines / pipelines
Possible damage to pipelines / flowlines passing across the road	All pipelines / flowlines passing across the road must be properly protected through sleeves and concrete support
Possible damage to pipelines / flowlines during heavy lifting operations at site	Take extreme precautionary measures during heavy lifting operation at site
Defective weld joint or pipe under stress	Carry out NDT (Non - Destructing Test) testing of pipeline and weld joints
Leakage due to cracked / damaged gasket in the flange joint	Ensure that the gaskets being used are of proper pressure rating & type & approved
Spillage as the pump failed to start although the closed drain vessel indicated high level	Check high level switch for the tank and power availability to the pump
Opening a well after completion of drilling, workover, or wireline operations	Ensure the flowline is connected to the production header at GC end
The outlet of PSV / Varec Unit opens to atmosphere	Ensure that outlet of PSV / Varec Unit is connect to closed drain header
Loading & unloading operation at berth	Ensure the installation and operation of positive hydraulic shut-off valve at the coupler. Ensure the ship is moored and secured properly
Collapse of fuel / vacuum tanker	Ensure the tanker is fit for the purpose / road worthy & having valid inspection certificate
Pipeline rupture due to surge in pressure	Closely monitor the pipeline parameters & ensure its functional availability of protective device

It should be noted that Al Mansouri and Alam's (2008) list of proposed measures is a company-specific list based on leaks and spills during a given period. However, many of the proposed preventive actions may be considered measures against HC leaks in general. An overall flaw, though, with the list is that the proposed measures are not evaluated in terms of effects – rather they are derived directly from a corresponding cause. Furthermore, the causes and measures are more or less purely technical and very specific, and as such inadequate in a total leak reduction perspective.

A second example of a study proposing concrete measures is identified in a master's thesis titled *How has industry achieved a significant reduction in Hydrocarbon Releases?* (Adejugba, 2013). Adejugba concludes that the mechanisms contributing to the reduction of HC releases are multidimensional. Examples of such mechanisms are investigation of every HC releases including near misses; establishment of documented guidance on HC leak prevention and the actions to be taken; tracking of leak investigation progress and application of quality assurance; and assurance or demonstration of training and competence concerning small-bore tubing. In addition, the author provides the following recommendations for further reduction in HC releases:

- Encouraging the reporting of all seeps and weeps to increase the HC release database
- Providing a central industry information access point targeted at HC release prevention
- Updating and rolling out the SCS HC release toolkit
- Ensuring continuous safety awareness among the workforce
- Efficient management of equipment contracting processes
- Ensuring that the industry continues to exploit all mechanisms that have contributed to the present reduction in HC releases.

A third example of studies proposing concrete measures is found in relation to a project conducted by the Norwegian oil and gas industry and the Norwegian Oil and Gas Association (in the period from 2003 to 2008) which aimed at reducing the number of HC leaks on Norwegian offshore installations. In a paper by Vinnem and Røed (2014), which is a summary of several previous papers by the authors (Røed et al., 2012; Røed and Vinnem, 2013; Vinnem and Røed, 2013), this project and its main activities are presented. The main scope of the work for the project was to analyse HC leaks that have occurred; contribute to exchange of experience between companies on the Norwegian Continental Shelf; and contribute to exchange of experience from other industries. With reference to identified causes of HC leaks, the following examples of potential risk reducing measures were provided (Vinnem and Røed, 2014):

- Using new bolts (always)
- Verification by another person (independently) that the correct gasket is chosen according to procedures
- Measures to ensure that both the correct torque table and the correct tool are used
- Verification on the correct torque by another person

A fourth example of studies identifying concrete measures is found in a study conducted by SINTEF on behalf of the PSA in 2010-2011 (cf. chapter 4.2.3). As regards causes, the main contributors of underlying causes were found to be deficient planning/preparation (23%), deficient risk assessments/analyses (13%), deficient communication/cooperation/interfaces (7%), and deficient work practice/operational follow-up of barriers (7%).[4] In the same study by PSA (2011), four operating companies ranked measures the following as the most important contribution to risk reduction related to HC leaks in the period 2002-2010:

- Company management/technical support
- Operator/technician – employees
- Technical design and condition of the installation

A fifth example of studies identifying concrete measures is found in a study conducted in the aftermath of SINTEFs study by Mostue et al. (2014). Mostue et al. compared causes of HC leaks from the PSA study with causes of two other event types in the petroleum industry: lifting incidents and fires in electrical installations. They identified risk reducing, preventive measures and areas of improvements for each of the three event types and common features in the recommendations include the following:

[4] See also Hauge et al. (2013).

- A more proactive approach in relation to redesigning away from inadequate technical solutions rather than to accept and adapting to them.
- Ensure appropriate learning and experience transfer and a systematic and efficient use of information from incident databases and other sources relevant to preventive work within and between companies.
- Improvements in defining precise and concrete measures to be taken in the wake of investigations.
- More attention to work operations that deviate from daily work and that may be more complex.

Despite the fact that the concrete measures proposed in the five examples above are explicitly empirically based, this is only true for the identified *causes* of HC leaks. The proposed *measures* are only derived from the causes and have not been subject to empirical testing. This being said, it should be noted again that quantitative evidence-based evaluations of measures against events with low frequency is difficult because the output measure rarely occurs. In studies of high reliability organizations this fact is well recognized, and by Lofquist (2010) referred to as "the art of measuring nothing" – i.e. the problem of measuring safety as an outcome variable in ultra-safe industries.

4.3.4 Attributes of successful measures and the action process

In addition to literature which focus on concrete measures against HC leaks (e.g. SCS, BORA, OMT), there is a rich area of literature which focus on how successful measures should be constructed and how they should be determined, formulated and implemented (referred to as the action process). This literature is not related to HC leaks in particular. However, it should be relevant for *How to get it Right* since this type of literature is of a more generic type – relevant across different industries. The number of publications focusing on attributes of successful measures and the implementation process is huge. Below, four directly relevant examples are selected and described.

The first example is a study by Rollenhagen et al. (in press) of measures implemented subsequent to incidents at two Swedish nuclear power plants. In brief, the authors have three basic suggestions with regard to how measures should be constructed in order to be effective. The first suggestion is that an effective process for measures should not only be based on errors and deviations identified in the investigation, but also on normal operations, i.e. when a process works according to plan. The rationale behind this idea is related to the fact that most operations are successful, and that organizations must be able to learn from these and not solely draw out learning points from operations that have gone wrong. This view is also highly supported by the resilience engineering literature (e.g. Hollnagel, 2014; Rosness et al., 2016). Rollenhagen et al.'s (in press) second suggestion is that measures not only should address the direct or underlying causes, but also address other factors that supports optimal performance in the process in which the incident took place. The rationale behind this idea is that measures aimed solely at reducing the probability and consequence of an event with the exact same causes will have less effect compared to measures/set of measures which also aim to strengthen other factors that success rely on. Rollenhagen et al.'s third suggestion is that measures not only should address negative proximal events in the causal chain, but also focus on the incubation phase of the incident and thus put emphasis on the distal latent weaknesses (e.g. poor design, shortfalls in training etc.) which precedes the negative proximal events. This view is highly supported by the safety literature in general (e.g. Taylor et al., 2015; Zohar, 2010; Reason, 1997; Wagenaar, 1998; Turner, 1978).

Although Rollenhagen et al.'s (in press) suggestions are based on a study of the nuclear power industry, they are generic and should be relevant for other industries. The relevance of the three suggestions is also strengthened by the fact that they rely on previous research and established organizational safety theory.

The second example of literature focusing on attributes of successful measures and the action process is a study among Dutch safety professionals and their view of critical steps in learning from incidents, performed by Drupsteen et al. (2013). The empirical part of their study is based on a literature review of critical steps in learning from incidents, and it is this part of their study that is relevant for *How to get it right*. According to

Drupsteen et al.'s review, an incident investigation should be followed by a planning process that involves (1) identifying and selecting measures that are expected to be most effective, and (2) a prioritising between these measures based on urgency. The next step involves formulating a realistic action plan. The measures in the action plan should be based on the recommendations from the planning process and have the following characteristics:

- Specific
- Measurable
- Attainable
- Relevant
- Date for commence

The next phase in Drupsteen et al.'s action process is the intervening phase. This phase constitutes the realisation of the action plan. According to the authors, the first requirement in this phase is that the people responsible for the actions should have ownership of the actions. Furthermore, adequate resources (time, money, human and technological capabilities) must be available. In addition, they highlight the importance of communicating the action plan and its objectives throughout the organisation. The purpose of this is to demonstrate a willingness to improve safety and to share the lessons learned from the investigation and planning process. In addition, employee involvement is important both in the planning phase and in the intervening phase.

The last phase in Drupsteen et al.'s action process is the evaluation phase. According to the authors, it is pivotal to evaluate whether the measure was fully realised or not, and whether the measure was fully effective or not. Hence, they underline both the importance of evaluating first-order learning (to what degree a given action is performed) and second-order learning (to what degree a given action was effective). Furthermore, they highlight the importance of identifying the reasons why a given measure did not have the intended effect.

To a certain degree, the success criteria that Drupsteen et al. highlight might seem self-evident in a paper exercise. However, the criteria are not self-evident when it comes to the way measures actually are carried out in real action processes. For example, in a study by Drupsteen and Hasle (2014) several bottlenecks related to the success criteria were identified when representatives from seven industrial companies were interviewed. For instance, in the intervening phase time limitations, no sense of ownership and fear of extra work were identified as significant bottlenecks. In the planning phase limited employee involvement, top down approach, limited integration between different measures and quick fix focus were identified as significant bottlenecks. (For a study of challenges related to governmental investigations and subsequent company actions, see Cedergren, 2013).

The third example of literature focusing on attributes of successful measures and the action process is a guideline developed by the International Atomic Energy Agency, IAEA (2005). As regards the attributes of successful measures, the IAEA (quite similar to Drupsteen et al., 2013) highlight seven essential characteristics. These are referred to with the acronym SMARTER:

- Specific
- Measurable
- Achievable
- Realistic
- Timely
- Effective
- Reviewed

Furthermore, as regards the action process, the IAEA (2005) highlights that it is preferable to select measures that strengthen already existing programmes and defence in-depth barriers instead of developing new ones.

This means, that it is not effective to develop new barriers when the existing ones remain weak. In addition, the IAEA emphasises the importance of addressing the root causes to effectively prevent repetitions. In the guideline, the IAEA operates with 11 overall characteristics that are essential for the effectiveness of corrective measures. These are (IAEA, 2005: 4-5):

- Policies are established by management to align the organization to effectively implement corrective actions and to set criteria for expectations and priorities.
- Personnel, including contractors, are actively encouraged by plant management to identify and report events. Reporting criteria and reporting systems are clearly defined and familiar.
- Reported events and minor problems are screened and evaluated in a timely manner based on their actual or potential consequences.
- Significant events and repeated problems are investigated to their root causes to identify effective corrective actions.
- Investigation of events of lower significance may focus on correcting immediate cause and trending and may not address the root cause.
- Personnel with sufficient knowledge and skills carry out investigations of significant events and recurring problems using well-defined root cause analysis techniques.
- Root causes, contributing causes and direct causes are identified by the investigation.
- The OE indicators (data gathered from significant events, low-level events, near misses, error-likely situations reporting, screening and investigation) are trended to identify system vulnerabilities, generic issues or weaknesses in the organization.
- Plant management encourages and reinforces the use of OE information (use of lessons learned) by personnel.
- Employees who identify problems receive feedback on decisions made and on corrective actions taken.
- Appropriate resources (personnel, equipment, funds) are allocated by the management to the corrective action programme.

The IAEA guideline is comprehensive and includes several specific advices on how to implement measures and improve performance at different parts of the organisation, including procedures, human performance, work practices, safety culture, teamwork, maintenance etc. Within the frames of this literature review, these specific advices will not be repeated. However, several of the advices given in the guideline are generic and should be highly relevant for the final product (the leadership guideline) of *How to get it right*.

A general consideration related to IAEA's guideline, though, is that the measures recommended are not evidence based in the sense that they are explicitly supported by previous research. All references used in the guideline are internal, i.e. other IAEA publications. However, it should be noted that the notion of SMARTER is supported (although not explicitly in IAEA's guideline) by safety research literature elsewhere (e.g. Drupsteen et al., 2013; Drupsteen and Hasle, 2014) and that the origin of the acronym stems from management research (Doran, 1981). Applications of SMARTER can also be found within the practitioner literature, such as TapRoot (2015) which is a tool for developing useful measures. In TapRoot, SMARTER is an acronym for Specific, Measurable, Accountable, Reasonable, Timely, Effective and Reviewed, i.e. roughly similar to that of IAEA. In sum then, the support for the logic behind SMARTER is relatively robust.

The fourth and last example of literature focusing on attributes of successful measures and the action process is a guideline developed by the Energy Institute (EI, 2016). The purpose of the guideline is to offer advices on learning from accidents and incidents in general, but one of its sections relates to measures specifically. Similar to IAEA (2005), the EI (2016) also operate with a SMART acronym. This means that (1) all measures should have a clear description of what is required and who is responsible and each action should address one recommendation or issue (Specific), (2) the level of implementation should be trackable (Measurable), (3) non-attainable recommendations should not be accepted (Attainable), (4) a given measure should address the intent of a given recommendation, relate to the circumstances of the incident and be targeted to prevent reoccurrence (Relevant), and (5) timescales for stages and completion should be available so that monitoring of progress is possible (Time-bound). In addition to the SMART-features the EI recommend that derived measures should not duplicate measures that already are in the system, as this can lead to an overload of the action process.

In contrast to the literature described above, the EI guideline also offers advices for developing recommendations. Recommendations are typically (but not exclusively) developed by an investigation team as a basis for developing concrete measures. Hence, the wording of the recommendations is, according to the EI, essential for the later development of proper measures. The EI highlights the following bullet points as relevant for recommendations:

- Recommendations should be worded as a single stand-alone item that includes an explanation of why it is made (i.e. linkage to finding).
- Wording should be free of emotive or judgemental language.
- Wording should not be vague or open to interpretation.
- Recommendations should address both direct and underlying causes.
- Recommendations should be clear on who is responsible and which part of the organisation it applies to.
- The intent of the recommendation should be clear and desired outcome should be specified. How to achieve the outcome should be determined by the organisation.
- Wording should not sound authoritarian or overly prescriptive.
- Broader learning points for the organisations/industry from recommendation should be emphasised.

Furthermore, the EI guideline emphasise the importance of including line managers in the action process, in particular at the stage where recommendations are formulated. The reason for this is that the line managers usually have the best expertise and ultimately are the ones who will implement the actions. Hence, recommendations written solely by an investigation team is not a recommended process. In addition, the EI emphasise the importance of involving personnel with frontline experience when developing recommendations, since they usually have a deeper understanding of the issue at hand. This is also emphasised by e.g. Drupsteen and Hasle (2014) and Størseth and Tinmannsvik (2012). Furthermore, involving frontline personnel in the search for recommendations is a key element in Boeing's tool for investigating flight crew operations system failure, referred to as the Procedural Event Analysis Tool (PEAT). Also, PEAT put emphasis on cooperation between investigators and managers when formulating recommendations (Moodi and Kimball, 2004). Despite focus on involvement of frontline personnel both in research literature and practitioner literature, a survey by Rollenhagen et al. (2010) of more than one hundred accident investigators has found that investigators seldom involve frontline personnel in the process of formulating recommendations.

The EI guideline (EI, 2016: 42) also includes an overview of blockers and enablers for effective recommendations and actions. These could be highly useful for the empirical parts of *How to get it right*. Some relevant blockers and enablers are:

- Blocker: recommendations are not accepted by line management.
- Blocker: recommendations are not accepted by frontline personnel.
- Blocker: too many recommendations.
- Blocker: loosely worded recommendations.
- Blocker: insufficient weight given to underlying causes.
- Enabler: ask line managers to define recommendations.
- Enabler: involve frontline personnel in discussing potential risk reducing measures.
- Enabler: present draft recommendations to frontline personnel.
- Enabler: prioritise recommendations based on risk management.

- Enabler: ensure that recommendations are risk proportionate.
- Enabler: ensure that recommendations are appropriate to the relevant human failure type.

Similar to the other literature related to attributes of successful measures and the action process, the advices offered by the IE guideline are not evidence based in the sense that they are explicitly supported by effect evaluations. This means that few of the advices that the guideline offer have been subject to empirical tests. However, as stated previously, the support for the logic behind SMARTER is relatively robust and extends far beyond the safety literature (e.g. Doran, 1981).

4.3.5 Preventing the main causes of HC leaks

In addition to literature which focus on (a) concrete measures against HC leaks (e.g. SCS, BORA, OMT), and (b) how successful measures should be constructed and acted upon (e.g. IAEA, IE), there is a (c) large amount of research which address the main causes of HC leaks and how they should be prevented or avoided. This literature is not HC leak specific, but since the main underlying causes of HC leaks to a large extent resembles causes of other high potential incidents this type of literature is evaluated as directly relevant - regardless of the type of incident or type of industry. However, there are two challenges with examining this type of literature. First, there is a massive amount of literature that is relevant for the prevention of the main causes. Hence, ordinary database search is not suitable within the limits of this study. Second, different main causes of HC leaks are identified across different studies. Hence, there is no universal agreement of what the main causes are (e.g. due to different classification schemes for causes).

In the following, the first challenge has been solved by selecting literature strategically on basis of the authors' knowledge of the subject supplied with some unstructured database searches. The second challenge has been solved by using the PSA's RNNP 2010 report which includes an in-depth study of investigation reports related to 36 different HC leaks in the period from 2002 to 2009 (PSA, 2011). According to the report, some of the most frequent underlying causes of HC leaks are (1) procedures and documentation, (2) procedure violations, and (3) lack of risk-awareness. These three causes will be treated separately in the following.

4.3.5.1 Procedures and documentation

In the safety research literature it is well documented that the quality of procedures and documentation (in the following referred to as procedures) is a real challenge – even in industries which rely heavily on written safety instructions. For example, in Simpson et al.'s (2009) guide to understanding human error in mine safety, it is emphasized that procedures are far from being appropriate, well written and well communicated, and that this is often at the expense of understanding and following the procedures (see also Laurence, 2005). Challenges related to for example procedure complexity, accessibility, applicability and clarity have been identified in a number accidents, near-misses and catastrophes such as the well-incident on Gullfaks C in 2010 (Austnes-Underhaug et al., 2011) and the Deepwater Horizon blowout in 2010 (Tinmannsvik et al., 2011) and by researchers across industries, including the oil and gas industry (e.g. Tinmannsvik, 2009; Dahl, 2013). For example, a study of offshore workers on the Norwegian Continental Shelf (NCS), found that roughly one of three were of the opinion that the procedures were written in a language that was difficult to understand, and that 70% were of the opinion that there is too much focus on preparing new procedures and too little focus on familiarization of procedures that already exist (Tinmannsvik, 2009). Similarly, a study by Dahl et al. (2013) of offshore vessel workers on the NCS found that 37% of the vessel workers find the procedures difficult to understand. Furthermore, a review study by Alper and Karsh (2009) has found that poorly designed procedures are among the top six causes of procedure violations. Their review study spanned across different high hazard industries, e.g. aviation, aviation maintenance, construction and mining. Challenges with procedures are also emphasised in the RNNP 2010 report, not only by the fact that it is among the top underlying causes of HC leaks, but also by the fact that the same report documents that measures related to procedures (e.g. revision or preparing new ones) are the second most frequently applied measure type in the aftermath of HC leaks (PSA, 2011). Furthermore, Olsen et al. (2015) have identified a significant negative correlation between familiarity with governing documentation and the number of hydrocarbon leaks on offshore platforms. Hence, procedure quality and clarity should be viewed as important measures against HC leaks, but how is this ensured most effectively?

Simpson et al.'s (2009) basic principles of procedure preparation in the mining industry might seem self-evident, but in the light of findings from the RNNP 2010 report (PSA, 2011), they should be highly relevant. The basic principles are (1) functional simplicity, (2) tailoring, (3) use of plain, positive language and (4) piloting. Functional simplicity implies the need to define the objectives as carefully and narrowly as possible from the perspective of the end-user of the procedure. This means to focus on the task under consideration, how it shall be performed and why, and not on external issues such as adjacent regulation and guidance. Tailoring implies to adjust the terminology to the audience for whom the procedure is being prepared. This involves a clear definition of the audience, their prerequisite knowledge and experience, and then modify the jargon accordingly. Use of plain, positive language implies focusing on what to do, in contrast to what not to do. Simpson et al. emphasise that positive statements are easier to understand, easier to remember and less likely to be misunderstood. Piloting implies the need to check the applicability of new or revised procedures. Without such piloting, Simpson et al. argue, it is impossible to be sure that any potential misunderstandings have been identified or whether the procedures are practical in the situations they are to be applied.

In line with Simpson et al.'s principles, the IAEA (2005) emphasise the importance of comprehensible language, clear definitions, accuracy and involvement of users. Furthermore, the IAEA recommends that improvements of procedures (like any other measures) should go through an evaluation process. Here the need for the change is assessed by for example considering (a) the consequences of not implementing the change, (b) the consequence of implementing the change, (c) possible hazards related to the change, (d) training requirements involved as a result of the change, (e) ALARP considerations, and (f) costs related to the change. Also, when procedure preparation or revision is defined as a concrete measure after an incident, the IAEA (2005: 30) recommends the following key elements to be emphasised;

- Procedure style and language is usable, familiar and comprehensible to personnel.
- Procedures are accurate, adequately detailed and complete, in order to ensure its credibility and guarantee continual use.
- Key decisions and safety critical steps are clearly delineated in the procedure.
- Steps of the procedure are described in proper sequence so that warnings and precautions are described before and not after the step is performed.
- Warnings and precautions do not contain decision steps or directive orders; they only have informative character.
- Acceptance criteria is included to ensure satisfactory accomplishment of the process.
- In addition, the following administrative measures are taken into account:
- Experienced workers are involved in procedure development with proper frequency for procedure updating that ensures procedures are accurate and describe the ways in which tasks are to be performed in reality.
- A process is established for procedure users to initiate procedure improvements.
- Procedures are explained and available to workers who are expected to use them.
- The plant’s quality management system ensures that the latest procedure version is available at the working place.

Similar to Simpson et al.'s (2009) basic principles of procedure preparation and IAEAs (2005) advices, Antonsen et al. (2009) argue, in their study of offshore supply bases, that the minimum requirements related to procedures are comprehensibility (understandable language), accessibility (access to the procedures) and accuracy (clear-cut description of the relevant tasks). In addition, Antonsen et al. found that procedure preparation is most effective, in terms of compliance, when the end-user is allowed to influence on the design of new procedures. In fact, end-user influence on procedure design was found to be the most critical success factor for compliance. This finding resembles the advices related to involvement of frontline personnel when formulating and determining preventive measures and recommendations in chapter 4.3.4 (e.g. Drupsteen and Hasle, 2014; Størseth and Tinmannsvik, 2012; Moodi and Kimball, 2004; EI, 2016). The finding is also in accordance with one of the main results from the Risk OMT project, where it was found that involvement across levels and disciplines have a high effect on risk reduction for HC leaks (Gran et al., 2012).

4.3.5.2 Procedure violations

According to the review of company internal investigations presented in the RNNP 2010 report, procedure violations constitute eight per cent of all underlying causes of HC leaks and 14 per cent of all immediate causes (PSA, 2011). This makes procedure violations among the top causes of HC leaks on the Norwegian Continental Shelf. Similarly, a study of underlying causes of HC leaks on the UK Continental Shelf found that procedure violations was the most frequent human causal factor (Li, 2011). These findings are not surprising as studies of other accident and incident scenarios within the oil and gas industry show pretty much the same pattern. Violations of safety regulations have, for example, been ranked as the most important cause of collisions between offshore service vessels and offshore installations on the NCS (Kvitrud, 2011; Kvitrud et al., 2012). Furthermore, a study by Walker et al. (2012) of 108 fatal accidents and 174 high potential incidents in 75 companies within the International Association of Oil & Gas Producers (OGP), found that one of the most common direct causes of this type of accidents are violations of safety rules and procedures.

In sum then, increased compliance with procedures should be viewed as a significant measure against HC leaks (and other types of incidents), but how is this ensured? There is definitely no quick fix answer to this question since violations are causally related to a number of factors. Some studies point to individual factors, such as gender, age, work experience and personality (e.g. Chan et al., 2002; Ashton, 1998; Salgado, 2002; Mount et al., 2008; Clarke and Robertson, 2005), whereas other point to system factors (i.e. working conditions). The individually oriented studies will not be treated in the following. Firstly, because individual characteristics only explain a minor part of the variation in violations. Secondly, because, as emphasised by Reason (2000), the human condition is not easily susceptible to change, whereas the conditions under which humans work largely is in the hands of management. Hence, only knowledge obtained from a system perspective have the potential to give relevant input to measures related to increased compliance with procedures.

In brief, studies carried out from a system perspective have identified several contextual factors that influence workers' propensity to act in accordance with procedures. For example, studies of safety climate, have demonstrated that workers’ perception of safety priorities within their organization influence safety-compliant behaviour (e.g. Biggs and Banks, 2012). Furthermore, several leadership studies have found that leaders who emphasize reward and encourage safe performance generate a higher level of compliance with procedures within their work group (e.g. Lu and Yang, 2010). Researchers have also found the balance between job demands and job resources to be important. For example, Hansez and Chmiel’s (2010) study of non-compliant behaviour within the energy sector demonstrated that imbalances between job demands and resources affect the frequency of violations negatively because of strain and lack of motivation.

As regards measures aiming at increased compliance with procedures, it is of pivotal importance first to investigate what type of violation that was involved in the incident scenario. In brief, there are two different types of violations; the intentional and the unintentional ones. Whereas intentional violations refer to deliberate violations of rules and procedures that are known and understood by the actor, unintentional violations refer to violations of rules and procedures that the actor has no or limited knowledge of and therefore operates without any clear reference to (Reason, 1997). The drivers behind these two types of violations are different. Whereas intentional violations are related to motivation, unintentional violations are related to knowledge. Correspondingly, organisational measures aiming at increased motivation should be qualitatively different from those aiming at increased knowledge.

To develop accurate measures it is necessary to further identify the root cause of why a motivation- or knowledge problem has come into being. The UK Health and Safety Executive (HSE, 1995) has developed a checklist with 48 checkpoints which could be used as a tool for examining such root causes. Some of these checkpoints are:

- Rules/procedures are factually incorrect
- Rules/procedures do not always describe the best way of working
- Deviations from rules/procedures are unavoidable
- Schedules do not allow enough time to do the job according to the rules/procedures
- Rules/procedures are difficult to understand
- There are incentives to ignore some rules/procedures
- Supervisors seldom discipline workers who break rules/procedures

Despite the fact that effective measures presuppose a root cause analysis, there are some general conditions that should be considered when aiming for improved compliance via the knowledge track and the motivation track. Regarding the first, the problem of lack of knowledge is frequently related to the quality of the procedures themselves. As was shown in chapter 4.3.5.1, an inappropriate share of workers on the NCS find procedures difficult to understand (e.g. Tinmannsvik, 2009). Under such circumstances, the advices offered under chapter 4.3.5.1 should be considered effective and relevant (e.g. Simpson et al., 2009; IAEA, 2005; Antonsen et al., 2009). However, lack of knowledge could also be related to factors separate from the procedures themselves. For example, a qualitative study of contractor workers in Statoil has identified several factors that can explain variation in knowledge of procedures (Dahl, 2013). The study indicate that measures aiming at increased knowledge of procedures first of all should consider whether all relevant end users have adequate physical and digital access to the procedures, whether or not they have received proper training in how to navigate among procedures and whether the user-friendliness of the safety management system is adequate. Secondly, determining measures aiming at increased knowledge of procedures presupposes a careful process of identifying whether a problem only exists within certain groups (e.g. among contractor workers) or whether the problem is more wide-ranging. Lastly, the study indicate that the process of determining adequate measures should consider whether lack of knowledge is caused by the impression that knowledge is not important and a further examination of why this impression has been formed. Such impressions are primarily not formed by formal organisational statements, but to a larger degree via workers' day-to-day interactions and observations of leaders (role models) and co-workers.

As regards intentional violations, measures aiming at improved motivation is necessary. However, inadequate motivation could be caused by a number of factors. Within the limits of the present study all such factors cannot be examined in detail here. Instead, we will look at Zohar's (2010) general framework in which all such detailed factors can be placed. According to Zohar (with support from a massive amount of literature), an employee's motivation and corresponding safety behaviour is shaped by the overall pattern and signals sent by a complex web of impressions. This web of impressions is usually spoken of as the organisation's safety climate, and it is within this climate that workers receive and interpret signals about what role behaviour it is that is expected, supported and rewarded. Employee behaviour (e.g. procedure compliance or violations) will then tend to align with these perceived expectations. According to Zohar's framework, these attitude-forming perceptions are influenced by three patterns in the organization. Hence, measures aiming at increased motivation for compliance must consider these patterns. The three dimensions are:

- *Relative priorities*. All organisations consists of different competing domains, e.g. safety vs. productivity. From the viewpoint of an employee, it is natural to discern which one of these are prioritized highest and then align ones behaviour in accordance with that perceived priority. This is done primarily by observing the behaviours of others, in particular by observing the behaviour and priorities of leaders or other significant actors. In Zohar's (2010: 1518) words: 'practically speaking, if productivity is favoured over safety across a variety of situations, it implies a higher priority and employees will align their behaviours accordingly to the detriment of safety'.

- *Alignment between espousals and enactments*. This pattern refers to the extent of alignment or misalignment between words and deeds on behalf of managers at different levels. Despite an espoused formal top-priority of safety and compliance, such priorities could be compromised by other enacted priorities in real situations. Over time, and across different situations, a pattern will emerge and it is this pattern of enacted priorities that will motivate and inform workers about what type of behaviour it is that is expected, supported and rewarded. Hence, faced with the enacted values, the formally espoused values are of little or no significance.
- *Internal consistency*. This pattern refers to the potential inconsistencies nested among organisational policies, procedures and practices. As workers are members of both small units and the organisation as a whole, they will receive signals about how to interpret and act upon a given procedure both from senior management and their local supervisor. These signals could be aligned or misaligned. Local practices which departs from signals sent by senior managers or organisational policies will inform employees about what behaviour it is that is expected, supported and rewarded. Local practices will be of more significance for motivation and behaviour compared to signals sent from actors not directly involved in production.

Zohar's (2010) framework for understanding safety motivation and behaviour is highly relevant for measures aiming at increased compliance. First and foremost, they clearly illustrate that there is no quick fix for increased compliance. I.e. there is no single measure that can improve motivation for compliance, rather it is dependent on a set of measures that, combined with already implemented practices and policies, must point in the same direction. This is also highly supported by other researchers, as is the patterns that Zohar highlights. For example, a study by Kvalheim and Dahl (2016) has found that the climate factor that is most important for compliance is work pressure. Kapp (2012) has found that leaders are particularly important as role models when it comes to violations, and Clarke (2013) has found that leaders who reward compliant behaviour and correct rule bending promote safety compliance.

4.3.5.3 Lack of risk-awareness

According to the review of company internal investigations presented in the RNNP 2010 report, cognitive errors constitute 11 per cent of all underlying causes of HC leaks and nine per cent of all immediate causes (PSA, 2011). In the report, lack of risk-awareness is described as one of the conditions that generate cognitive errors. Lack of risk-awareness is also an explanatory factor frequently used to describe underlying causes in governmental investigations of accidents and incidents, including HC leaks (e.g. PSA, 2008).

Despite the frequent use of the term 'risk-awareness', both by operating companies and the regulatory authorities, it is not fully clear what the term means. In a thorough examination of the term and how it has been used in PSA investigations, Safetec (2010) conclude that the term is used by the PSA to communicate the impression that there exists (1) an insufficient attention towards risk in the petroleum industry, and (2) a lack of substantive knowledge of issues relating to various risk factors. The situations in which the term is used are, according to Safetec, typically when the involved actors misjudge the probability of an event occurring or when they misjudge the consequences of potential events. Furthermore, the authors conclude that the term is used both as a description of an individual (leaders and staff) and an organisational phenomenon. Safetec (2010: 6) define risk-awareness as people's and organisations' 'knowledge of the human, technological and organisational conditions that influence risk within the system they are a part of'.

According to Vinnem et al. (2010), lack of risk-awareness is particularly challenging with respect to the mechanisms that may cause major accidents, such as HC leaks. The reason for this, the authors claim, is that the frequency is so low that attention tends instead to be directed towards more frequently occurring incidents, such as occupational injuries. According to this logic, lack of risk-awareness related to the precursors of HC leaks is caused, not by an overall *lack* of attention, but by gradually *misplaced* attention towards other areas of risk over time. This might also be the reason why Vinnem et al. relate lack of risk-awareness to the lack of appreciation of lessons learned. Following this logic, repetitions of lessons learned should also be a proper measure to increase risk-awareness (this is also supported by Safetec, 2010).

In line with the views of Vinnem et al. (2010), Sklet and Steiro (2005), in their study of offshore cable operations, recommend that lessons learned from previous similar operations are integrated into the planning and execution phase. Furthermore, they also recommend that lessons learned across different installations and companies are integrated into HAZID and HAZOP analyses to ensure that attention is directed towards potential risk elements. This study is highly relevant since 18 of the 21 incidents analysed in their study involved HC leaks.

Sklet and Steiro's recommendations indicate that lessons learned must be systematically (and not randomly) implemented into the planning, analysing and execution phase of operations in order to increase risk-awareness. Appreciation of lessons learned is also emphasised as an important measure to increased risk-awareness by Weick and Sutcliffe (2007). However, Weick and Sutcliffe (who prefer the term 'anticipation' rather than 'risk-awareness') emphasise that memories based on previous events are important, but that high reliability organisations (HRO) typically are capable of not loosing concentration on what is going on here and now. This means that although HROs draw on previous experience, they do not simplify the situation at hand so that it fits into the logics and categories of previous events – as this will lead to a lack of foresight of unanticipated possibilities. Hence, using lessons learned as a measure to increase risk-awareness is necessary, but not at all sufficient, according to Weick and Sutcliffe.[5] The other factors that Weick and Sutcliffe emphasise as important for increased risk-awareness/anticipation are, however, not subject to quick fixes or simple measures in the aftermath of incidents. Rather, these are in-depth cultural changes such as creating a climate where people (1) feel safe to question assumptions and to report problems or failures, (2) are suspicious of quiet periods and concerned about stability, (3) are encouraged to present alternative analyses of technology and production processes, (4) are encouraged to view near-misses as a kind of failure that reveals potential danger rather than success, and (5) where employees with non-typical prior experience are engaged.

The in-depth cultural characteristics presented by Weick and Sutcliffe (2007) represent fundamental organi-sational changes and are, as such, usually not associated with measures in the aftermath of incidents. Another type of measure, which is more common in the aftermath of incidents, is safety training. Research focusing on the effect of safety training has shown a positive relationship between training and risk-awareness. For example, two studies by Rodríguez-Garzón et al. (2015 and 2016) of construction workers have shown that workers with more than 40 hours of safety training exhibit significantly higher risk-awareness (measured as perceived risk) than workers with less than 40 hours of safety training. In both studies, the researchers also attempted to establish a link between the level of perceived risk and several socio-demographic variables. However, the conclusion was that only the safety training variable significantly altered the perception of risk. Despite the importance of these findings, a drawback is that the studies performed by Rodríguez-Garzón et al. do not describe explicitly the content of the training. Hence, on basis of the studies it is impossible to determine which type of training that is favourable.

In line with the findings of Sklet and Steiro (2005) and Rodríguez-Garzón et al. (2015 and 2016), Safetec (2010) argue that the two factors that are most important for increased risk-awareness are communication and competence. According to Safetec, the minimum requirements related to competence are an understanding of:

- What can possibly go wrong, how can this happen and with what consequences.

[5] For a similar view within the field of patient safety, see Youngberg (2011).

- How one's own decisions and actions influence the risk
- How the decisions and actions of others' influence the risk
- Potential consequences and emergency measures

This means that all risk-based decisions should be taken on the basis of such competence. Among other sources of information, this competence is attainable via documents such as technical design basis, quantitative risk analysis, qualitative risk analysis, reports of unwanted incidents and conditions, investigation reports, revisions, safety procedures etc. Ideally, this information should be available and be communicated in a comprehensible way to all those who are in the position to take risk-based decisions. However, according to Safetec, this is not always the case. Often, they argue, such information is written and communicated by experts for experts. Furthermore, the availability of the information is not always appropriate and there is often a problem of abundance of information. Hence, reduced risk-awareness is often a result of unavailability of information and lack of comprehensibility. The consequence, they argue, is that the apprehension of risk of the involved actors are incomplete. In brief, this means that the apprehension of risk that sharp-end actors have is dominated by competence acquired from the field, whereas the apprehension of risk that blunt-end risk managers have is dominated by competence acquired from rational-technical risk analysis.

According to Safetec, there is no quick-fix available to solve the challenges of lack of risk-awareness that are related to communication and competence. Instead, they argue that measures aiming at increased risk-awareness should seek to balance the rational-technical apprehension of risk and the everyday apprehension of risk acquired from the field. This means that measures aiming at increased risk-awareness should include a recognition of the importance of both practical field experience and formalized knowledge, and not treat them as two separate sources of knowledge. Ultimately, this means that measures aiming at increased risk-awareness should stress the importance of open communication between the sharp end (where practical field experience is acquired) and the blunt end (where rational-technical knowledge is acquired). As a result of this communication, Safetec argue, it will be possible to develop a common understanding of risk, which in turn provides adequate conditions for further development for all actors involved. That is; the actors within the rational-technical domain achieve greater insight into what they should emphasise in their analyses and what needs they should relate to, and the actors within the operating domain achieve greater knowledge of what to look and listen for and what warning signs they should emphasize.

4.3.6 Summing up research question 3

The literature study has identified 34 publications of which 25 are considered as directly relevant and nine as indirectly relevant for answering research question 3. The identified literature falls in three different categories. The first type is related to measures against HC leaks, specifically. The second type focuses on the characteristics of successful measures in general and how they should be determined, formulated and implemented. The third type addresses some of the main causes of HC leaks and how such causes should be avoided.

Regarding the first category of literature, some concrete measures against HC leaks specifically are offered. Step Change in Safety's *Guidance on Hydrocarbon Release Reduction Plans* offers advices on concrete measures against HC leaks that we consider relevant as it is based on operating companies' leak reduction plans from a period in which operators on the UK continental shelf experienced significant improvements in HC leak rates. However, the proposed measures lack empirically based evaluations of effectiveness. Furthermore, we regard the proposed risk reducing measures from the BORA-Release and Risk OMT projects as directly relevant. Although the estimated effect of the measures are not proven through evidence-based research, these models have offered an interesting approach with respect to modelling the effectiveness of given measures by using relevant RIFs. When it comes to the remaining proposed concrete measures in this chapter, one of the weaknesses of these is that they are often either extremely specific (in particular Al Mansouri and Alam's (2008) study) or extremely general (e.g. Mostue et al., 2014). However, we consider the various proposed lists of measures as valuable contributions to the project, in particular in terms of being highly relevant inputs to further empirical investigations.

In addition to finding effective measures according to literature, a part of research question 3 was to answer what measures have been proven not to be effective. In brief, the conclusion related to this is that no documents were identified that disregard certain measures as ineffective. However, the results from the OMT study (Gran et al. 2012) indicates that certain measures, such as improving availability and faster updating of technical documentation, have low effectiveness (see Table 4).

Regarding the second category of literature, this literature presents advices or research on how successful measures should be constructed and how they should be determined, formulated and implemented. This literature is both academic and practically oriented in the form of guidelines, but not related to HC leaks in particular. However, this type of literature is of a more generic type and it should therefore be relevant for *How to get it right*. The evidence for the advices that this literature offers does not fall within the strict requirements of evidence-based research (with a possible exception for the idea of SMARTER). Anyway, the advices offered are expert-based and directed towards other high-risk industries. Hence, the relevance should be considered high.

The third category of literature differs from the other two in the sense that it addresses the main causes of HC leaks and how they should be prevented or avoided. Three types of such causes with corresponding measures have been examined further; (1) procedures and documentation, (2) procedure violations, and (3) lack of risk-awareness. Regarding procedures and documentation, the review underlines the significance of e.g. functional simplicity, tailoring, use of plain and positive language, piloting, end user involvement and accuracy. Regarding procedure violations, the review emphasise the importance of identifying the root cause of why procedure violations have become a problem by e.g. following the checklist offered by HSE (1995). Despite the importance of identifying root causes before concrete measures are decided, some general advices were identified. Some of these are related to unintentional violations, others to intentional violations. The drivers behind these two types of violations are different. Whereas intentional violations are related to motivation, unintentional violations are related to knowledge. Regarding lack of risk-awareness, the review emphasise systematically repetitions of lessons learned, safety training, and increased amount and quality of communication between actors within the rational-technical domain and the operating domain.

In sum, the three different types of literature should offer a significant contribution to the question of which types of preventive measures against HC leaks have been proven effective. However, the literature is far from being complete and illustrates clearly that there are no quick fixes available.

4.4 Methods to categorize and evaluate the costs related to measures after HC leaks (research question 4)

Based on the identified literature, research question 4 is addressed in this chapter: *Which methods have previously been applied in order to categorize and evaluate the costs related to measures after HC leaks or other incidents with major accident potential?*

Several publications emphasise cost and benefit evaluation of different measures as important criteria for assessing which risk mitigation measures to implement. However, specific literature on methods or frameworks for categorising such costs (both in general and for HC leaks in particular) appears to be scarce. We have identified ten publications that explicitly include either specific methods, cost and/or benefit categories or discussions on these. These publications include master's theses, books, reports and articles. In addition, we refer to nine publications that provide more background information (supporting literature). Many publications were discarded, as they did not present any frameworks or methods for categorising or evaluating costs of measures, even though costs and benefits were discussed as important parts of a holistic risk analysis. The detailing level is generally low with respect to HC leaks. However, some publications include case studies, figures and other methods where cost (and cost-benefit) analysis is a constituent.

Many publications discusses the importance of analysing costs and benefits of a risk reducing measure, but very few actually presents a framework or methodology for categorisation and evaluation of these costs (e.g. Götmar and Lundberg, 2007). In the literature, a cost-benefit analysis (CBA) is often combined with other analyses to form a framework for holistic risk assessment which seems like the dominant method for many industries, including the petroleum industry. This claim is supported by Humberset (2009), who also emphasises that in order to ensure that the CBA provide the decision maker with the best possible information, other analyses, such as QRA to evaluate which measure to implement and sensitivity analysis to account for uncertainty and show ruggedness in results, should be included. Dhar (2009) uses risk assessment techniques, generally based on CBA to assess the benefits and costs of installing a Subsea Isolation Valve (SSIV), whose purpose is to limit the duration and severity of hydrocarbon leaks by isolating the subsea pipeline from the topside platform. They emphasise that when concluding whether a measure should be implemented, a holistic approach should be taken, of which the CBA only is one of many considerations. A CBA is also an important (but should not be the only) constituent in ALARP processes (Vinnem et al., 2006).

A CBA enables decision-makers to add information on costs and benefits to investment decisions regarding prevention or mitigation. Evaluating both costs and benefits in such an analysis can be very useful as safety investment decisions often involve choosing between different measures. In particular, for some measures there will be large differences in cost distribution over time. Some measures, such as technology improvements, may have a short-term (investment) cost, but a low long-term cost. Other measures, such as organizational measures, may have a low short-term cost (training programs, etc.), but may have a higher long-term cost. In order to compare the cost-effectiveness of such different measures, it is important to be able to both quantify the costs and to include a discount rate that allows for a fair comparison. The different measures will also, most likely, result in different probabilities for future accidents/events. As such, the measures provide different benefits and these should also be taken into account when evaluating the potential measures. Given that it might be difficult to assign monetary values to the benefits, alternative approaches may be considered.

The CBA approach plays an important part in Paltrinieri and Khan (2016) on risk analysis in the chemical and petroleum industry. Based on the significance of CBA in the literature, we provide an overview of the general CBA framework, and discuss extensions to this in order to account for challenges arising when considering low-probability, high-impact events, in which HC leaks may be categorised.

4.4.1 Cost-benefit analysis

The following is a description of CBA, based on Paltrinieri and Khan (2016). A CBA is an economic evaluation in which all costs and consequences of a certain decision are expressed in the same units, usually monetary (Jackson, 2012; Paltrinieri et al., 2012). It can support decision-makers in their decisions regarding risk prevention or mitigation. Figure 3 illustrates the breakdown of a CBA.

Paltrinieri and Khan (2016) emphasise that the concept of CBA in relation to low-probability, high-impact should be broadened as the traditional net present value (NPV) calculation does not adequately take into account the real risks. They present tutorials and examples for CBA for safety measures for these types of events by including a so-called disproportion factor and a multi-criteria decision-making approach. These approaches might be relevant in the context of HC leaks due to its low-probability, high-impact nature. Before describing the methodologies related to these approaches, an introduction to general CBA is provided.

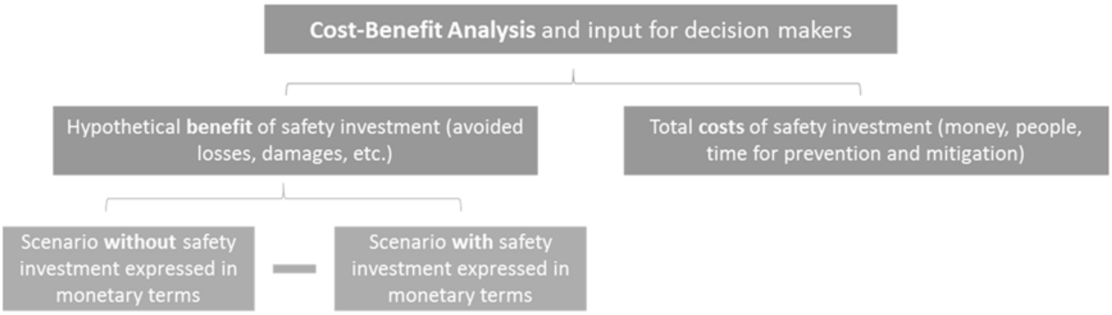

Figure 3: Illustration of the cost-benefit approach for decisions in safety investments. Source: Paltrinieri and Khan (2016).

To conduct a traditional CBA, the following steps need to be taken:

1) Identify the most important costs and benefits,
2) Calculating the net present value (NPV) of these costs and benefits,
3) Compare the NPV for costs and benefits for different safety measure alternatives

An important element in the calculation of the NPV is the discount rate. The level of the discount rate will highly affect the value of the NPV. The higher the discount rate, the less emphasis is put on costs and benefits at a late stage, and the lower the total NPV will be. A positive NPV suggests that the investment is profitable. Due to the considerable uncertainty involved in estimating both the costs and benefits from most safety investments, it is important to treat this uncertainty in the NPV analysis. This can be done by scenario analysis, using probability-weighted numbers or by increasing the discount rate such that the risk is appropriately accounted for.

Relevant costs related to safety investments include *initial costs*, *installation costs*, *operating costs*, *maintenance costs* and *inspection costs*. Some of the potential benefits from avoided accidents are *supply chain benefits*, *damage benefits*, *legal benefits*, *reputation benefits*. See Table 6 for a list of categories of costs and hypothetical benefits related to new safety measures.

Table 6: Categories of costs and benefits. Source: Paltrinieri and Khan (2016)

Categories of costs	Subcategories of costs	Types of benefits (avoided costs)	Subcategories of benefits (avoided costs)
Initial costs	Investigation Selection and design Material Training Changing guidelines and information team	Supply chain	Production loss Start-up Schedule
Installation costs	Production loss Start-up Equipment Installation	Damage	Damage to own material / property Damage to other companies' material / property Damage to surrounding living areas Damage to public material property
Operating costs	Utilities	Legal	Fines Interim lawyers Specialized lawyers Internal research team

			Experts at hearings Legislation Permits and licenses
Maintenance costs	Material Maintenance team Production loss Start-up	Insurance	Insurance premiums
Inspection costs	Inspection team	Human and environmental	Compensation victims Injured employees Recruiting Environmental damage
Logistics and transport safety costs	Transport of hazmat Storage of hazmat Drafting of control lists Safety documents	Intervention	Intervention
Contractor safety costs	Team selection Training	Reputation	Share price
Other safety costs	Other safety costs	Other	Manager working time Cleaning

An important element when performing the CBA is the frequency at which the consequence/event occurs. Consequences should therefore be multiplied by the frequency in order to obtain the expected consequences from an accident, and take into account the lifetime of the facility. The NPV calculation of the expected consequences should then be performed for both excluding and including the safety measures implemented. The difference between those two gives the hypothetical benefit, see Figure 3.

In order to determine whether the costs of a safety measure outweigh its benefits, one might use the following equation (if the left hand side is *not* greater than the right hand side, the cost of implementing the safety measure outweighs its benefits):

$$[(C_{without} \cdot F_{without}) - (C_{with} \cdot F_{with})] \cdot Pr_{control} > \text{Safety measure cost}$$

Where $C_{without}$ = cost of accident without safety measure, C_{with} = cost of accident with safety measure. $F_{without}$ = statistical frequency of initiating event if the safety measure is not implemented, F_{with} = statistical frequency of the initiating event if the safety measure is implemented, and $Pr_{control}$ = Probability that the safety measure will perform as required. If frequencies of initiating events are not obtainable, one can use statistical frequency of the accident, $F_{accident}$, instead. All of the costs must be discounted back to the present value by using the appropriate discount rate. Figure 4 shows an example of how a cost-benefit analysis may be illustrated for a measure with investment costs of 50 MNOK, and yearly maintenance of 150 000 NOK, and yearly benefits of 8 MNOK, and discount rate of 15%. The numbers shown are cumulative. The interesting number is the cash flow in year 20, which in this example is positive, meaning that the measures' benefits outweigh its costs and should be implemented, according to the simple CBA procedure.

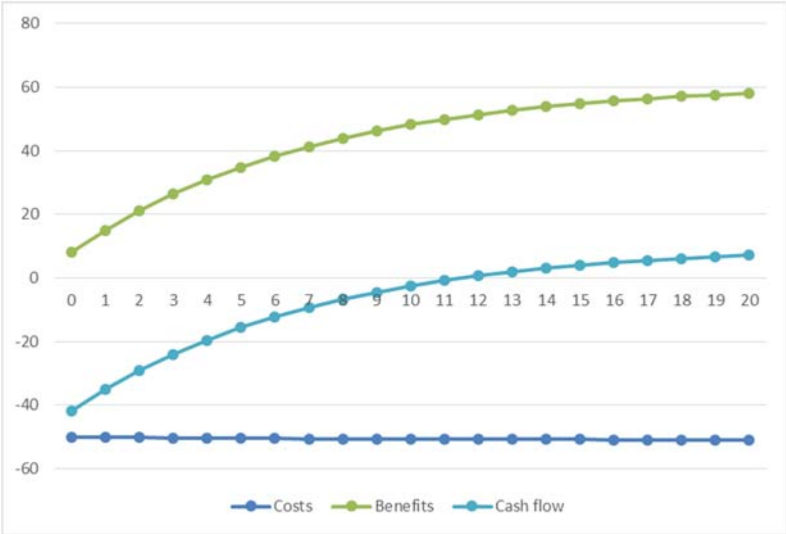

Figure 4: Example of a simple cost-benefit analysis for a risk reducing measure for a system with 20 years lifetime. Numbers in MNOK.

Wang et al. (2015) presents a Quantitative Risk Analysis (QRA) model of offshore fire and explosion, of which CBA is an important constituent. They use CBA to obtain insights on what is the most beneficial measures in order to reduce the fire/explosion risk of an offshore platform. They do not go into detail on how this analysis should be conducted. Damnjanovic and Røed (2016) focus on planning as a way of reducing system' response uncertainty and finds that better planning can reduce both major accident risks, such as HC leaks, and the cost of operations. They include two case studies on hydrocarbon leaks on the Heimdal offshore installation and the Oseberg C offshore installation and show that better planning reduces uncertainty in all interventions and thus reduces the time and cost spent. The most significant impacts from planning can be obtained in the following situations: 1) Interventions that involve expensive and scarce resources, and 2) interventions on sensitive parts of the system.

4.4.2 Extensions of CBA

Here we have provided the *general* CBA. In many cases, such as low-probability, high-impact events, where there may be challenges to accurately estimate costs and benefits, data is unreliable, and/or more than only economic factors should play a role in evaluating the measures considered, extensions to the general CBA is needed. As HC leaks may fall into this event category, it can be beneficial to include two extensions proposed by Paltrinieri and Khan (2016): CBA based on the *disproportion factor* and CBA based on *multi criteria decision making.*

The approach illustrated in Figure 5, based on the disproportion factor concept, was used to find the Maximum Justifiable Spend (MJS), i.e. the amount of money worth spending to reduce risk to "acceptable" levels, for prevention of domino effects in a chemical plant (see Janssens et al., 2015). The MJS can be used within a CBA to identify alternative safety investments where a *disproportion factor* is included to favour safety over costs. Thus, when the disproportion factor is included, a safety measure investment is reasonably practicable as long as the costs are not grossly disproportionate to the benefits. The flowchart describing the methodology is given in Figure 5, and is based on Thomas and Jones (2010). For specifics in the four steps described, such as the calculation of the disproportion factor, we refer to Paltrinieri and Khan (2016). The inclusion of a disproportion factor is mainly relevant for low probabilities and where challenges with calculation of cost and benefits associated with investments leads to shortages with the pure NPV approach, which can lead to inadequate decision support.

Figure 5: Flowchart of CBA based on the disproportion factor. Source: Paltrinieri and Khan (2016)

Another methodology that remedy the challenges lack of data and/or high levels of uncertainty represent in order to conduct a full CBA, is the concept of multi criteria decision-making, which includes both quantitative and qualitative evaluation elements. A multi criteria analysis (MCA), based on a general CBA, can be used to compare alternative safety investments and detect a number of options for more detailed investigation. An MCA extends the classical CBA by including other aspects than pure economic. In Paltrinieri and Khan (2016), they exemplify the use of MCA in a public railway transport organisation, where the approach is used to evaluate complex safety investments intended for preventing/mitigating major risks. In the context of HC leaks, where the potential consequences might include more than purely economic impacts, such an approach might be relevant. The steps in a multi-criteria analysis is illustrated in Figure 6. For more detailed description of the steps, see Paltrinieri and Khan (2016), (for more literature on MCA in general, see Brans and Mareschal, 2005; Talarico et al., 2015a; Talarico et al., 2015b).

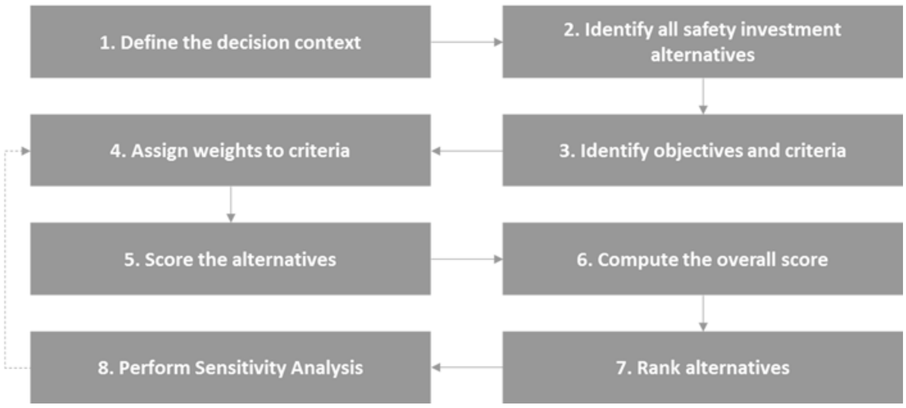

Figure 6: Flowchart of a multi-criteria analysis. Source: Paltrinieri and Khan (2016)

4.4.3 Alternative approaches

In general, the CBA in itself is not considered adequate to conduct estimates on costs and evaluations regarding choice of measures in the case of measures related to HC leaks. This approach should be used with great care and preferably in a more holistic framework, especially when the probability is low and impact is high, as is the case of HC leaks. Aven and Abrahamsen (2007) present an alternative in the form of a list of principles that could be adopted for safety management, where they emphasise that a cost-benefit analysis should only be considered as decision support. These principles are also incorporated in frameworks for risk management (presented in Aven and Kristensen, 2005; Aven et al., 2007). In the latter, the focus is on the offshore oil and gas industry. The principles include:

1. Use some minimum safety requirements to protect human beings and the environment.

2. Assess the risk, i.e. the possible consequences, and the associated uncertainties. An important element here is to what extent we are able to manage the risks, the level of manageability. Professional risk assessments are performed, describing and evaluating the risks.
3. Balance the different concerns (safety, costs, etc.); implement risk-reducing processes. Cost-benefit analyses may be used to support decision-making.
4. Adopt managerial review and judgement. The decision support is evaluated in a broader context, taking into account concerns and information, as well as the assumptions and limitations of the tools used.

In a more simple context, the Canadian Association of Petroleum Producers (2007) consider the economics of repairing a leak or replacing components, and claim that decisions should be based on the market value of the leaked fluid, the repair or replacement costs, and the life expectancy of the barrier. Vinnem and Aven (2006) present an approach to decision-making processes for management of health, environment and safety, which gives management a broader and more informative decision basis than a traditional approach based on predefined risk acceptance criteria, that is narrower and with short-term cost minimisation as the driving force. According to the authors, using this new broad decision-making process might lead to more funds being allocated to risk reducing measures compared with the expected funds when the traditional approach is considered. The alternative approach includes 1) Framing of decision problem and decision process, stating goals and criteria and definition of the problem, 2) Generation and evaluation of alternatives, and 3) managerial review and decision. Although the case in which this new approach was used was critical fire/explosion, it may be relevant to consider such broad decision-making processes also for the case of HC leaks. Ibarrondo-Dávila et al. (2015) examine the weaknesses of current managerial accounting systems in enterprises in relation to the provision of systematic information on the cost of measures to ensure health and safety in the workplace. They propose a new model of management accounting to calculate, analyse and control such costs, and implement this model in a construction company. Their model consists of a breakdown of costs in the following manner: 1) safety costs, including prevention and monitoring and evaluation costs, and 2) Non-safety costs, consisting of tangible and intangible costs. Although their article focus solely on the construction industry, many of the different elements in each of the cost types (safety and non-safety costs) could be relevant also for the oil and gas industry in general, and for HC leak prevention measures in particular. Some of the elements could be added, or used in combination with the elements in the traditional CBA listed in Table 6.

4.4.4 Summing up research question 4

The literature study has identified ten relevant publications that present either general methodologies and/or categories for costs and benefits that should be relevant for categorising and evaluating HC leaks. Various publication types have been identified, including theses, reports, books, and articles. The publications address both analysis frameworks and discussions of relevant cost components. There are however few publications that address our research question directly. In terms of quantitative risk analysis, cost-benefit analysis is mentioned as an appropriate framework for assessing the costs and benefits related to measures, often as part of other more holistic methodologies. Several important aspects need to be taken into consideration when performing economic analysis of measures to prevent HC leaks. For instance, assessing the true cost of measures in the short- and long-run may be difficult. Also, assessing the reduced probability of an HC leak from a given measure is very challenging, because todays risk models are not detailed enough for this purpose. This especially applies for soft (organisational and human) measures. Here, Bora/OMT may offer some help, but as discussed earlier the use of these methods are rather resource-demanding. Additionally, in order to perform a trade-off between high short-term costs and potentially higher long-term costs it is important to find an appropriate discount rate for the future costs. Normally, different measures will have different impact on the future probability of leaks such that some evaluation of expected benefit should also be included in the analysis. This can, however, be achieved in different ways where the most challenging may be to express it purely in monetary terms.

In conclusion, there are several relevant examples in the literature that will provide a good starting point for developing a methodology that can address the research question posed here. The final choice of method and framework for analysis should however be tailor-made to the application at hand and to the available data. In this project, where it is most relevant to consider categories/types of typical measures (rather than specific measures such as installation of an SSIV, or installing an interlock to prevent overpressure during start-up), a rather "coarse" method may be appropriate. E.g. in the form of a two-dimensional matrix where four-five types/levels of lifecycle costs are given versus four-five types of risk reduction potentials.

5 Discussion and conclusion

5.1 Key findings and practical implications for the project

The overall objective of *How to get it right* is to develop a guideline that leaders in Statoil can use to identify measures that are effective against HC leaks and the economic costs related to different measures. The guideline will be based on empirical data and a study of the state of the art within the research and practitioner area of HC leak prevention. The aim of the present literature study has been to present the state of the art. Four research questions have been asked. These are:

1. Do there exist previously developed methods to evaluate the effect of measures against HC leaks or other incidents with major accident potential? If this is the case, how are these methods designed?
2. Do there exist previously developed taxonomies to categorize measures against HC leaks or other incidents with major accident potential? If this is the case, how are these taxonomies constructed?
3. According to the literature, which types of preventive measures against HC leaks have been proven effective, which have not and under which conditions are different measures most effective?
4. Which methods have previously been applied in order to categorize and evaluate the costs related to measures after HC leaks or other incidents with major accident potential?

In order to answer these questions 116 different publications have been reviewed. 65 of these have been evaluated as either directly or indirectly relevant, whereas the remaining 51 have been used to support arguments or give examples of further readings.

The review of literature related to the first research question, regarding methods developed to evaluate the effect of measures against HC leaks, reveals that *no* methods for evaluating the *observed* effect of preventive measures have been identified. This is not unexpected – since HC leaks have a low frequency and as a result it is very difficult to isolate the effect of single measures. However, two relevant methods for *modelling* the effect of proposed risk reducing measures related to HC leaks have been identified. These are the BORA-Release method and the Risk OMT-model (e.g. Aven et al., 2006; Sklet et al., 2006; Gran et al., 2012). Both of these methods are resource demanding, and the application of the methods depend on input of large amounts of data and expert judgements. Both methods demonstrate that quantitative predictions of effect on leak frequency not are subject to quick fixes. Similarly, the HSS model, which is a model developed to predict the risk of different helicopter accident scenarios, demonstrates that such predictions are resource demanding and not subject to quick fixes (Herrera et al., 2010). However, parts of the method behind all of these three models are relevant for *How to get it right*. Most significantly, the methods demonstrate that the use of expert judgements, and a corresponding quantification of such judgements, is an appropriate way of collecting and interpreting data. Hence, a further examination of the qualitative and quantitative handling of interview data in these models should be considered useful for the empirical parts of the project – in particular for the interview study (activity 5) and the retrospective study (activity 8).

Furthermore, methods designed for process evaluations of occupational health and safety interventions should be considered highly useful for the project (Nielsen and Randall, 2013). In contrast to methods that focus on the outcome variable, such methods focus on the mechanisms that hinder and facilitate desired intervention outcomes. This is a perspective that is highly relevant for the interview study (activity 5) and the retrospective study (activity 8). Elements of process evaluations can also be found in IAEA's guideline for effective corrective actions on nuclear installations (IAEA, 2005). These elements should also be considered relevant for activity 5 and 8.

The review of literature related to the second research question, regarding previously developed taxonomies to categorize measures against HC leaks, reveals that *no* available taxonomies are applicable in the current project without adaptions and rework. However, the taxonomies and categorisations that already exist and their strengths and weaknesses give valuable input to a revised taxonomy. Hence, the industry standards, user guidelines and research literature that are reviewed should be highly relevant for activity 3 of the project, where the objective is to categorize different measures against HC leaks. A proper utilisation of this literature presupposes that the weaknesses and strengths identified in the different taxonomies are considered. This implies to take consideration of five major points. Firstly, that a revised taxonomy should include categories that either classifies a given measure in accordance with (a) the end purpose of the measure, (b) the actual content/nature of the measure itself, or (c) the problem the measure addresses. A combination of these three types of categories will result in a taxonomy where a given measure could be classified in accordance with different principles. Hence, it should be better, for the purpose of easier classification, to stick to one of the approaches. Secondly, that a revised taxonomy should include categories that are suitable for (a) continuous measures under normal operating conditions and for (b) measures initiated as a response to a certain incident. Thirdly, that a revised taxonomy should include categories that are, as far as possible, mutually exclusive. Fourthly, that a revised taxonomy should include categories that covers both human, organizational and technical measures. Fifthly, that a revised taxonomy should be based on information that is readily available.

The review of literature related to the third research question, regarding preventive measures against HC leaks that have been proven effective, reveals that three different categories of literature are relevant. The first is related to concrete measures against HC leaks, specifically. The second type focuses on the characteristics of successful measures in general and how they should be determined, formulated and implemented. The third type addresses the main causes of HC leaks and how they should be avoided.

Regarding the first category of literature, strict empirical evidence for concrete effective measures is scarce. Again, this is because the observed effect is not readily available for observation because of the low frequency of leaks. Hence, best available evidence for concrete measures are user guidelines and risk modelling. Both of these are based on the views of experts. As regards guidelines, the SCS's *Guidance on Hydrocarbon Release Reduction Plans* offers advices on concrete measures against HC leaks that are relevant (SCS, 2012). The guideline consists of ten different components with corresponding sub-components and examples of activities. All of this is based on an analysis of operating companies' HC leak reduction plans. As regards risk models, the BORA-Release and Risk OMT have conducted sensitivity analyses for pre-defined risk scenarios (e.g. Aven et al., 2006; Sklet et al., 2006; Gran et al., 2012). The models include predictions concerning the effect that changes in different risk influencing factors (RIFs) have on the probability of HC leaks. This allows for contrasting the effect of different measures. However, it should be noted that the models have not been subject to predictions of an exhaustive list of measures. Hence, the results are limited to the measures actually evaluated. An advantage with the models is that they include both organisational, human and technical measures. A disadvantage is that the use of the model is rather resource-demanding and applies to specific measures.

Regarding the second category of literature, this literature presents advices or research on how successful measures should be constructed and how they should be determined, formulated and implemented. This literature is both academic and practically oriented in the form of guidelines, but not related to HC leaks in particular. However, this literature include some general advices related to preventive measures that should be considered highly relevant for the project. The advices offered do not fall within the strict requirements of evidence-based research. However, the advices of Rollenhagen et al. (in press) relies heavily on organizational safety research and resilience engineering, IAEAs (2005) advices are based on comprehensive experience within the nuclear power industry, and the idea of SMARTER is identified in a number of publications and stretches far beyond the subject of safety research. Hence, the advices offered by this type of literature should be considered highly relevant for the leadership guideline (activity 2).

Regarding the third category of literature, it differs from the other two in the sense that it addresses the main causes of HC leaks and how the arise of such causes should be avoided. As such, they should also be highly relevant for the leadership guideline. Three types of causes with corresponding measures were examined; (1) procedures and documentation, (2) procedure violations, and (3) lack of risk-awareness. The review of literature related to procedures and documentation emphasises the significance of e.g. functional simplicity, tailoring, use of plain and positive language, piloting, end user involvement and accuracy. The review of literature related to procedure violations emphasises the importance of identifying the root cause of why procedure violations have become a problem by e.g. following the checklist offered by HSE (1995). The importance of identifying the root causes of violations prior to eventual decisions of preventive measures is also emphasised in TapRoot's *Corrective Action Helper Guide* (TapRoot, 2015). Despite the importance of identifying root causes before concrete measures are decided, some general advices were identified. Some of these are related to unintentional violations, others to intentional violations. The drivers behind these two types of violations are different. Whereas intentional violations are related to motivation, unintentional violations are related to knowledge. Hence, the preventive measures implemented should be qualitatively different. Regarding lack of risk-awareness, the review emphasise systematically repetitions of lessons learned, safety training, and increased amount and quality of communication between actors within the rational-technical domain and the operating domain.

The review of literature related to the fourth research question, regarding costs related to measures after HC leaks, addresses both analysis frameworks and discussions of relevant cost components. The review reveals that several publications discuss the importance of analysing costs and benefits of risk reducing measures. However, the review also reveals that *very few* actually presents a framework or methodology for categorisation and evaluation of these costs. In the literature, a cost-benefit analysis (CBA) is often combined with other analyses to form a framework for holistic risk assessment. This seems like the dominant method for many industries, including the petroleum industry. For example, it is emphasised that in order to ensure that the CBA provide the decision maker with the best possible information, other analyses, such as QRA to evaluate which measure to implement and sensitivity analysis to account for uncertainty and show ruggedness in results, should be included. Within the frames of *How to get it right*, the extended CBAs reviewed might stretch far beyond the scope of the project and far beyond the final leadership guideline. However, some of the simplified methods, such as the list of principles presented by Aven and Abrahamsen (2007), should be considered relevant.

5.2 Strengths and limitations

Accident and incident investigations is a learning process consisting of several stages (Drupsteen et al., 2013). The goal of the first stage, the investigation phase, is to understand causation. The goal of the second stage, the planning phase, is to determine a realistic action plan. The goal of the third stage, the intervening phase, is to realise the actions. The goal of the fourth stage, the evaluation phase, is to evaluate the process and the impact. According to Rollenhagen et al. (in press), the early stage of the learning process has received much attention, both by practitioners and researchers. This means that the accumulated knowledge about the investigation phase far exceeds the accumulated knowledge about the later phases. An apparent strength of the present study is that focus has been on the late phases of the process and that, to our knowledge, no such literature reviews have been performed previously. In addition, the lack of attention that the late phases have received previously is a clear reminder of the importance of *How to get it right* as such. The review reveals that no single study offers a straight forward recipe for how the project should progress further. This is not unexpected. However, the review offers significant input to the leadership guideline, to the development of categories for measures against HC leaks and to the empirical parts of the project.

As with other literature studies, however, the present study do also have some limitations. First, the results lean, with some exceptions, upon the applied search strings and the visited predefined websites. Applying other search strings and examining the websites of other actors might have led to other or broader results. Secondly, even though we have strived for a critical review of the available literature, the study leans upon our reliance of previously published research and guidelines. Because the late phases of the learning from incidents process is a relatively untapped area of research, competing perspectives and research traditions are lacking. Hence, a fully balanced critical discussion of the literature is challenging.

References

Adejugba, O., 2013. How has industry achieved a significant reduction in Hydrocarbon Releases? Master's thesis, University of Aberdeen.

Alper, S.J., Karsh, B.-T., 2009. A systematic review of safety violations in industry. Accident Analysis & Prevention 41, 739-754.

Antonsen, S., Almklov, P., Fenstad, J., 2008. Reducing the gap between procedures and practice – Lessons from a successful safety intervention. Safety Science Monitor 12, 1-16.

Ashton, M.C., 1998. Personality and job performance: the importance of narrow traits. Journal of Organizational Behavior 19, 289-303.

Austnes-Underhaug, R., Cayeux, E., Engen, O.A., Gressgård, L.J., Hansen, K., Nesheim, T., Nygaard, G., Skoland, K., 2011. Læring av hendelser i Statoil – En studie av bakenforliggende årsaker til hendelsen på Gullfaks C og av Statoils læringsevne. Stavanger: IRIS.

Aven, T., Abrahamsen, E., 2007. On the use of cost-benefit analysis in ALARP processes. International Journal of Performability Engineering 3, 345.

Aven, T., Kristensen, V., 2005. Perspectives on risk: review and discussion of the basis for establishing a unified and holistic approach. Reliability Engineering & System Safety 90, 1-14.

Aven, T., Sklet, S., Vinnem, J.E., 2006. Barrier and operational risk analysis of hydrocarbon releases (BORA-Release): Part I. Method description. Journal of Hazardous Materials 137, 681-691.

Aven, T., Vinnem, J.E., Wiencke, H., 2007. A decision framework for risk management, with application to the offshore oil and gas industry. Reliability Engineering & System Safety 92, 433-448.

Bergh, L.I.V., Ringstad, A.J., Leka, S., Zwetsloot, G.I.J.M., 2014. Psychosocial risks and hydrocarbon leaks: an exploration of their relationship in the Norwegian oil and gas industry. Journal of Cleaner Production 84, 824-830.

Biggs, S.E., Banks, T.D., 2012. A comparison of safety climate and safety outcomes between construction and resource functions in a large case study organisation. Paper prepared for presentation at the Occupational Safety in Transport Conference, Gold Coast, Australia 20–21 September 2012.

Biron, C., Karanika-Murray, M., 2014. Process evaluation for organizational stress and well-being interventions: Implications for theory, method, and practice. International Journal of Stress Management 21 (1), 85-111.

Brans, J.-P., Mareschal, B., 2005. Multiple criteria decision analysis. State of the art surveys. Springer.

Briner, R.B., Walshe, N.D., 2015. An evidence-based approach to improving the quality of resource-oriented well-being interventions at work. Journal of Occupational and Organizational Psychology 88, 563-586.

Canadian Association of Petroleum Producers (CAPP), 2007. Best Management Practice. Management of Fugitive Emissions at Upstream Oil and Gas Facilities. Canadian Association of Petroleum Producers (CAPP).

Cedergren, A., 2013. Implementing recommendations from accident investigations: A case study of inter-organisational challenges. Accident Analysis & Prevention 53, 133-141.

Chan, R., Molassiotis, A., Eunice, C., Virene, C., Becky, H., Chit-ying, L., Pauline, L., Frances, S., Ivy, Y., 2002. Nurses' knowledge of and compliance with universal precautions in an acute care hospital. International Journal of Nursing Studies 39, 157-163.

Clarke, S., 2013. Safety leadership: A meta-analytic review of transformational and transactional leadership styles as antecedents of safety behaviours. Journal of Occupational and Organizational Psychology 86, 22-49.

Clarke, S., Robertson, I.T., 2005. A meta-analytic review of the Big Five personality factors and accident involvement in occupational and non-occupational settings. Journal of Occupational and Organizational Psychology 78, 355-376.

Dahl, Ø., 2013. Safety compliance in a highly regulated environment: a case study of workers' knowledge of rules and procedures within the petroleum industry. Safety Science 60, 185-195.

Dahl, Ø., Fenstad, J., Kongsvik, T., 2013. Antecedents of safety-compliant behaviour on offshore service vessels: a multi-factorial approach. Maritime Policy & Management 41, 20-41.

Damnjanovic, I., Røed, W., 2016. Risk management in operations of petrochemical plants: Can better planning prevent major accidents and save money at the same time? Journal of Loss Prevention in the Process Industries 44, 223-231.
Dhar, R., 2009. Risk Assessment as a Tool in Establishing the Requirement of Subsea Isolation Valves in Subsea Pipelines. SPE Americas E&P Environmental and Safety Conference. San Antonio, Texas, 23-25 March 2009.
Doran, G.T., 1981. There's a S.M.A.R.T. way to write management's goals and objectives. Management Review 70 (11), 35–36.
Drupsteen, L., Groeneweg, J., Zwetsloot, G.I.J.M., 2013. Critical Steps in Learning From Incidents: Using Learning Potential in the Process From Reporting an Incident to Accident Prevention. International Journal of Occupational Safety and Ergonomics 19, 63-77.
Drupsteen, L., Hasle, P., 2014. Why do organizations not learn from incidents? Bottlenecks, causes and conditions for a failure to effectively learn. Accident Analysis & Prevention 72, 351-358.
Duguay, A., Polo, J., Pages, B., Belgaroui, J., 2012. Zero Tolerance to Hydrocarbon Leaks; A Multidisciplinary Success. SPE Middle East Health, Safety, Security, and Environment Conference and Exhibition, Abu Dhabi, UAE, 2-4 April 2012.
EI, 2016. Learning from Incidents, Accidents and Events. London: Energy Institute.
Gettman, D., Head, L., 2003. Surrogate Safety Measures from Traffic Simulation Models. Transportation Research Record: Journal of the Transportation Research Board 1840, 104-115.
Gilroy, J., Dumolo, D., 2013. An Organisation-wide Investigation into the Human Factors-related Causes of Hydrocarbon Releases on Offshore Platforms. SPE Offshore Europe Oil and Gas Conference and Exhibition, 3-6 September, Aberdeen, UK
Gran, B.A., Bye, R., Nyheim, O.M., Okstad, E.H., Seljelid, J., Sklet, S., Vatn, J., Vinnem, J.E., 2012. Evaluation of the Risk OMT model for maintenance work on major offshore process equipment. Journal of Loss Prevention in the Process Industries 25, 582-593.
Gravseth, H.M., 2011. Arbeidsskader og arbeidsrelaterte helseproblemer. Unge menn skader seg oftest på jobb. Samfunnsspeilet, 2011 (2).
Götmar, A., Lundberg, J., 2007. Effective Recommendations in Loosely Coupled Accident Investigations. Proceedings of the ECCE 2007 Conference, 28-31 August 2007, London, UK.
Hansen, O.R., Ulvang, D.M., Langeland, T., Middha, P., 2011. CFD and VR for risk communication and safety training.
Hansez, I., Chmiel, N., 2010. Safety behavior: job demands, job resources, and perceived management commitment to safety. Journal of Occupational Health Psychology 15, 267–278.
Haugen, S., Vinnem, J.E., 2011. Analysis of causes of hydrocarbon leaks from process plants. SPE European Health, Safety and Environmental Conference in Oil and Gas Exploration and Production. Vienna, Austria, 22-24 February 2011.
Herrera, I., Håbrekke, S., Kråkenes, T., Hokstad, P.R., Forseth, U., 2010. Helicopter Safety Study 3 (HSS-3). Trondheim: SINTEF.
Hollnagel, E., 2014. Safety-I and Safety-II: The Past and Future of Safety Management. Farnham: Ashgate.
HSE, 1995. Improving Compliance with Procedures. Reducing Industrial Violations. Sudburry: HSE Books (Health and Safety Executive).
Humberset, I., 2009. Practical use of the cost-benefit analysis, Faculty of Science and Technology. University of Stavanger.
IAEA, 2005. Effective Corrective Actions to Enhacne Operational Safety of Nuclear Installations. Vienna: International Atomic Energy Agency.
Ibarrondo-Dávila, M., López-Alonso, M., Rubio-Gámez, M., 2015. Managerial accounting for safety management. The case of a Spanish construction company. Safety science 79, 116-125.
ISO, 2015. ISO 13702: 2015 Petroleum and natural gas industries - Control and mitigation of fires and explosions on offshore production installations - Requirements and guidelines. Geneva: International Organization for Standardization (ISO).

ISO, 2016. ISO 14224: 2016 Petroleum, petrochemical and natural gas industries -- Collection and exchange of reliability and maintenance data for equipment. Geneva: International Organization for Standardization (ISO).
Jackson, D., 2012. Healthcare economics made easy. Royal College of General Practitioners.
Janssens, J., Talarico, L., Reniers, G., Sörensen, K., 2015. A decision model to allocate protective safety barriers and mitigate domino effects. Reliability Engineering & System Safety 143, 44-52.
Jimmieson, N. L., Terry, D. J., & Callan, V. J., 2004. A longitudinal study of employee adaptation to organizational change: The role of change-related information and change-related self-efficacy. Journal of Occupational Health Psychology, 9, 11–27.
Kapp, E.A., 2012. The influence of supervisor leadership practices and perceived group safety climate on employee safety performance. Safety Science 50, 1119-1124.
Kinateder, M., Pauli, P., Müller, M., Krieger, J., Heimbecher, F., Rönnau, I., Bergerhausen, U., Vollmann, G., Vogt, P., Mühlberger, A. Human behaviour in sever tunnel accidents: Effects on information and behavioural training. Transportation Reserach Part F 17 (2013) 20-32.
Kvalheim, S.A., Dahl, Ø., 2016. Safety compliance and safety climate: A repeated cross-sectional study in the oil and gas industry. Journal of Safety Research 59, 33-41.
Kvitrud, A., 2011. Collisions between platforms and ships in Norway in the period 2001-2010. The International Conference on Ocean, Offshore and Arctic Engineering, 19-24 June 2011, Rotterdam, Holland.
Kvitrud, A., Kleppestø, H., Skilbrei, O.R., 2012. Position incidents during offshore loading with shuttle tankers on the Norwegian Continental shelf 2000-2011. The International Society of Offshore and Polar Engineers Conference, 17-23 June 2012, Rhodes, Greece.
Laurence, D., 2005. Safety rules and regulations on mine sites – the problem and a solution. Journal of Safety Research 36, 39-50.
Li, A., 2011. Cross industry hydrocarbon release analysis. SPE Offshore Europe Oil and Gas Conference and Exhibition. Aberdeen, UK, 6-8 September 2011.
Lofquist, E.A., 2010. The art of measuring nothing: The paradox of measuring safety in a changing civil aviation industry using traditional safety metrics. Safety Science 48, 1520-1529.
Lu, C.-S., Yang, C.-S., 2010. Safety leadership and safety behavior in container terminal operations. Safety Science 48, 123–134.
Lundberg, J., Rollenhagen, C., Hollnagel, E., Rankin, A., 2012. Strategies for dealing with resistance to recommendations from accident investigations. Accident Analysis & Prevention 45, 455-467.
Al Mansouri, F., Alam, M.A., 2008. Sources of Hydrocarbon Leaks and Spills in Upstream Oil Industries, Its Potential Reasons and Preventive Measures. SPE International Conference on Health, Safety, and Environment in Oil and Gas Exploration and Production. Nice, France, 15-17 April 2008.
Moodi, M., Kimball, S., 2004. Example Application of Procedural Event Analysis Tool (PEAT). Seattle: Boeing and the Golbal Aviation Information Network.
Mostue, B.A., Sandvik, P.C., Hansen, A.S., Storesund, K., 2014. Analysis of causal factors related to three different event types on the Norwegian continental shelf: Hydrocarbon leaks, lifting incidents and fires in electrical installations. In: Steenbergen et al. (Eds.) Safety, Reliability and Risk Analysis. London: Taylor and Francis.
Mount, M.K., Oh, I.S., Burns, M., 2008. Incremental validity of perceptual speed and accuracy over general mental ability. Personnel Psychology 61, 113-139.
Mullen, E.J., Streiner, D.L., 2006. The evidence for and against evidence-based practice. In: A.R. Roberts, K.R. Yeager (Eds.) Foundations of Evidence-Based Social Work Practice. New York: Oxford University Press.
Nielsen, K., Randall, R., 2013. Opening the black box: Presenting a model for evaluating organizational-level interventions. European Journal of Work and Organizational Psychology 22 (5).
NORSOK, 2010. NORSOK Z-013: 2010 Risk and emergency preparedness assessment. Oslo: Standards Norway.

Olsen, E., Næss, S., Høyland, S., 2015. Exploring relationships between organizational factors and hydrocarbon leaks on offshore platform. Safety Science 80, 301-309.
Paltrinieri, N., Bonvicini, S., Spadoni, G., Cozzani, V., 2012. Cost-Benefit Analysis of Passive Fire Protections in Road LPG Transportation. Risk analysis 32, 200-219.
Paltrinieri, N., Khan, F., 2016. Dynamic Risk Analysis in the Chemical and Petroleum Industry: Evolution and Interaction with Parallel Disciplines in the Perspective of Industrial Application. Elsevier Science.
Peltola, H., Rajamäki, R., Luoma, J., 2013. A tool for safety evaluations of road improvements. Accident Analysis & Prevention 60, 277-288.
Porru, S., Calza, S., Arici, C., in press. Prevention of occupational injuries: Evidence for effective good practices in foundries. Journal of Safety Research.
Pratt, D.B., 2002. Reducing Leaks Offshore - A U.K. Regulatory Initiative. SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production. Kuala Lumpur, Malaysia, 20-22 March 2002.
PSA, 2008. Gransking av hendelse. Hydrokarbonlekkasje i utstyrsskaftet på Statfjord A 24.5.2008. Stavanger: Petroleum Safety Authority Norway.
PSA, 2011. Risikonivå i norsk petroleumsvirksomhet. Hovedrapport, utviklingstrekk 2010, norsk sokkel. Stavanger: Petroleum Safety Authority Norway.
PSA, 2016. Risikonivå i petroleumsvirksomheten. Hovedrapport, utviklingstrekk 2015, norsk sokkel. Stavanger: Petroleum Safety Authority Norway.
Randall, R., 2013. Process Monitoring in Intervention Research: A 'Dashboard' with Six Dimensions, In: Bauer, G.F., Jenny, G.J. (Eds.), Salutogenic organizations and change: The concepts behind organizational health intervention research. Springer Netherlands, Dordrecht, pp. 259-272.
Reason, J., 1997. Managing the Risks of Organizational Accidents. Ashgate, Aldershot.
Reason, J., 2000. Human error: models and management. British Medical Journal 320, 768-770.
Rodríguez-Garzón, I., Lucas-Ruiz, V., Martínez-Fiestas, M., Delgado-Padial, A., 2015. Association between Perceived Risk and Training in the Construction Industry. Journal of Construction Engineering and Management 141 (5).
Rodríguez-Garzón, I., Martínez-Fiestas, M., Delgado-Padial, A., Lucas-Ruiz, V., 2016. An Exploratory Analysis of Perceived Risk among Construction Workers in Three Spanish-Speaking Countries. Journal of Construction Engineering and Management 142 (11).
Rollenhagen, C., Alm, H., Karlsson, K.-H., in press. Experience feedback from in-depth event investigations: How to find and implement efficient remedial actions. Safety Science.
Rollenhagen, C., Westerlund, J., Lundberg, J., Hollnagel, E., 2010. The context and habits of accident investigation practices: A study of 108 Swedish investigators. Safety Science 48, 859-867.
Rosness, R., 1999. Search for safety. The methodology and process of risk influence analysis. Trondheim: NTNU (PhD thesis).
Rosness, R., Haavik, T., Tinmannsvik, R., 2016. What do you do when you Build Safety? Practitioners Guide to Learning from Successful Operations. Trondheim: SINTEF.
Røed, W., Vinnem, J.E., 2013. Initial Achievements in Norwegian Oil and Gas Industry Project to Reduce the Number of Hydrocarbon Leaks. European Safety and Reliability Conference, ESREL. Amsterdam, Netherlands, 29 September – 2 October 2013.
Røed, W., Vinnem, J.E., Nistov, A., 2012. Causes and Contributing Factors to Hydrocarbon Leaks on Norwegian Offshore Installations. SPE International Conference on Health, Safety, and Environment in Oil and Gas Exploration and Production. Perth, Australia, 11-13 September 2012.
Safetec, 2010. Risikoforståelse – forprosjektrapport. Trondheim: Safetec/Studio Apertura.
Salgado, J.F., 2002. The big five personality dimensions and counterproductive behaviors. International Journal of Selection and Assessment 10, 117-125.
Schiefloe, P.M., Vikland, K.M., Ytredal, E., Torsteinsbø, A., Moldskred, I.O., Heggen, S., Sleire, D.H., Førsund, S.A., Syversen, J.E., 2005. Årsaksanalyse etter Snorre A hendelsen, 28.11.2004. Stavanger: Statoil.
SCS, 2009. Hydrocarbon Release Reduction Toolkit. Aberdeen: Step Change in Safety.

SCS, 2012. Guidance on Hydrocarbon Release Reduction Plans. Aberdeen: Step Change in Safety.
Shappell, S., Wiegmann, D., 2006. Developing a methodology for assessing safety programs targeting human error in aviation. Office of Aerospace Medicine, Washington DC.
Simpson, G., Horberry, T., Joy, J., 2009. Understanding Human Error in Mine Safety. Ashgate, Farnham.
Sklet, S., 2006. Hydrocarbon releases on oil and gas production platforms: Release scenarios and safety barriers. Journal of Loss Prevention in the Process Industries 19, 481-493.
Sklet, S., Ringstad, A.J., Steen, S.A., Tronstad, L., Haugen, S., Seljelid, J., Kongsvik, T. & Wærø, I., 2010. Monitoring of human and organizational factors influencing the risk of major accidents. SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production. Rio de Janeiro, Brazil, 12–14 April 2010.
Sklet, S., Steiro, T., 2005. Lekkasje i forbindelse med kabeloperasjoner. Tekniske og operasjonelle forholds betydning for lekkasjer med storulykkepotensiale. Trondheim: SINTEF.
Sklet, S., Vinnem, J.E., Aven, T., 2006. Barrier and operational risk analysis of hydrocarbon releases (BORA-Release) Part II: Results from a case study. Journal of Hazardous Materials A137, 692-708.
Størseth, F., Tinmannsvik, R.K., 2012. The critical re-action: Learning from accidents. Safety Science 50, 1977-1982.
Talarico, L., Reniers, G., Sörensen, K., Springael, J., 2015a. Intelligent Systems in Managerial Decision Making. In: Intelligent Techniques in Engineering Management. Springer, pp. 377-403.
Talarico, L., Sörensen, K., Springael, J., 2015b. A biobjective decision model to increase security and reduce travel costs in the cash-in-transit sector. In: International Transactions in Operational Research.
TapRoot, 2015. Corrective Action Helper Guide. Knoxville: System Improvements Inc.
Taylor, R.H., van Wijk, L.G.A., May, J.H.M., Carhart, N.J., 2015. A study of the precursors leading to 'organisational' accidents in complex industrial settings. Process Safety and Environmental Protection 93, 50-67.
Thomas, P., Jones, R., 2010. Extending the J-value framework for safety analysis to include the environmental costs of a large accident. Process Safety and Environmental Protection 88, 297-317.
Thunem, A.P.J., Kaarstad, M., Thunem, H.P.J., 2009. Vurdering av organisatoriske faktorer og tiltak i ulykkesgranskning. Halden: Institutt for energiteknikk.
Tinmannsvik, R.K., 2009. Stille avvik – trussel eller mulighet? [Silent deviations – threat or possibility?] In: Tinmannsvik, R.K. (Ed.), Robust arbeidspraksis. Hvorfor skjer det ikke flere ulykker på sokkelen? [Robust Work Practice. Why don't More Accidents Occur on the Continental Shelf?] Tapir akademisk forlag, Trondheim, pp. 133-146.
Tinmannsvik, R.K., Albrechtsen, E., Bråtveit, M., Carlsen, I.M., Fylling, I., Hauge, S., Haugen, S., Hynne, H., Lundteigen, M.A., Moen, B.E., Okstad, E., Onshus, T., Sandvik P.C., Øien K., 2011. Deepwater Horizon-ulykken: Årsaker, lærepunkter og forbedringstiltak for norsk sokkel. Trondheim: SINTEF.
Turner, B.A., 1978. Man-Made Disasters. London: Wykeham Science Press.
Vinnem, J.E., Aven, T., 2006. Case illustration of a decision framework for health, environment, and safety management. Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability 220, 115-121.
Vinnem, J.E., Haugen, S., Vollen, F., Grefstad, J.E., 2006. ALARP-prosesser. Gjennomgang og drøfting av erfaringer og utfordringer. Report No: 200584-3. Bryne: Preventor.
Vinnem, J.E., Hestad, J.A., Kvaløy, J.T., Skogdalen, J.E., 2010. Analysis of root causes of major hazard precursors (hydrocarbon leaks) in the Norwegian offshore petroleum industry. Reliability Engineering & System Safety 95, 1142-1153.
Vinnem, J.E., Røed, W., 2013. Norwegian Oil and Gas Industry Project to Reduce the Number of Hydrocarbon Leaks with emphasis on Operational Barriers Improvement. SPE European Health, Safety, and Environmental Conference and Exhibition. London, UK, 16-18 April.
Vinnem, J.E., Røed, W., 2014. Norwegian Oil and Gas Industry Project to Reduce Hydrocarbon Leaks. 164981-PA SPE Journal Paper.
Wagenaar, W.A., 1998. People make accidents but organisations cause them. In: Feyer, A.-M., Williams, A. (Eds.), Occupational Injury. Risk, Prevention and Intervention. Taylor & Francis, London, pp. 121-128.

Walker, K., Poore, W., Eales, M., 2012. Improving the opportunity for learning from industry safety data. SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, 11-13 September 2012, Perth, Australia.
Wang, Y.F., Li, Y.L., Zhang, B., Yan, P.N., Zhang, L., 2015. Quantitative Risk Analysis of Offshore Fire and Explosion Based on the Analysis of Human and Organizational Factors. Mathematical Problems in Engineering 2015.
Weick, K.E., Sutcliffe, K.M., 2007. Managing the Unexpected. Resilient Performance in an Age of Uncertainty. John Wiley & Sons, San Francisco.
Youngberg, B.J., 2011. Principles of Risk Management and Patient Safety. Sudbury: Jones & Bartlett Learning.
Zohar, D., 2010. Thirty years of safety climate research: Reflections and future directions. Accident Analysis & Prevention 42, 1517-1522.

Appendix A: List of included literature

Table A1 shows the complete list of search results from the literature review. Marks in the columns to the right indicate what research questions (RQ1-4) each of the publications address.

As described in chapter 3.2, 42 publications were evaluated as directly relevant for answering one or more of the research questions. These have been indicated in the table using bold marks in black. 23 publications were evaluated as indirectly relevant, meaning that they are of some relevance, but that they either are too general, too specific or only *supports* literature which already has been evaluated as directly relevant. These are indicated with grey marks in the table. When including these, the total number of publications is 65.

Table A1: List of included publications

Title	Author(s)	Year	Doc. type	RQ1	RQ2	RQ3	RQ4
A biobjective decision model to increase security and reduce travel costs in the cash-in-transit sector	Talarico et al.	2015	Book chapter				✓
A decision framework for risk management, with application to the offshore oil and gas industry	Aven et al.	2007	Article / paper				✓
A decision model to allocate protective safety barriers and mitigate domino effects	Janssens et al.	2015	Article / paper				✓
ALARP-proseser. Gjennomgang og drøfting av erfaringer og utfordringer	Vinnem et al.	2006	Report / note				✔
An evidence-based approach to improving the quality of resource-oriented well-being interventions at work	Briner & Walshe	2015	Article / paper	✓			
An Exploratory Analysis of Perceived Risk among Construction Workers in Three Spanish-Speaking Countries	Rodríguez-Garzón et al.	2016	Article / paper			✔	
An Organisation-Wide Investigation Into The Human Factors-Related Causes Of Hydrocarbon Releases On Offshore Platforms	Gilroy & Dumolo	2013	Article / paper			✓	
Analysis of causes of hydrocarbon leaks from process plants	Haugen & Vinnem	2011	Article / paper			✓	
Analysis of root causes of major hazard precursors (hydrocarbon leaks) in the Norwegian offshore petroleum industry	Vinnem et al.	2010	Article / paper			✔	
Analysis of the causal factors related to three different event types on the Norwegian continental shelf: Hydrocarbon leaks, lifting incidents and fires in electrical installations	Mostue et al.	2014	Article / paper		✔	✔	
Association between Perceived Risk and Training in the Construction Industry	Rodríguez-Garzón et al.	2015	Article / paper			✔	
Barrier and operational risk analysis of hydrocarbon releases (BORA-Release): Part I. Method description	Aven et al.	2006	Article / paper	✔			

Barrier and operational risk analysis of hydrocarbon releases (BORA-Release): Part II: Results from a case study	Sklet et al.	2006	Article / paper	✓		✓	
Best management practice. Management of Fugitive Emissions at Upstream Oil and Gas Facilities	CAPP	2007	Report / note				✓
Case illustration of a decision framework for health, environment, and safety management	Vinnem & Aven	2006	Article / paper				✓
Causes and contributing factors to hydrocarbon leaks on Norwegian offshore installations	Røed et al.	2012	Article / paper			✓	
CFD and VR for risk communication and safety training	Hansen et al.		Article / paper	✓			
Cost-Benefit Analysis of Passive Fire Protections in Road LPG Transportation	Paltrinieri et al.	2012	Article / paper				✓
Critical Steps in Learning From Incidents: Using Learning Potential in the Process From Reporting an Incident to Accident Prevention	Drupsteen et al.	2013	Article / paper			✓	
Cross Industry Hydrocarbon Release Analyses	Li	2011	Article / paper			✓	
Developing a methodology for assessing safety programs targeting human error in aviation	Shappell & Wiegmann	2006	Report / note		✓		
Dynamic Risk Analysis in the Chemical and Petroleum Industry: Evolution and Interaction with Parallel Disciplines in the Perspective of Industrial Application	Paltrinieri & Khan	2016	Book				✓
Effective Corrective Actions to Enhacne Operational Safety of Nuclear Installations	IAEA	2005	Guideline	✓	✓	✓	
Evaluation of the Risk OMT model for maintenance work on major offshore process equipment	Gran et al.	2012	Article / paper	✓		✓	
Experience feedback from in-depth event investigations: How to find and implement efficient remedial actions.	Rollenhagen et al.	In press	Article / paper		✓	✓	
Exploring relationships between organizational factors and hydrocarbon leaks on offshore platform	Olsen et al.	2015	Article / paper			✓	
Extending the J-value framework for safety analysis to include the environmental costs of a large accident	Thomas & Jones	2010	Article / paper				✓
Guidance on Hydrocarbon Release Reduction Plans	Step Change in Safety	2012	Guideline		✓	✓	
Healthcare economics made easy	Jackson	2012	Book				✓
Helicopter Safety Study 3 (HSS-3)	Herrera et al.	2010	Report / note	✓			
How has industry achieved a significant reduction in Hydrocarbon Releases?	Adejugba	2013	Thesis			✓	
Human behaviour in severe tunnel accidents: Effects of information and behavioural training	Kinateder et al.	2012	Article/ paper	✓			

Hydrocarbon Release Reduction Toolkit	Step Change in Safety	2009	Guideline			✓	
Hydrocarbon releases on oil and gas production platforms: Release scenarios and safety barriers	Sklet	2006	Article / paper	✓			
Improving Compliance with Procedures. Reducing Industrial Violations	HSE	1995	Guideline			✓	
Initial Achievements in Norwegian Oil and Gas Industry Project to Reduce the Number of Hydrocarbon Leaks	Røed & Vinnem	2013	Article / paper			✓	
Intelligent Systems in Managerial Decision Making	Talarico et al.	2015	Book chapter				✓
ISO 13702: 2015 Petroleum and natural gas industries - Control and mitigation of fires and explosions on offshore production installations - Requirements and guidelines	ISO	2015	Standard		✓		
Learning from Incidents, Accidents and Events	IE	2016	Guideline			✓	
Lekkasje i forbindelse med kabeloperasjoner. Tekniske og operasjonelle forholds betydning for lekkasjer med storulykkepotensiale	Sklet & Steiro	2005	Report / note			✓	
Managerial accounting for safety management. The case of a spanish construction company	Ibarrondo-Dávila et al	2015	Article / paper				✓
Managing the Unexpected. Resilient Performance in an Age of Uncertainty	Weick & Sutcliffe	2007	Book			✓	
Multiple criteria decision analysis. State of the art surveys	Brans & Mareschal	2005	Book				✓
NORSOK Z-013: 2010 Risk and emergency preparedness assessment	NORSOK	2010	Standard		✓		
Norwegian oil and gas industry project to reduce hydrocarbon leaks	Vinnem & Røed	2014	Article / paper			✓	
Norwegian Oil and Gas Industry Project to Reduce the Number of Hydrocarbon Leaks with emphasis on Operational Barriers Improvement	Vinnem & Røed	2013	Article / paper			✓	
On the Use of Cost-Benefit Aanlysis in ALARP Processes	Aven & Abrahamsen	2007	Article / paper				✓
Opening the black box: Presenting a model for evaluating organizational-level interventions	Nielsen & Randall	2013	Article / paper	✓			
Perspectives on risk: review and discussion of the basis for establishing a unified and holistic approach	Aven & Kristensen	2005	Article / paper				✓
Practical use of the cost-benefit analysis	Humberset	2009	Thesis				✓
Process evaluation for organizational stress and well-being interventions: Implications for theory, method, and practice	Biron & Karanika-Murray	2014	Article / paper	✓			
Process Monitoring in Intervention Research: A ‘Dashboard’ with Six Dimensions	Randall	2013	Book chapter	✓			

Psychosocial risks and hydrocarbon leaks: An exploration of their relationship in the Norwegian oil and gas industry	Bergh et al.	2014	Article / paper		✓	
Quantitative Risk Analysis of Offshore Fire and Explosion Based on the Analysis of Human and Organizational Factors	Wang et al.	2015	Article / paper			✓
Reducing the gap between procedures and practice – Lessons from a successful safety intervention	Antonsen et al.	2008	Article / paper		✓	
Risikoforståelse – forprosjektrapport	Safetec	2010	Report / note		✓	
Risk assessment as a tool in establishing the Requirement of subsea isolation valves in subsea pipelines	Dhar	2009	Article / paper			✓
Risk management in operations of petrochemical plants: Can better planning prevent major accidents and save money at the same time?	Damnjanovic & Røed	2016	Article / paper			✓
Risk of Major Accidents: Causal Factors and Improvement Measures Related to Well Control in the Petroleum Industry	Hauge et al.	2013	Article / paper		✓	
RNNP Hovedrapport - Utviklingstrekk 2010 - Norsk sokkel. Risikonivå i norsk petroleumsvirksomhet	PSA	2011	Report / note	✓	✓	
RNNP Hovedrapport - Utviklingstrekk 2015 - Norsk sokkel. Risikonivå i norsk petroleumsvirksomhet	PSA	2015	Report / note		✓	
Safety compliance in a highly regulated environment: a case study of workers' knowledge of rules and procedures within the petroleum industry	Dahl	2013	Article / paper		✓	
Sources of Hydrocarbon Leaks & Spills in Upstream Oil Industries-Its Potential Reasons & Preventive Measures	Al Mansouri & Alam	2008	Article / paper		✓	
Thirty years of safety climate research: Reflections and future directions	Zohar	2010	Article / paper		✓	
Understanding Human Error in Mine Safety	Simpson et al.	2009	Book		✓	

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