

BARRIER MANAGEMENT IN OPERATION FOR THE RIG INDUSTRY

GOOD PRACTICES

March 2014



A DNV GL report commissioned by NSA



PREFACE

The rig industry is getting more complex every year, every month and every day. However, the hazards we are facing are the same, and have to be managed in a proper way on a daily basis. The Macondo accident was an eye opener for the whole industry, and the Petroleum Safety Authority Norway challenged the industry on different levels. One challenge given was to strengthen the work on barrier management.

As a response to this challenge, the members of the Operations and Environmental committee for Offshore Entrepreneurs at the Norwegian Shipowners' Association decided to unify their knowledge and resources, and develop a project to raise the level and quality of barrier management in the rig companies.

The final product of the project is a document called "Barrier Management in Operation for rig industry, Good Practices".

Barrier Management is not something that can be performed as a stand-alone activity. Barrier Management must be incorporated in all operation activities. However, it is essential to have a clear structure and understanding of what forms the basis for a good system.

The term Good Practices is used in the understanding that what is good practice depends on the context where it is used. The aim of the project is to provide a common understanding of the methodology and level of the work that is needed to establish an appropriate barrier management system.

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Task and objective:

The Norwegian Shipowners' Association (NSA) has initiated the work of developing this report as means to provide rig owners in Norway with a common understanding and approach on how to implement and manage barriers in daily operation to prevent major accidents. The main objective of this report is to give readers an increased understanding of barrier management in practice, with emphasis on implementation of solutions for the operational phase. This is achieved through the following scope of work: 1) Definitions of relevant terminology, such as those related to risk, major accidents and barriers; 2) Explanation of the rationale, or purpose, of barrier management as means to prevent major accidents; 3) Framework, including a process, for implementing barrier management solutions in operations and how barrier performance can be maintained in operations; 4) Explain how the framework can be implemented and used in operations with use of relevant examples, such as maintenance and training.

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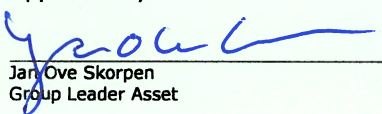

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Reference to part of this report which may lead to misinterpretation is not permissible.

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INTRODUCTION

The Norwegian Shipowners' Association (NSA) has initiated the work of developing this report as means to provide rig owners in Norway with a common understanding and approach on how to implement and manage barriers in daily operation to prevent major accidents.

Guidelines and standards stating the requirements for barriers and major accident risk management are well described by the Petroleum Safety Authorities (PSA) and other sources. The ways of compliance, however, vary significantly from rig owner to rig owner.

The report is developed on behalf of, and with input from, the NSA's member organizations. More specifically, through a kick-off meeting and a two-day workshop the Operations and Environment Committee (Drift og Miljø-utvalget, DMU) in NSA met to discuss and express their topics of concern, challenges and needs of the industry. The meetings were facilitated by DNV GL who was also responsible for capturing relevant input from the rig owners and developing the report. In addition, relevant expertise in DNV GL has contributed to ensure that important topics have been addressed in a suitable manner. This includes representatives from Asset & Safety Advisory Services, as well as Offshore Class.

Objective

The main objective of this report is to give readers an increased understanding of barrier management in practice, with emphasis on implementation of solutions for the operational phase. The proposed solutions are intentionally named "Good Practices" with the following reasoning;

The field of barrier management is constantly developing and in a rapid pace. Capturing everything that is "best" would be impossible. In addition, different companies have different needs depending on their maturity levels and focus areas within barrier management. Hence, what is best for one company may not be the best for another. Consequently, it is here believed that the term "Best Practice" would be misleading and it is acknowledged that challenges can be solved with different solutions.

Following the same logic, efforts have been made to balance between being too specific and too general when recommending Good Practices. It is not this report's intention to promote exclusive ways of managing barriers, but instead provide hints and tips about how issues can be addressed. Companies will be able to review general Good Practices and consider what they have in place, improvement areas, and ways to go about for refining their barrier management practice. Another upside of being general is that it allows room for interpretations. This creates debate in the industry, and from debate comes increased learning. Thus, some room for interpretation is considered healthy.

Nevertheless, being overly general may in some cases foster confusion. This is the argument behind the more specific solutions described in this report. While some confusion about barrier management is likely to exist in several years to come, this report targets key areas which have been subject for confusion in the last couple of years. This ranges from basic questions about what barriers are and how they are identified, to more complex considerations regarding equipment classification. The report will inevitably add some confusion, but hopefully remove more.

Finally, the rig industry has long traditions when it comes to managing safety and assets. This has resulted in well-established routines for activities related to barrier management, such as maintenance, training and processes for safe operation. Barrier management taps into such practices by providing a more structured, integrated and systematic approach to managing major accident risk. Still, an underlying message in this report encourages companies not to introduce new and additional systems, but instead adapt and utilize their existing practices to accompany principles from barrier management. Managing barriers must not become a time consuming "add-on", subject to frustration and down prioritization among already busy employees. Instead it must become an integrated part of managing the installation.

Scope of work

A main goal for this document is to provide guidance on barrier management for the operational phase. For this to be successful it is a pre-requisite that the necessary preparations have been made. This refers to a basis for implementation, such as knowing what should be considered as barriers and how they must perform to reduce risk. First when the basis is in place, suitable solutions for managing barriers in operations can be implemented. The scope in this report reflects this principle, and can be summarized as following:

- Definitions of relevant terminology, such as those related to risk, major accidents and barriers. The purpose is to create a common language in the industry for how to understand barriers and accident scenarios.
- Explanation of the rationale, or purpose, of barrier management as means to prevent major accidents. The purpose is to explain how barrier management can contribute to reduce the uncertainty of whether major accident risk is managed in operations.
- Framework, including a process, for implementing barrier management solutions in operations and how barrier performance can be maintained in operations. The purpose is to provide a description of methods, tools and activities for systematic implementation and performance management of barriers.
- Explain how the framework can be implemented and used in operations with use of relevant examples, such as maintenance and training. The purpose is to provide guidance on improvement areas and how existing systems and practices can be adapted to accommodate barrier management.

Limitations

The following limitations apply:

- Barrier management interfaces with several other aspects related to management of safety, environment, and asset risk. Examples are safety culture, operational risk management, and organizational learning, to name a few. All these areas are highly relevant for managing risk, and it is acknowledged that barrier management alone is not a complete solution of preventing major accidents. Nevertheless, the scope of this report is limited to concern barrier management.
- Trying to cover everything about barrier management in one document would make for an unpractical and excessively long report. The content of this report captures how to further improve the industry's status quo by addressing key topics and challenges experienced by various stakeholders.
- The report does not include prescriptive recommendations on how barrier management should be operationalized. Rig owners organizations vary in terms of systems and processes in place, type of rigs, resources available, and barrier management maturity level. Instead recommendations are developed to target the average rig owner. In cases where rig owners are known to be similar, more specific recommendations are made where found relevant. In cases where there are more variations, the recommendations are made on a more general level.
- Objective and scope of work is first and foremost relevant for Norwegian regulations. The challenges related to moving rigs between shelves with different regulatory regimes are acknowledged, but out scope. The report will however provide useful information for how to comply with Norwegian regulations when moving a rig from e.g. the UK Continental Shelf onto the Norwegian Continental Shelf.
- This report does not describe how requirements relevant to classification societies support barrier management e.g different survey arrangements will give valuable information about integrity of barriers on a rig.



Target group

This report targets the rig owners' management level, both onshore and offshore. Its relevance is therefore highest for managers, discipline leads, and process owners within operations, asset, HSE and HR.

How to read this report

For educational purposes, the report follows a certain structure and logic:

- Frequent use of examples to accommodate and improve the reader's understanding of various topics. Examples are typically found in tables, figures and diagrams.
- Text boxes are used to highlight important content:
 - **Blue** boxes are used for Good Practices. These have individual numbers for easy referencing, tracking and overview.
 - **Green** boxes for key definitions.
 - **Grey** boxes for relevant requirements.
- In each text box, the Good Practice, definition or requirement is indicated with text in *italics* format. Additional explanation is indicated with text in normal font under "Comments:".
- The text boxes make it easy to re-visit the most important topics after having read the report or selected chapters of particular interest.

ABBREVIATIONS

This section list and defines all abbreviations used in this document.

Abbreviations	
BOP	Blowout Preventer
CCR	Central Control Room
CRIOP	Crisis Intervention and Operability Study
CM	Corrective Maintenance
CMMS	Computerized Maintenance Management System
CRM	Crew Resource Management
DMU	Drift og Miljøutvalget
DNV GL	Det Norske Veritas - Germanischer Lloyds
EDS	Emergency Disconnect System
e.g.	For Example
ENS	Engineering Numbering Standard
ESD	Emergency Shutdown System
F&G	Fire and Gas
FMECA	Failure Mode Effect and Criticality Analysis
FW	Firewater
HAZID	Hazard Identification
HAZOP	Hazard and Operability Study
HC	Hydrocarbons
HMI	Human Machine Interface
HRA	Human Reliability Analysis
HSE	Healthy, Safety & Environment
i.e.	That Is
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
KPI	Key Performance Indicator
LTI	Loss Time Injury
MAH	Major Accident Hazard
MOB	Man Over Board
MoC	Management of Change
MODU	Mobile Offshore Drilling Unit
MOU	Mobile Offshore Unit
NCS	Norwegian Continental Shelf
NORSOK	Norsk Sokkel's Konkurransesposisjon
NSA	Norwegian Shipowners' Association
OJT	On-the-job Training
PA	Public Address
PLC	Programmable Logic Solver
PM	Preventive Maintenance
PS	Performance Standard
PSA	Petroleum Safety Authorities
PSF	Performance Shaping Factors
PtW	Permit to Work
QRA	Quantitative Risk Analysis
RCM	Reliability Centred Maintenance
RNNP	Risikonivå i Norsk Petroleumsvirksomhet
SCE	Safety Critical Element
SCT	Safety Critical Task
SCTA	Safety Critical Task Analysis
SIL	Safety Integrity Level
SJA	Safe-job-analysis
TBT	Tool-box-talk
WP	Work Permit

1 RISK AND MAJOR ACCIDENTS

Offshore drilling involves significant risk. However, where there is no risk there is also no reward.

Examples could be:

- A rig that never leaves the dock,
- a plane that never takes off the runway, or
- a train that never leaves the station

of which none will be able to collect any rewards. The purpose of managing risk is therefore not to eliminate the risk itself, but to understand and control it so that rewards can be maximized and losses minimized. The purpose of this chapter is to describe the concept of risk and nature of accidents.

Risk is a complex and abstract term, but is mostly thought of as a function of the probability and consequence associated with an undesired event. Put differently, risk is the combined answer to three questions (Rausand, 2011):

- (1) What can go wrong?
- (2) What is the probability of that happening? and;
- (3) What are the consequences?

Another perspective is to address risk as the degree or effect of uncertainty on objectives (ISO 31000). So, if the goal (i.e. objective) is to have no accidents, risk refers to the uncertainty of whether this goal is achievable. Thus, one of the purposes of risk management is to predict and reduce this uncertainty.

Risk

Risk can be defined as the combination of the probability of an [hazardous] event and its consequence (ISO Guide 73).

Several definitions of major accident exist. Although somewhat different, they all have in common that they refer to large scale consequences, in terms of impact on life, property and the environment. They also indicate that the consequences may be immediate or delayed, suggesting that there is a potential for escalation. Occupational accidents, in comparison, have smaller consequences with minimum escalation potential.

Major accident

A major accident is defined as an acute incident, such as a major discharge/emission or a fire/explosion, which immediately or subsequently causes several serious injuries and/or loss of human life, serious harm to the environment and/or loss of substantial material assets (ref. www.ptil.no).

Comment:

Accident categories to consider on the NCS are indicated in PSA's "RNNP and major accident risk" where the following categories are identified:

- Leaks of flammable gas or liquids; either ignited or un-ignited
- Well control incidents; either ignited or un-ignited
- Fire/explosion in other areas; could be in critical areas of the rig causing escalation (e.g. machinery fire/explosion leading to loss of position control, resulting in drift off when operating on DP)
- Collisions and other structural damage; including ship collision and dropped objects.

Whether or not an event or incident is considered to have major accident potential depends on the degree of expected losses and harm against a set of consequence categories. These categories have pre-defined impact levels and intervals with respect to loss of life, harm to the environment, damage to assets and depreciation of reputation. For example, loss of life can be measured in potential number of fatalities, harm to the environment in barrels or cubic meter of emission/spill, and damage to asset in financial loss.

Good practice 1

Define impact levels and intervals for potential major accident consequence categories.

Comments:

For the major accident categories as described in definition of Major Accidents above, PSA outlines a requirement in Management Regulations, Section 9 stipulating that acceptance criteria is available for the following risk parameters:

- a) Risk to loss of lives
- b) Risk to loss of main safety functions;
 - a. prevent escalation,
 - b. maintain global structural integrity,
 - c. protection of safety critical functions (e.g. control room, muster area, temporary refuge, emergency equipment etc.)
 - d. Escape routes and evacuation facilities
- c) Acute pollution from the offshore facility
- d) Damage to 3rd party (personnel)

Absolute values for acceptance criteria is not given, however guidance of parameters to use when establishing these can be found in NORSOK Z-013.

1.1 Hazard and hazardous events

Managing major accident risk is about controlling hazards which have a potential of realizing hazardous events with subsequent consequences defined as major accidents (see definition of major accident). These hazards are sometimes referred to as major accident hazards, and hazardous events can sometimes be referred to as intermediate, top, or central critical event.

Hazard

Potential for human injury, damage to the environment, damage to property, or a combination of these (ISO 13702).

Hazardous event

Incident which occurs when a hazard is realized (NORSOK Z-013; ISO 13702).

In the oil and gas industry, potential sources of harm (i.e. hazards) can be explained by eight basic forms of energy (see Figure 1-1). Several (or all) of these energy forms can be involved when performing an operation. If control of the energy is lost, this may realize the hazard and cause a hazardous event to occur. Using the diagram in identifying energy forms involved in activity / design feature is found to be an effective tool for identifying hazards and consequences as part of hazard identification (HAZID) on all detail levels. The model can be adopted for preparation of a HAZID for a QRA as well as for performing an operational task like "storage of a container in a not normal location".

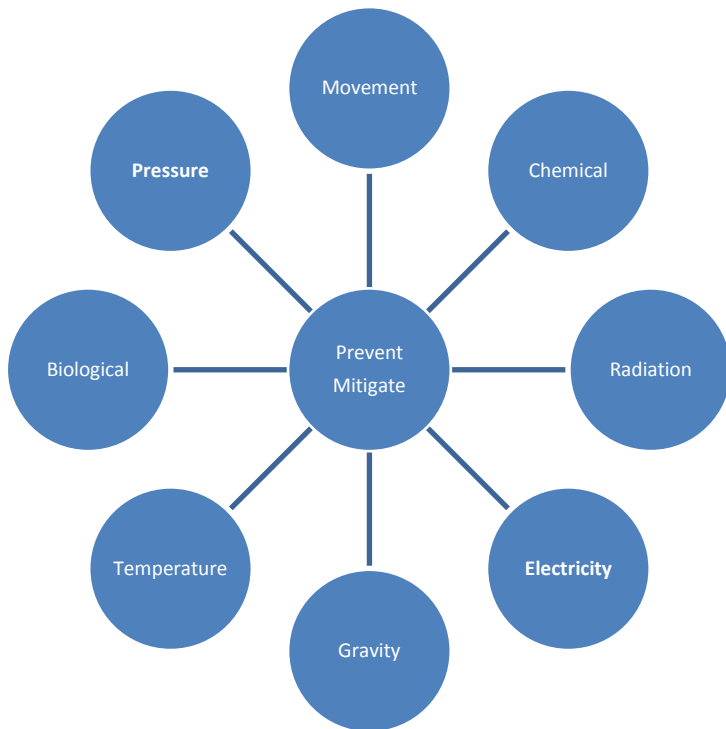


Figure 1-1: Eight basic energy forms

Major accident scenarios refers to event sequences starting from triggering events realizing one or several hazards, resulting in hazardous events which ultimately causes large scale consequences. Example: For the case of drilling into the reservoir section of a well. A significant hazard (i.e. energy forms) is the formation pressure which needs to be controlled to prevent unintentional flow, or influx, from the formation and into the wellbore. If not controlled, a small influx may develop into a well kick and thereby “realizing” the hazard, causing a hazardous event to occur. Well kicks can be considered a hazardous event since, if allowed to escalate, it can cause a blowout. A blow out commonly accepted a major accident with potentially large-scale consequences, such as spills to the environment and explosions (if ignited) with subsequent loss of lives.

Table 1-1: Examples of hazards and hazardous events representing different major accident scenarios

Major accident hazard	Hazardous event	Scenario
Formation pore pressure	Shallow gas blowout	Blowout
	Blowout at drill floor	
	Underground blowout	
	Topside blowout	
Hydrocarbons in mud	Fire and explosion in mud process area	Fire related to drilling
	Fire in shale-shaker area	
	Fire and explosion in well test area	
H ₂ S in formation	H ₂ S release	Toxic Release
Maritime traffic	High energy ship collision	Ship collision
Helicopter transport	Helicopter crash onto installation	Helicopter Crash
Accommodation utilities	Fire and smoke in accommodation	Fire/Explosion (not related to drilling)
Helicopter transport	Helifuel fire	
Normal operation	Fire and explosion in engine compartment	
	Fire/explosion in other areas on rig without fixed firefighting equipment	
	Fire/explosion in other areas on rig with fixed firefighting equipment	
Power generation	Fire/explosion in main generator room	
	Fire in emergency generator room	
Position keeping	Critical loss of position (drive-off / drift-off), not relevant for jack-ups	Loss of position
Jacked-up while drilling	Loss of structural integrity	Toppling
	Punch through	
Ballasting / buoyancy	Loss of buoyancy	Capsize
	Loss of stability	
Transit	Loss of manoeuvring ability during transit	Loss of control in transit
	Collision during transit	
Jacking operation	Loss of control while jacking (only relevant for jack-ups)	Jacking failure

1.2 Risk picture

Understanding the risk picture within the activity is an important factor of manage, avoiding or minimizing the risk exposure.

Management regulation, section 16

"The responsible party shall ensure that analyses are carried out that provide the necessary basis for making decisions to safeguard health, safety and the environment."

Management regulations, section 17

"Risk analyses shall be carried out to identify and assess contributions to major accident and environmental risk, as well as ascertain the effects various operations and modifications will have on major accident and environmental risk."

"Emergency preparedness analyses shall be carried out and be part of the basis for making decisions when e.g. defining hazard and accident situations, and [...]selecting and dimensioning emergency preparedness measures."

Comments:

NORSOK Z-013 can normally be used to fulfil the requirements for risk analyses and emergency preparedness analyses.

Broadly the risk can be divided in two, i.e. one basic level which is governed by the activity in question and the second contributor being the technical condition and activity driven risk see Figure 1-2.

For the "basic level" the inherent risk level is a product of the engineering phase of a rig. In this phase several safety studies are carried out to ensure that the design includes the necessary safety functions to control identified hazards and reduce the risk to an acceptable level, against set criteria. Examples of safety studies are Hazard and Operability studies (HAZOP), Failure Mode Effect and Criticality Analysis (FMCEA), Human Reliability Analysis (HRA), Quantitative Risk Analysis (QRA), Emergency Preparedness Analysis (EPA), and others.

The "variable level" is associated by deterioration of technical condition, operational and organizational factors, activity level, external impacts etc. The QRA presents this level as an average but states important assumptions and limitations for technical and operational factors that should not be exceeded.



Variable risk level

- Technical condition
- Operational/organisational "condition"
- Activity level
- External impacts

Basic risk level

- Design
- Nature of business
 - Offshore
 - HP/ HT

Figure 1-2: The risk picture

A good understanding of the risk picture is vital in order to control hazards and prevent accidents. The risk analysis is therefore a key document and natural starting point when working to manage risk in operation. The main results and recommendations from the risk analyses should therefore be known to decision takers both onshore and offshore a rig.

Good practice 2

Decision makers in the company, both onshore and offshore, should know how and when the QRA (plus other risk assessments) can be used to make risk informed decisions.

Comments:

Understanding the risk picture for a rig is imperative for managing major accident risk in planning phase as well as in daily operations. I.e. the risk assessment can be used to identify main risk drivers for a given activity, a specific area on the installation etc. Furthermore, there will be assumptions in the risk assessment related to operational parameters such as activity level of e.g. lifting, number of and type of well activities, duration of well tests, manning level and distribution, which are influencing the risk picture independent of the barrier status and performance.

2 THE RATIONALE BEHIND BARRIER MANAGEMENT

Understanding how major accidents occur and how they differ from occupational accidents is an important part of barrier management. The risk of occupational accidents will almost always be expressed in terms of medium to high probability and medium to low consequence. They occur relatively often, especially compared to major accidents, and their consequences are usually low (sprained ankle, cut in the finger etc.). Major accidents, on the other hand, occur relatively seldom. When they do occur, however, they have large impacts, and have greater potential for escalation than occupational hazards.

Expressed as a risk, major accidents are by definition low-probability / high-consequence events. One of the reasons why major accidents are rare events is due to the number of safety measures in place. The question may then be: If major accidents occur so rarely, why do they require so much attention? The answer is found in the *uncertainty* aspect of major accident risk. Major accidents are complicated by nature and hard to predict. They involve a complex risk picture, multi-linear chain of events, failure in several safety features, and with a potential for uncontrolled escalation. So, if a risk analysis predicts a major accident to occur one time in a hundred years, it is hard to tell whether this happens tomorrow, in fifty years or in a hundred. Consequently, management of major accident risk requires good systems which captures this complexity and reduces uncertainty. This is the main objective, or rationale, behind barrier management. It allows operators to prioritize important safety measures related to technology and operation, so that the risk of major accidents can be reduced. Occupational accidents, in contrast, have single-linear event chains with little or no potential for escalation.

The oil and gas industry has a long tradition of measuring safety risk with parameters suitable for occupational accidents (e.g. Loss-Time-Injury, LTI). Unfortunately, this has led people to believe that the same parameters can be used as indicators for major accident risk. Lessons learned from accident investigations reveals that due to their different nature, occupational accidents and major accidents require different risk management approaches.

Good practice 3

Personnel on all levels in the organization know the difference between occupational accidents and major accidents, and why they require different risk management approaches.

One of the most acknowledged barrier models is James Reason's (1997) "Swiss Cheese Model" of accident causation (Figure 2-1). The model builds on the principles of "defences in depth", with a set of successive protection layers (i.e. barriers) preventing hazards from being realized and causing accidents to happen.

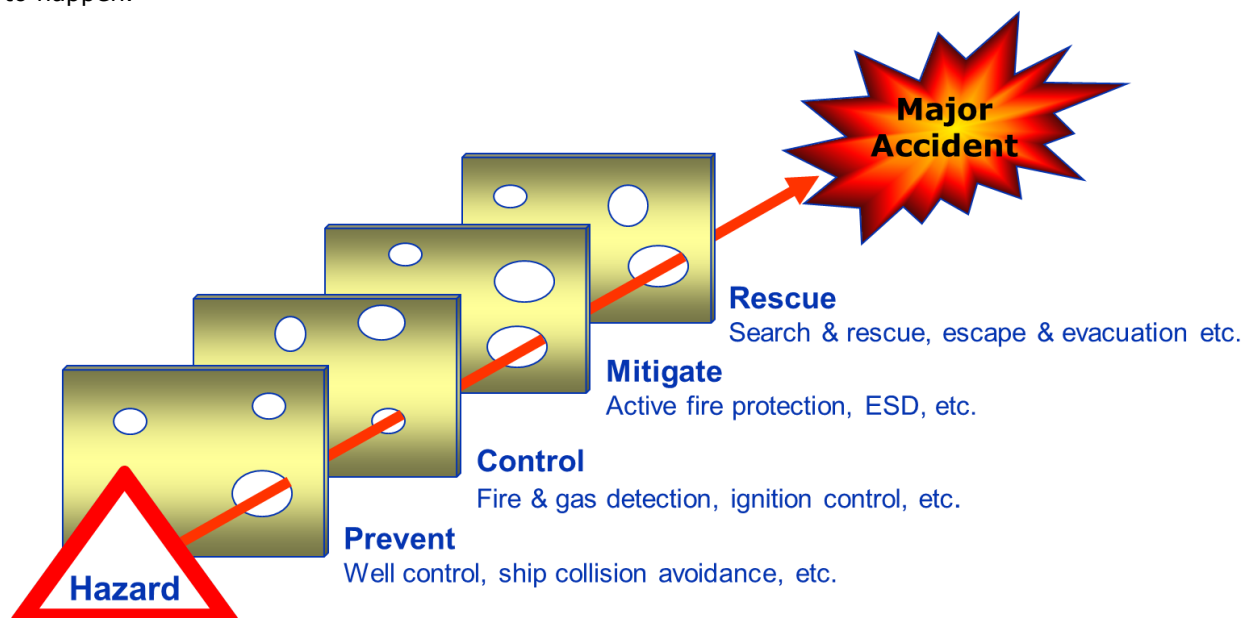


Figure 2-1: Swiss cheese model (adapted from Reason, 1997)

As revealed by its name, the Swiss Cheese model illustrates an event sequence in which barriers are presented as cheese slices. The "holes" in the cheese slices represent weakened barriers either caused by active failures or latent failures.

- Active failures are caused by humans (unsafe actions) or technology and have a direct influence on the accident causation. Examples can be failure to operate BOP in case of a well kick, or a fire damper that fails to close when activated.
- Latent failures are defects or flaws in the system which indirectly allows accident scenarios to develop. One example can be incorrect line-up of valves after e.g. a maintenance job, which at a later stage may cause flow of hydrocarbons to undesired locations (see chapter 3.5).

Throughout the lifetime of a rig, holes in this model are expected to constantly move and change sizes depending on the type operation, asset management, external environments etc. For a major accident to happen, holes in the Swiss Cheese Model need to align allowing for an "accident trajectory."

The strength of the Swiss Cheese Model is how it exemplifies and promotes the following strategy for management;

- Each barrier should either prevent hazards from being realised or escalation of the event
- If one barrier fails, the subsequent barrier comes into play
- Barriers should, as far as possible, be independent of each other
- Barriers should be in place to reduce the risk as low as reasonably practicably
- No single failure should be able to cause a major accident
- "Holes" i.e. degradation in barrier performance should be as small and few as possible

For this strategy to be successful, barrier needs to be managed in a way which ensures that they perform as intended at all times. This includes a comprehensive and common understanding from design and throughout operations of what constitutes barriers to hazards, and how barriers are verified, monitored and maintained.

3 BARRIER TERMINOLOGY

One way of managing risk is to implement safety *barriers* with purpose of preventing and mitigating hazardous events.

Barrier

Barriers refer to measures established with an explicit purpose to (1) prevent a hazard from being realized, or (2) to mitigate the effects of a hazardous event.

To be able to manage barriers it is essential to have a common understanding of what constitutes a barrier. The way a company defines barriers and other associated terms ultimately determines what is identified as barriers to be managed. Several definitions are already made available by regulatory bodies (e.g. the PSA), national standards (e.g. Norsok) and others. While these can be applied, care must be taken when adopting them. For example, they may originate from ideas and perspectives not necessarily in line with individual company needs.

The purpose behind a selected set of definitions, such as barrier- functions and -elements, is to make sense of the barrier concept. Consequently, the definitions need to be coherent and specific. A common pitfall is that definitions allow too much room for interpretation, and thus they fail to serve their purpose. Furthermore, avoid mixing up the terms and definitions of safety systems, safety functions etc. with those used to explain the concept of barriers (e.g. barrier element and -function). While all terms may be applied, if it is not made clear how they relate to each other, this may be a source of unnecessary confusion.

This chapter presents a set of coherent definitions and examples of what they refer to in real life. It also discusses the similarities, differences and relationships between different terms. The definitions are based on a review of available definitions, comments and feedback from rig companies, and industry experience. Efforts have been made to capture relevance against expectations from regulatory bodies.

Good practice 4

Establish company definitions of barrier function, barrier elements and other associated terms required to explain the concept of barriers.

From a risk perspective, the notion of barriers being either preventive or mitigating translates into reducing the probability and consequence of a hazardous event. This can be illustrated through barrier diagrams, such as Bow-Tie (see Figure 3-1).

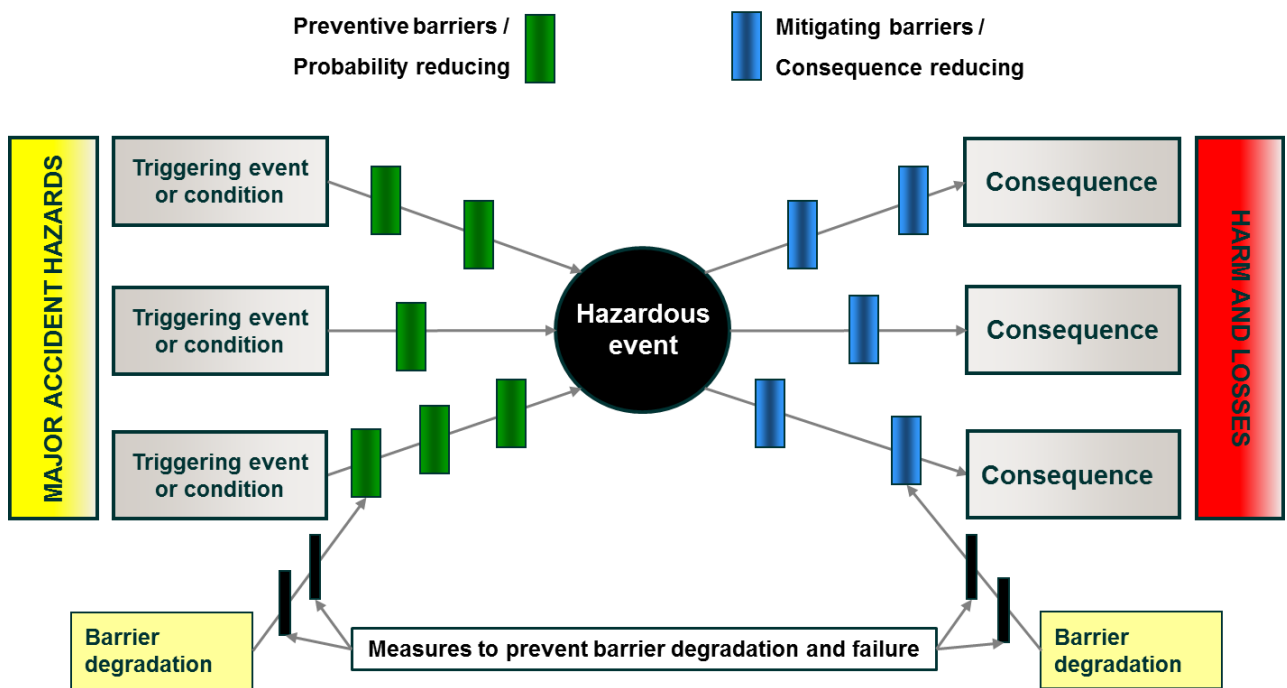


Figure 3-1: Bow-Tie barrier diagram

3.1 Barrier function

As described in the definition of barriers, barriers are intentionally established (i.e. implemented) with an explicit, safety related purpose in mind. The purpose, or role, of a barrier is referred to as a *barrier function*. It can easily be defined by answering two simple questions about a barrier:

- Purpose: Why is it necessary?
- Role: How does it work?

For example; drilling fluid, or mud, prevent well kicks (why; the purpose) by exerting hydrostatic pressure (how; the role). Another example; the blowout preventer, or BOP, prevents blowouts (obviously) by shutting in or sealing off the well.

Barrier function

The purpose or role of a barrier.

To fully understand how barrier functions work it is useful to separate between main- and sub-barrier functions. The concept of barrier main- and sub-functions can be used to explain how different barriers alone or together work to prevent and/or mitigate hazardous events.

The purpose of a barrier represents the barrier main-function which, if successfully realized, should have a direct and significant effect on the hazard and/or event sequence. Examples are "prevent blowout", "maintain position" and "reduce fire load" (see Table 3-1).

Barrier sub-functions represent the roles performed by various barriers that are necessary to realize the barrier main-function. Examples of sub-barrier functions are "detect kick", "shut in well", and "circulate out kick" – all which are required to realize the barrier main-function "prevent blowout". If one or several of the barrier sub-functions fail, the barrier main-function may be potentially weakened or lost. To exemplify, it may be futile to shut in the well if the kick is detected too late.

Table 3-1: Examples of barrier functions

Barrier functions		Purpose
Preventive barrier functions	Prevent impact	Prevent damage to installation and equipment by ships, dropped objects etc.
	Maintain position	Prevent potential major accidents caused by loss of position or stability.
	Prevent well kick	Prevent loss of well control, i.e. preventing fluids from flowing unintentionally from the formation into the wellbore.
	Prevent blowout (topside or subsea)	Prevent hydrocarbon from surfacing, i.e. preventing fluids flowing unintentionally from the wellbore to the external environment.
	Prevent leaks	Reduce likelihood of leaks.
Mitigating barrier functions	Minimize leakage	Reduce size and duration of a leak.
	Prevent ignition	Prevent formation of an ignitable gas cloud. Remove or reduce intensity of ignition sources. Reduce probability of exposure (prevent contact between flammable material and the ignition sources that are required to remain in operation).
	Mitigate explosion effects	Mitigate the consequences of an explosion.
	Reduce fire load	Reduce duration and intensity of fire.
	Prevent escalation	Includes both internal (between equipment) and external escalation (between areas).
	Ensure effective escape	Enable quick, reliable and safe escape.
	Ensure effective rescue	Enable quick, reliable and safe rescue.
	Ensure effective evacuation	Enable quick, reliable and safe evacuation.

There are several reasons for why a functional approach to barriers is useful. The most obvious is Section 5 in the Management regulations stipulating that the function of barriers shall be known. Furthermore, understanding the barriers' functions will also assist to establish correct requirements for how barriers shall perform. E.g. if one of the barrier functions of a BOP is identified to be "seal off well by shearing drill string" a performance requirement can be made for what type of pipes the shear ram shall be able to cut, how fast, and more. Performance requirements are covered more in detail in later chapters (e.g. see chapter 0).

3.2 Barrier element

A wide range of systems, structures, personnel and tasks are responsible for realizing (i.e. performing) various barrier functions. Such measures are referred to as technical or operational *barrier elements*.

Barrier element

Technical, operational or organisational measures which alone or together realize one or several barrier functions.

Comment:

“Realize” means performing barrier functions when required.

For practical reasons, such as identifying and managing barrier elements, it is necessary to further define what is meant by technical, operational and organisational measures. Drilling rigs and ships are equipped with a wide range of systems, structures and other design features which have barrier functions. This is referred to as *technical barrier elements*.

Technical barrier element

Engineered systems, structures, or other design features which realize one or several barrier functions.

Technical barrier elements can further be divided into two main categories – those that do and those that do not alter shape state or condition in order to perform a barrier function. The former is commonly referred to as active or functional barrier elements, while the latter is often called passive or structural barriers. Active barriers can be characterized by being dependent on actions of an operator, a control system and/or some energy sources to perform their functions. Passive barriers refer to measures integrated into the design of the platform or vessel, and do not require operator actions, energy sources or control systems to perform their functions.

Examples include:

- **Active / functional:** Fire and gas detectors, fire dampers, sprinklers, emergency shutdown valves, PA, communication equipment, BOP, choke and kill system, etc.
- **Passive / structural:** Fire and explosion walls, casing, cements, 500m safety zone, passive fire protection, drains, escape routes, temporary refuge etc.

There is no prescriptive list or overview available which pre-defines what the technical barrier elements are, and on which detail level they shall be identified. What constitute a barrier should be based assessments of the hazards involved with the rig’s technology-, operation- and regulatory- regime (see barrier analysis in chapter 5.1). The levels of detail on which technical barrier elements are identified depend much on the systems in question. Some systems are large and complex, while others are simpler and made up of fewer parts. For technical barrier elements under the category of “active fire protection”, a suitable detail level can be:

- Fire water supply (pumps and associated equipment)
- Fire water ring main and distribution pipework
- Fire hydrants, hoses and fire water monitors
- Water spray/ foam deluge systems
- Water mist systems
- Helideck and refuelling fixed foam system
- Dual agent skids for the helideck (powder and foam)
- Aragonite extinguishing systems

Technical systems can be broken down to the tiniest screw. Thus, a second important factor when deciding on detail level is for which purpose barrier elements are identified. Knowing the barrier elements function, requirements for performance, and how they can be weakened or impaired, are important objectives for identifying barriers which should be considered when determining a preferred detail level.

Some barrier functions are automatically realized by technical barrier elements performing according to a predefined logic when triggered. Other barrier functions are partly automatic or fully manual and rely on operators to perform certain tasks. Such tasks are referred to as *operational barrier elements*.

Examples of operational barrier elements in a secondary well control incident are (note: this is a high level example for illustration purposes):

- To monitor kick detection indicators on various displays and gauges (continuous),
- To perform flow checks and records pit gain in case a kick is suspected
- If a kick is confirmed; to close in the well using the BOP panel
- To perform necessary calculations of well kill parameters (kill sheet)
- To circulate the well using the choke panel and adjust pump rates

As with technical barrier elements, the operational barrier elements can be broken down into very detailed actions, such as "push button on BOP panel". Again, the description detail level must be adjusted to the purpose for which the operational barrier element is documented. When described in e.g. barrier strategies and performance standards, the level should be at a detail level which allows it to be audited and understood by personnel responsible for performing the task or following it up. The mapping and documentation of operational barrier elements is further described in chapter 5.3.1.

Operational barrier element

A task performed by an operator, or team of operators, which realizes one or several barrier functions.

The personnel performing the tasks, i.e. operational barrier elements, are referred to as organisational barrier elements. In a well control situation, organisational barrier elements may include the driller, assistant driller, but also the Toolpusher and other personnel may be involved. For example, in case of well kick during a connection, a roughneck may be responsible for installing a stabbing valve.

Organisational barrier element

Personnel responsible for, and directly involved in, realizing one or several barrier function.

Note: Due to the considerable interrelationship and overlap between organisational and operational barrier elements, it is not considered practical or useful to apply both terms. Consequently, *the term organisational barrier element is not used throughout this report*. Instead it is here argued that the concept of organisational barrier elements can be captured through performance requirements for the operational barrier elements. To illustrate; in case of event X, personnel Z and Y shall be present and responsible, due to their required competence and level of authority. Establishing performance requirements for operational barrier elements is further described in chapter 5.3.1.

The degree of interaction and dependence between operational and technical barrier elements may vary considerably. Some barrier main-functions, such as those associated with well control, rely on a high degree of interaction between operators and technical systems involved. This happens between the operator(s) and various control panels, displays, gauges and alarms, etc. For example, in many cases both the sequence and timing of when various BOP rams are activated depends on operator actions. This human-machine interaction is illustrated in Figure 3-2.

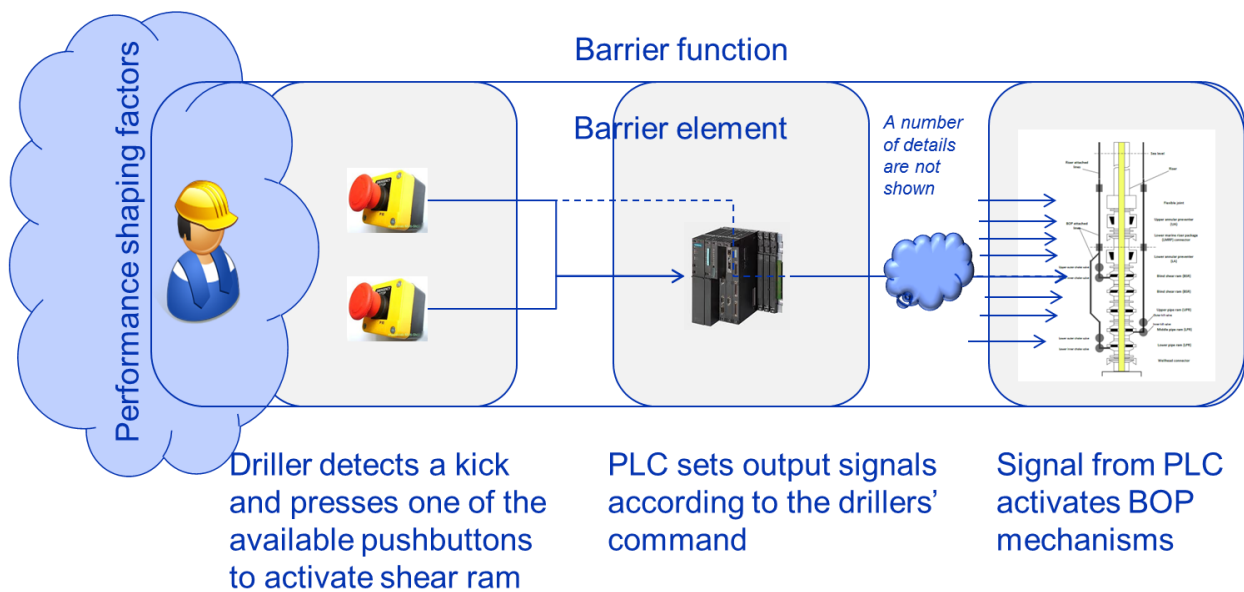


Figure 3-2: A barrier function being realized by organisational, operational and technical barrier elements.

However, it is also important make notice of the various operator *tasks* (i.e. set of actions) leading up to the activation of the BOP or adjustment of pump rates and choke valves. These actions are highly depending on how the kick was detected and diagnosis of situation criticality. This process is not just a result of interpreting information on displays and monitors, but may also depend on communication between the Driller, drilling crew, Toolpusher and others.

Task

A piece of work (physical action or a cognitive process) that an operator, or team of operators, is required to do in order to achieve system goals (Kirwan & Ainsworth, 1992).

Comments:

In the case of operational barrier elements, the system goal is to realize a barrier main-function.

Figure 3-3 shows a simple, sequential task model of which cognitive and physical actions may comprise a operational barrier element. The figure also illustrates the influence of performance shaping factors on task performance. This refers to how procedures, training, workload and other human factors influence how the task is performed (see chapter 5.3.1 for further explanation).

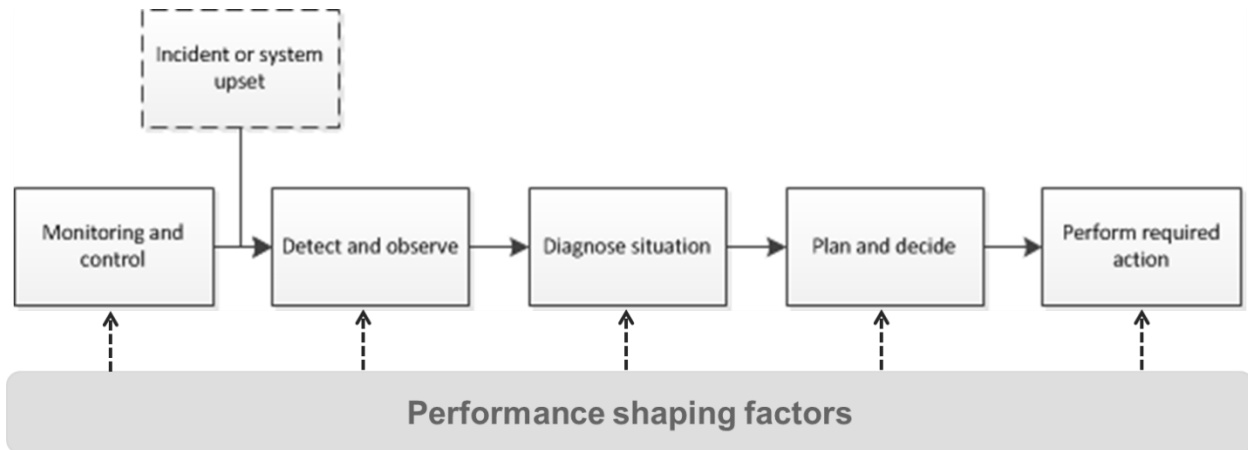


Figure 3-3: Cognitive and physical actions in an operational barrier element

It is important to note that not all operational barrier elements work in close conjunction with technical barrier elements to realize barrier functions. Other operational barrier elements, such as some of those related to emergency preparedness are almost exclusively performed by operating personnel and with little or no direct use of technical barrier elements (e.g. search and rescue).

Furthermore, operational barrier elements should not be confused with tasks having an *indirect* influence on performance of technical barrier elements. This typically includes tasks associated with testing, inspection and maintenance of barrier elements. While these tasks may be critical to safety and environment, they are *not directly* part of realizing barrier functions. For example, in case of drilling into formations with unexpected (high) formation pore pressure, maintenance on the BOP will not help you to deal with the situation there and then.

Table 3-2 gives examples of barrier elements based on the definitions in this report.

Table 3-2: Example of barrier elements

Categories	Technical barrier elements (active)	Technical barrier elements (passive)	Operational barrier elements
Drilling	Mud pumps, de-gasser, BOP rams and preventers, choke & kill line incl. valves, control systems etc.	Wellhead, casing and liner, marine riser, drilling fluid (mud), cement, in-situ formation etc.	Monitoring and control of well pressures and volumes, kick detection, operating BOP and choke/diverter panel etc.
Topside	Fire and gas detectors, PA and alarms, ignition source control etc.	Fire walls, open and closed drains, layout arrangements, piping and flanges etc.	Search & rescue, operating firefighting equipment, etc.
Maritime	Ballasting system, thrusters, position keeping system etc.	Hull, water tight compartments, anchor lines etc.	Operate MOB boat, weather monitoring, emergency and controlled disconnect, ballasting operations, monitor and notify ships etc.

3.3 Safety system and safety function

PSA requirements refer to safety systems, safety functions, and barriers but without any clear distinction between what is what. The definitions may also vary somewhat between different standards. Systems such as those labelled as Fire and Gas, Ignition Source Control, Emergency Power Systems, Active Fire Protection etc. are often used to categorize safety systems which perform safety functions. These system names are also commonly used as titles for Performance Standards (see chapter 0) in which performance requirements for barrier elements are described.

Safety function

Physical measures which reduce the probability of a situation of hazard and accident occurring, or which limit the consequences of an accident (NORSOK S-001; NORSOK Z-008).

Safety system

System which realises one or more active safety functions (NORSOK Z-008).

As can be read from the definitions, the terms safety system and function overlap with barrier element and barrier function. In this report, the following logic applies:

- Safety systems can be identified as barrier elements, or contain several barrier elements. This depends on the level of detail each company chooses to use for defining barrier elements and their corresponding performance standard structure.
- A safety system is not per definition a barrier element. Barrier elements are identified based on whether or not they perform a barrier function for preventing major accidents.
- A barrier function represents a type of safety function which purpose is to reduce major accident risk. Safety functions may also cover measures for reducing occupational accident risk.

Also, the wording used in rules and regulations has implications on the interpretation of safety terms. Section 5 of PSA Management Regulations specifically refers to the term barrier, and not safety system. Consequently, safety systems may not fall under the requirements stipulated in Section 5 unless identified as a barrier.

3.4 Safety critical element

Another common term used by several companies is *safety critical element* (SCE). The term originates from the UK Offshore Installations (Safety Case) Regulations 2005. This regulation states that a record of safety critical elements shall be established for hazards with the potential to cause a major accident. The party responsible for risk must have a verification scheme covering the identified safety critical elements on the installation. An independent and competent person must ensure by examination that the Safety Critical elements are suitable and remain in good repair and that conditions are met.

Safety critical element

Safety critical elements mean such parts of an installation and such of its plant (including computer programs), or any part thereof:

- a) the failure of which could cause or contribute substantially to; or*
- b) a purpose of which is to prevent, or limit the effect of, a major accident;*

(HSE UK, 2005)

Note: There is a lot of discussion in the industry about whether or not a SCE is the same as a barrier element. A reason for people believing that there *is* a difference may stem from generic SCEs lists available (e.g. see Step Change in Safety). These lists usually consist of high level safety systems under which several sub-elements, or equipment, can be identified. These sub-elements can seem more similar to what is typically considered barrier elements on the NCS. Because these safety systems (i.e. SCEs) may also contain measures more relevant for occupational safety (e.g. PPE or life buoy), this can create confusion when trying to make comparisons with barrier elements for major accident hazards. However, such SCE lists must only be considered to be for information purposes (as is often stated) and not absolute. Furthermore, what constitutes a barrier element or SCE shall be the result of an identification and analysis process (e.g. Bow-Tie, HAZID) and not to be based on generic lists. Finally, this process must be based on the *definition* of SCEs which does not explicitly list a set of systems or system levels, but does state that it applies exclusively for major accidents.

Based on the above, there is no obvious reason for this report not to say that SCEs can be considered the same as a barrier element.

3.5 Safety critical task

Humans contribute to major accident risk both in positive and negative ways. Positively, they detect and correct failures in technical systems through e.g. testing and maintenance, they diagnose and respond to system upsets and abnormalities in ways which computers are incapable of, and they perform other tasks which cannot be replaced machinery and automation. Negatively, as with technical systems, humans are prone to error under certain circumstances, such as working under stress, lacking proper training or operating with misleading procedures. This contribution happens through what is called safety critical tasks (SCT), which in many ways can be considered the operational, or human, equivalent to SCEs.

Safety critical tasks

Tasks where human performance contribute positively or negatively to major accident risk, through either:

- Initiation of events;
- Detection and prevention;
- Control and mitigation; or,
- Emergency response.

Definition is adopted from Energy Institute's *Guidance on human factors safety critical task analysis*.

Operational barrier elements can be considered safety critical because they represent operator tasks which play a direct role in realizing preventive or mitigating barrier functions. For example, tasks required to ensure correct mud density and volume can be identified as a critical operational barrier element part of the barrier function "prevent well kick". At the same time, these tasks can be critical because *unsafe actions* can contribute to the initiation of an accident. Losing track of the mud volume, for example, can cause a well kick to occur. This illustrates a certain dilemma; should a task be identified as an operational barrier element because it prevents accidents from occurring, or because incorrect performance can cause an accident to occur? The answer is that this needs to be decided upon when identifying operational barrier elements or SCTs.

Unsafe actions

Actions inappropriately taken, or not taken when needed, resulting in a degraded plant safety condition, such as:

Type A: Actions where operator(s) error introduce a latent failure.

Type B: Actions where operator(s) error contribute directly to initiation of an incident.

Type C: Actions where operator(s) error allows an incident to escalate.

Comments:

Type A actions are commonly associated with inspection, testing and maintenance activities.

Type B actions are typically critical operations, or as part of operational barrier elements performing a preventive barrier function.

Type C actions are often associated with operational barrier elements performing a mitigating barrier function.

See Table 3-3 for further examples of different unsafe actions

However, *the SCT term is broader and covers a wider range of tasks* than just operational barrier elements. Some tasks can be critical because of their indirect influence on barrier performance. This typically refers to inspection, testing and maintenance of technical barrier elements. On the positive side they can also be considered critical because they are means of detecting and correcting technical failures. On the negative side they may introduce *latent failures* if performed incorrectly.

Latent failures

Equipment degradation, incorrect configuration, or other failures which do not initiate an incident when introduced, but contributes to initiation or escalation of incidents in combination with other failures occurring at a later stage.

Unsafe actions are a result of a term that should be used with care; human error. Luckily, few human errors have a negative impact on safety. This is because good practices are in place, such as proven

procedures and good training. However, in those cases unsafe actions may result in critical outcomes, human error should be managed systematically. Well control and emergency preparedness are good examples.

Human error

Out-of-tolerance actions, or deviations from the norm, where the limits of acceptable performance are defined by the system.

Note: As a general rule, personnel shall not be subject to sanctions for committing errors. Humans correct more errors than they cause, for example by working around poor or incorrect procedures, or making faulty technology work. When humans err, it is more likely a result *error producing conditions* than deliberate violations. Only when an operator or team of operators has repeatedly committed errors, despite prior warnings, sanctions can be considered. If violations are a result of company culture, such as pressure to continue production, sanctions should not be applied. While the human condition cannot be changed, but we can change the conditions under which humans work. This should be the principle both for prevention and explanation of human error.

Table 3-3: Examples of unsafe actions

Unsafe actions	Examples
<p>Type A:</p> <p><i>Actions where operator(s) error introduce a latent condition.</i></p>	<ul style="list-style-type: none"> - Wrong line-up of valves and piping arrangement, for example after maintenance or testing → at a later stage, this may cause unexpected pressure build ups, leaks, or unavailability of equipment. This may especially occur if pressure levels or flow rates/routes change a later time. - Incorrect calibration or testing of gas detectors, such as cleaning the detector lens before performing the test → in case of a gas leak, this may cause detectors not working as expected when needed. The detector may not detect intended gas levels if the lens is dirty. - Applying wrong rating levels when pressure testing the BOP, or testing pressure levels in the wrong order → may cause damage to critical components, or the test results may not reflect expected pressure levels in the well. In case of a kick or blowout, the BOP may malfunction or not perform as expected.
<p>Type B:</p> <p><i>Actions where operator(s) error contribute directly to initiation of an incident.</i></p>	<ul style="list-style-type: none"> - Connecting wrong mud pit (e.g. premix) to the active system resulting in circulation of mud with too low density, combined with infrequent, incorrect or omitted mud weight controls → if circulated too long, and if mud s.g. is already close to the pore pressure, this may cause unintentional flow from formations to wellbore. - Exceeding lifting capacities or maloperation of crane and lifting equipment → may cause dropped or swinging object onto critical equipment, such as well testing equipment, well template or subsea pipelines.
<p>Type C:</p> <p><i>Actions where operator(s) error allows an incident to escalate.</i></p>	<ul style="list-style-type: none"> - Shutting in the well too late → If the well is shut in too late, this may contribute to escalation of a well kick, potentially resulting in a blowout. For example, gas may have reached the riser (if the BOP is subsea) and have to be diverted. The pressure build up may become higher than annular preventer is capable of handling, causing erosion and flow paths for the kick.

Unsafe actions	Examples
	<ul style="list-style-type: none"> - Incorrect spacing out of the drill string, or activating BOP rams in wrong order in case of a well kick → may allow flow paths for the kick and hydrocarbons entering the riser. High pressure and flow levels may in turn cause erosion and weakening of BOP functions. - Omitting to disconnect rig from the well in case of e.g. extreme weather → may cause loss of well integrity (e.g. damage to well head and BOP) and in worst case a well control incident. In case of a blowout, omitting to disconnect will expose the rig to hazards (e.g. hydrocarbons) and allow incident escalation.

3.6 Performance shaping factors

Operator task performance, such as in operational barrier elements, is influenced by what is called *performance shaping factors* (PSFs). This refers to *human factors*, such as mental and physical capabilities, but also contextual (e.g. workplace) factors in which the operator is situated. Imagine the case of a well control situation. The driller, drill crew, toolpusher and company man all rely heavily on their competence and experience, procedures (e.g. Driller’s Method), and human-machine interface (HMI) to successfully handle the situation. Social factors also come into play, such as norms concerning work practice, teamwork and leadership. The influence of PSFs on task performance is illustrated in Figure 3-2 and Figure 3-3.

Performance shaping factors

Human, workplace or other contextual factors which have a significant effect on an operator’s or crew of operator’s performance.

Comments:


The term performance shaping factors is also sometimes used about factors which in general have an indirect influence barrier performance, thus including e.g. weather, maintenance, barrier degradation mechanisms, and more. This makes it an “everything and nothing” kind of term, with little added explanatory value. Consequently, in this report, performance shaping factors is exclusively used about factors with significant influence on human performance.

4 BARRIER MANAGEMENT FRAMEWORK

To be able to manage barriers a framework needs to be established, integrated and operationalized in the management system within the rig organisation. Necessary processes and systems to fulfil the framework need to be identified, with relevant information needs, owners and responsibilities. Existing processes, systems and tools for HSE and risk management like QRA, ALARP, SJA, toolbox talk, reporting, communication and training will also have relevance for barrier management. To be able to support the barrier management perspective, some existing documentation or processes structure may have to be adjusted to suite also this prospective.

The framework is divided into:

- Establish and implement barrier management
- Barrier management in operation
 - Monitoring barrier performance
 - Operational risk management



“Establish and implement barrier management” includes identification of barrier elements with description of roles and performance requirements. The barriers should be identifiable; both in the technical hierarchy and in procedures. Program to prevent degradation of barriers needs to be established and implemented. Activities to assure and verify barrier performance needs to be implemented to be able to monitor barrier performance.

“Barrier management in operation” includes a process for monitoring barrier performance and a process for managing risk in operation. Objective of the barrier monitoring activity is to provide decision support for different management levels in the organisation. Risk management in operation can be achieved by considering both activity level and barrier status prior to each (set) of operations to be performed.

Elements to consider in a barrier management framework is visualised in Figure 4-1 and each element is described in Table 4-1.

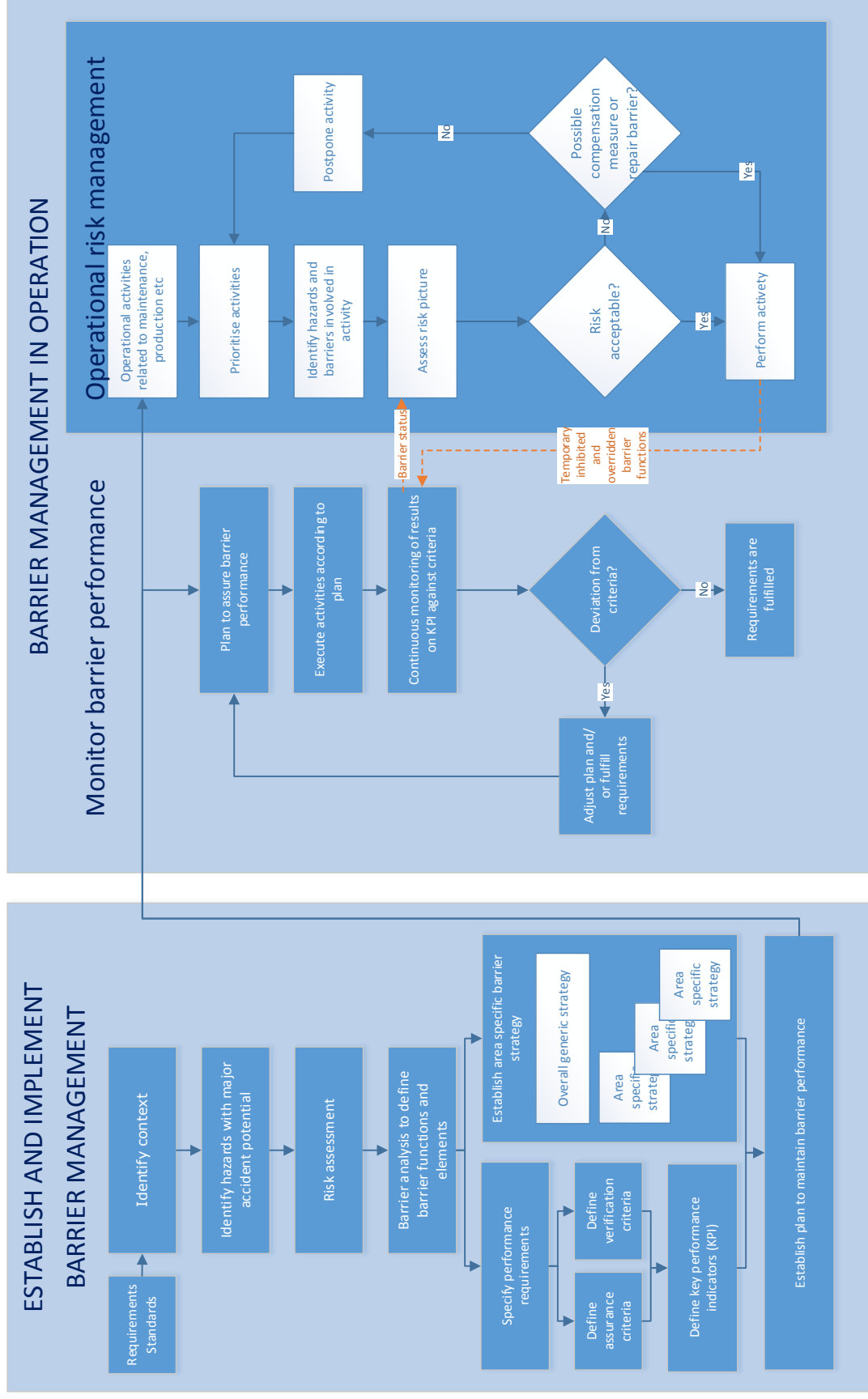


Figure 4-1: Barrier management framework

Table 4-1: Description of elements to consider in a barrier management framework

Phase	Elements	Description of element and where relevance necessary input and output	Reference to Good practice no.
ESTABLISH AND IMPLEMENT BARRIER MANAGEMENT	Identify context	<p>The rig should be described with associated regulatory regime, boundaries and limitations for operation.</p> <p>Input to this element will be rules/standards/class requirements that the unit is designed for. Based on requirements prescriptive barrier elements with performance requirement should be identified as an output.</p> <p><i>(e.g. all air inlets shall be equipped with 3 gas detectors, detecting 20% LEL, raising alarm no later than 5 seconds after exposure to gas concentrations above 20%LEL).</i></p>	1
	Identify hazards with major accident potential	<p>Use "HAZID (from risk assessment)" to identify hazards and evaluate if each hazard can realize hazardous events with a major accident potential (MAH). The HAZID should also identify existing and any required additional requirements to control the MAH picture in question. It is recommended that this evaluation is done per area.</p> <p>Output will be a list of MAH per area and argument for hazards that are not included. This list should be included in the barrier strategy.</p>	3
	Risk assessment	<p>The risk assessment is to evaluate and identify if additional controls are required to prevent or mitigate the actual accidental loads. The risk assessment will also quantify functional requirements to the barrier elements.</p> <p><i>(e.g. "area coverage" for gas detection in an area - well test area - could be at least 5 detectors in operation to obtain sufficient "sensitivity" or "detection probability" for the area.)</i></p>	2
	Barrier analysis to define barrier functions and elements	<p>For each MAH within each area identified in the HAZID, barrier functions to prevent and mitigate the MAH should be further detailed. For each function barrier elements as controls should be included. It is recommended that this step aligns definitions and terms as far as possible to the technical hierarchy in the maintenance system to allow for synergies in feedback reporting from testing & repairs etc.</p> <p>Output from this element can be barrier diagrams (e.g. Bow-Tie) and barrier matrices or tables and should be included in the barrier strategy.</p>	4 5 6 7

Phase	Elements	Description of element and where relevance necessary input and output	Reference to Good practice no.
ESTABLISH AND IMPLEMENT BARRIER MANAGEMENT	Specify performance requirements	Develop Performance Standard (PS), to describe performance requirements for function, integrity and survivability for all safety critical failures of identified barrier elements including PSF's posing threats to performance of the element.	9 10 11 12 13 14 30
	Define assurance criteria	Based on the safety critical failures identified through FMECA or HRA (see "Establish plan to maintain barrier performance") measures to assure performance of the barrier and assurance criteria for "allowable" degradation should be established. These activities should be included in the PS, in the CMMS and in the training program.	21
	Define verification criteria	Based on the performance requirements verification activities and acceptance criteria should be defined to ensure established processes for managing performance of barriers are working as intended. These activities should be included in the PS and in audit programs.	23
	Define key performance indicators (KPI)	To be able to monitor barrier performance information relevant for early warning about deterioration and impairment of barrier functions must be identified.	24 25 29
	Establish area specific barrier strategy	An overall generic strategy for the rig supported by area specific strategies should describe MAH in area, the role of barrier functions related to this MAH and barrier elements. The output is a document relevant for all of the involved parties.	8
	Establish plan to maintain barrier performance	All barriers will be submitted to degradation due to wear and tear. Degradation may cause critical failure modes. Based on the FMECA or HRA safety critical failures should be defined for barrier elements. Based on these safety critical failures activities and intervals to ensure performance should be identified and stored in CMMS, training programs and systems, processes and tools for safe planning and correct execution of tasks.	15 16 17 18 19 20 22

Phase	Elements	Description of element and where relevance necessary input and output	Reference to Good practice no.
MONITOR BARRIER PERFORMANCE	Plan to monitor barrier performance	The assurance and verification activities scheduled make a plan for monitoring barrier performance.	27 28 31
	Execute assurance and verification activities according to plan	It is important that the assurance activities are performed according to test procedures and reported correctly.	26
	Continuous monitoring of results on KPI against criteria	Based on the test results and information relevant for early warning of deterioration of barriers KPI should be monitored and evaluated against established criteria.	
	Deviation from criteria?	Based on evaluation of the barrier status related risk should be assessed and communicated.	
	Requirements are fulfilled	Barrier status is accordance to the performance requirements.	
	Adjust plan and/or fulfil requirements	The performance requirements are not met. The plan for ensure performance of barriers should be adjusted by introducing more efficient activities or changing the interval	
	Operational activities related to maintenance, production etc.	Based on input from different processes as drilling, maintenance, management of change etc. activities to facilitate safe and efficient operation will be proposed.	
	Prioritise activities	Different levels of planning will to a certain extent evaluate, prioritise and coordinate activities but at the sharp end the Work Permit process and the evening meeting needs to risk assess and prioritise among proposed activities to be performed the next day. These activities can be grouped in: Activities that require WP, normal routine work. Most rig companies have established systems, processes and tools for managing risk in these activities.	
OPERATIONAL RISK MANAGEMENT	Identify hazards and barriers involved in activity	This element includes an identification of hazards the activity may cause and relevant requirements for the activity to be performed. Technical and operational barriers to prevent and control these hazards need to be identified. Competence on risk and technical safety are vital to perform this element.	

Phase	Elements	Description of element and where relevance necessary input and output	Reference to Good practice no.
	Assess risk picture	With knowledge of barrier status the risk picture in the activity and overall on the rig must be assessed.	
	Risk acceptable?	This element includes an evaluation of the risk picture in the activity itself and based on the risk picture on an overall rig level. If all identified requirements are met the risk is acceptable.	
	Possible compensation measure or repair barrier?	If risk picture in the activity is not acceptable due to requirements not met or impaired barriers a solution can be to introduce compensating measures or fixing barriers. If compensation measures introduced are long term/permanent the Performance requirements in PS should include this information.	
	Postpone activity	If risk level in activity is not acceptable the activity should postponed and evaluated for re-planning if still relevance for safe and efficient operation.	
	Perform activity	If risk level is acceptable and requirements are met the activity can be performed.	

5 ESTABLISH AND IMPLEMENT BARRIER MANAGEMENT

A pre-requisite for successful barrier management in operations is that the principles of barrier management are implemented as part of the rigs design and management system. Although it is outside scope of this document to describe barrier management in the design phase of a rig, it is still necessary to revisit some key topics. For rigs in operations, some preparations normally made in the design phase have to be considered. This especially concerns documentation of rationale behind why the barriers have been implemented in the first place, and what their requirements for performance are.

This chapter explains the purpose and scope of documentation which is essential when it comes to forming the basis for barrier management, namely:

- Barrier analysis (Bow-Tie's and barrier matrices/tables)
- Performance requirements documented in performance standards
- Area specific barrier strategies

For more details on implementation of barrier management in design, see PSA's document titled "Principles for barrier management in the petroleum industry" (PSA, 2013).

5.1 Barrier analysis

Section 5 of PSA's Management Regulations stipulates that personnel shall be aware of what barriers have been established, their functions, and performance requirements.

Management regulations, section 5

"Personnel shall be aware of what barriers have been established and which function they are intended to fulfil, as well as what performance requirements have been defined in respect of the technical, operational or organizational elements necessary for the individual barrier to be effective."

In order to understand and be aware of the rig's barrier elements and their functions, a systematic approach is recommended to capture and structure the complexity of barriers. To manage the rig's barriers you must first know what they are and what they do. This is the main objective of a *barrier analysis*. By tying everything together it allows a systematic approach to management of barriers. The main purpose is to "paint the complete picture" for a given area where hazards and hazardous events are linked to corresponding preventive and mitigating barrier functions, barrier element, their role and performance requirement for each element and function. Once this picture is established it can be used in planning in operations to identify or highlight barrier elements in "active service" and can assist in identifying the status of the specific elements to consider for the specific task. The result from a barrier analysis will also be a startingpoint for identifying performance requirements. See example Table 5-1 and Table 5-2.

Good practice 5

Perform a barrier analysis, covering each installation areas, with the following objectives:

- Identify major accident scenarios, incl. hazards, hazardous events and consequences (e.g. through a HAZID)
- Identify barrier main-functions necessary to prevent hazardous events and control/mitigate their consequences
- Identify barrier elements responsible for realizing the barrier main-functions
- Describe the role of each barrier element, explaining how it contributes to the barrier main-function
- Describe the interactions and interfaces between the different barrier elements

Comments:

There is no standard approach to barrier analysis, but a combination of barrier diagrams (e.g. Bow-Tie) and barrier matrices or tables are commonly used.

The barrier analysis should be based on a risk or accident model illustrating how the barriers contribute to risk reduction (i.e. either as preventive or mitigating). For identification of major accident scenarios, review existing HAZID from QRA or Safety Case, and identify hazardous events within each area for which barrier functions and barrier elements will be identified. Hazards and hazardous events which do not have the potential to escalate into major accidents can be excluded from further evaluations.

The results can be structured and visualized differently dependant of the end use. E.g Table format of the results is found a effective tool to assist in develop/verify performancew standards and to assist in developing PM programme to identify assurance activities. Other use commonly use of Barrier diagrams such as Bow-Tie's or Swiss Cheese are for visualizing results for communication purposes. Several different software solutions are available for making Bow-Tie or other types of barrier diagrams. Most tools allow for visualizing barrier main-functions and barrier elements responsible for realizing the function. The diagram set-up is ultimately a matter of company preferences, e.g. depending on how barriers are defined and for what purpose the Bow-Tie is developed. However, a few "rule of thumbs" exist:

- Avoid complex and detailed Bow-Tie's, or alternatively enable Bow-Tie's to be presented with different levels of detail. Overly complex Bow-Tie's can become follow and understand and personnel can be discouraged to use them.
- Avoid confusing measures implemented to avoid barrier degradation (e.g. corrosion monitoring) with actual barriers implemented with a specific purpose of preventing or mitigating hazardous events (e.g. containment).
- For identifying barriers, include barrier functions which has a significant effect on the Bow-Tie event sequence. This means that barrier sub-functions such as "gas detection", or barrier elements such as "gas detector", should not be included as a single barrier in the Bow-Tie diagram. If single barrier elements are included in the Bow-Tie's event sequence, this may:
 - give a false or incorrect impression of how well safeguarded the system is,
 - create a confusing sequence of the barriers in terms of when they are required or activated throughout the accident event chain,
 - will not describe the purpose, i.e. function, of the barrier elements
- Many of the Bow-Ties will have similar consequences. This is particularly relevant for "loss of life". Barrier functions to ensure safe rescue, emergency and evaluation will most likely be the same for many of the hazardous events. In this case a Bow-Tie for "safe evacuation" can be made instead of repeating same barriers in every Bow-Tie.

There is no “book of rules” for describing barrier main-functions, but the examples provided in Table 3-1 are often used. Barrier elements (e.g. BOP) responsible for performing the barrier main-functions can be identified by asking “how is the barrier main-function realized?” (e.g. “how do we prevent blowout?”) . The answer to this question will be the role of barrier elements (e.g. “shut in well”), also called barrier sub-functions. The other way around, the role of barrier elements can be verified by asking “why” (e.g. “why do we shut in the well?”), to which the barrier main-function will be the answer (e.g. to prevent blowout).

Good practice 6

Define the purpose and application areas of Bow-Ties.

Comments:

For example, Bow-Tie diagrams can be used to:

- Describe major accident scenarios
- Identify barriers as either preventive or mitigating
- Link barriers to specific hazards (triggering events/conditions) and consequences
- Graphical presentation of area specific barrier strategies
- Create awareness about which barriers are in place (e.g. as part of training and maintenance)

Bow-Tie software also includes functions to identify barrier degradation mechanisms (e.g. corrosion, unsafe acts etc.) and measures maintain barrier condition and performance (e.g. maintenance, procedures, training etc.).

A Bow-Tie may look something like the example in Figure 5-1 developed for the major accident scenario “blowout on drill floor”.

Major accident scenario

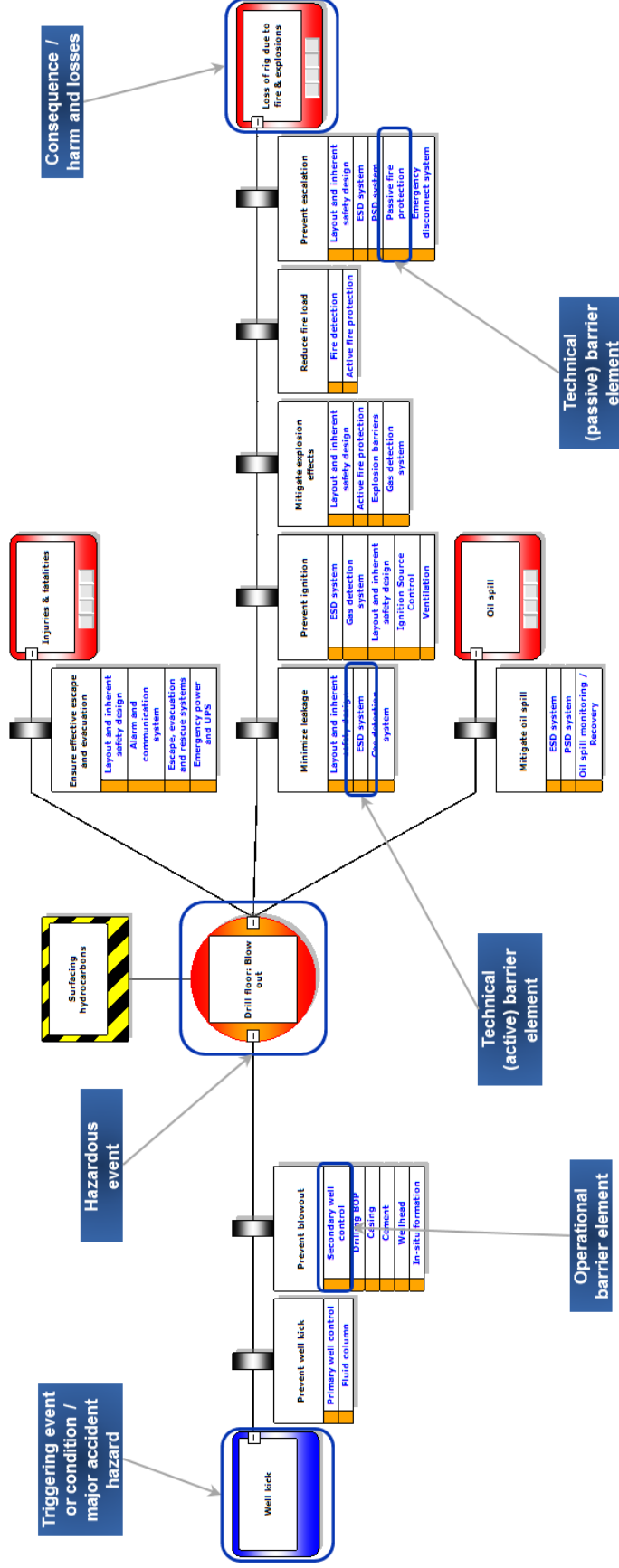


Figure 5-1: Example of Bow-Tie diagram

Figure 5-1 illustrates one way of setting up Bow-Tie diagrams. In this case it was chosen to include barrier main-functions and high level barrier elements. For each barrier element, a list was made to further specify what type of equipment and tasks were involved, and what their role (i.e. barrier sub-function) was in performing the barrier main-function. For example, relevant tasks under secondary well control were listed (e.g. Driller's Method).

Bow-Ties' are effective tools for graphical presentation of barriers but has limitations when it comes to further documentation needs. The format is not suitable for including detailed system descriptions, and barrier elements are described on a high level. The next step is then to identify and describe more in detail which equipment, structures and tasks should be categorized as barrier elements. This determines specifically what is going to be followed up as part of the barrier management process. For this purpose various barrier tables and matrices are effective tools. They accommodate input or use of references from other information sources such as equipment lists in the maintenance system (e.g. technical hierarchy) and task descriptions (e.g. procedures). This is explained further in chapter 5.5 and 5.6.

Good practice 7

Develop barrier tables and matrices to capture links between:

- *Different main areas of the Installation*
- *Hazards*
- *Hazardous events*
- *Barrier functions*
- *Barrier elements/ SCE's*

Comments:

The tables and matrices are suitable formats for documenting:

- Equipment, structures, tasks representing barrier elements (see chapter **Error! Reference source not found.**)
- Performance requirements for barrier elements (see chapter 0)
- Known safety critical (barrier) failures to be prevented (see chapter **Error! Reference source not found.**)

Furthermore, the barrier analysis is used as input for:

- Developing Performance Standards (see chapter 0)
- Establishing area specific barrier strategies (see chapter 0)
- Linking performance shaping factors (procedures, training etc.) to operational barrier elements (see chapter 5.3.1)
- Establishing indicators for performance monitoring (see chapter 6.1)

5.2 Barrier strategy

Management regulation, Section 5

“The operator or the party responsible for operation of an offshore or onshore facility, shall stipulate the strategies and principles that form the basis for design, use and maintenance of barriers, so that the barriers' function is safeguarded throughout the offshore or onshore facility's life.”

In order to fulfil this requirement a strategy document is commonly established, although it is not strictly required to have gathered all this information in one document. The document is normally referred to as the Safety Strategy or Barrier Strategy and it is stated that it should be area specific.

Barrier Strategy

The results of a process that, based on the risk picture, describes what barrier functions and barrier elements shall be (have been) implemented in order to reduce risk. (PSA, 2013).

The purpose of the barrier strategy document is to describe for all of the involved parties the link between hazardous events, barriers and requirements. Normally the strategy is divided in two; one generic part and one area specific. The generic part describes:

- Inherent safe design principles like layout, orientation of rig (weather vaning vs fixed orientation), fail safe principles for safety features (e.g. energize to activate vs. de-energize to activate).
- an general overview of hazard
- brief description of safety systems in place to manage these hazards
- processes and systems in place for managing major accident risk and safety barriers.

Some operators have developed “area risk maps” as part of the QRA or safety case. These documents describe the potential hazardous events and risk picture in each area. This information is regarded valuable input as starting point for developing “area specific barrier strategies”. In these the hazards within the area are associated with corresponding safety systems. In the area specific barrier strategy the items in the bullet list below should be included for each (group) of areas:

- Potential hazards (local risk picture) including typical scenarios from the most probable scenarios
- Barrier functions in place to prevent and mitigate hazards
- Performance requirements on a high level (ref. performance standard)
- Risk Maps including barrier function associated with the area specific hazards

Examples of communicating the relationship between the hazards, barrier functions, barrier elements and their requirements can be illustrated as in Table 5-2, or by using Bow-Ties (ref. Figure 5-1) and linking them up to the area they have relevance for.

Good practice 8

Establish and document barrier strategies

Comments:

Design and Construction phase:

A barrier strategy describes chosen philosophy during the design/engineering process. It also links each area to relevant hazards, barrier function, barrier elements and performance standard so that the reasons for establishing the given performance requirements are understood in relation to the risk picture.

The barrier strategy should preferably be established as an integrated part of the design and construction process, as the decisions on what safety systems to install and evaluations of how they will work together are made during this phase. The overall conceptual strategies must be documented, including:

- Inherent Safe Design principles, e.g. type of installation, arrangement of main areas, size & shape of main areas, orientation, manning level etc.
- High level strategies, e.g. fail safe functions, solutions not considered to be common engineering practice
- Implemented barrier elements/safety critical elements

The strategy needs to be area specific, which can be achieved by the following steps:

- Define "main areas" - as in QRA;
- Map relevant main accident categories to each main area
- For each area; map preventive and mitigating barrier functions with associated barrier elements.
- For each area; visualize results in e.g. Bow-Ties or table format to show role of each barrier element.

Operation phase:

When establishing a barrier strategy document for a rig in operation, information can be gathered from relevant documents, interviews, workshops etc. basically following the same process as described in chapter 5.2. However developing strategy is based on "actual design" rather than how to "arrive at a good design".

In operation the barrier strategies can be used to identify barriers in "operation" during a specific operational mode / activity.

Table 5-1: Example of format for an area specific barrier strategy

Topside blowout				
Operational phase: Drilling				
Probability reducing barriers				
In order to prevent influx, control kicks and prevent hydrocarbons from reaching the surface, the strategy presented below applies.				
Hazard	Barrier function	Barrier system	Strategy	Performance requirements
Formation / reservoir pore pressure	Prevent influx	Primary Well Control	In order to prevent influx, ensure overbalance through sufficient planning, ensuring correct mud weight and circulation. Ensure well integrity by sufficient well design, e.g. by ensuring that casing and cement are designed to maximum anticipated well pressures.	PS – Well Control
		Well Monitoring	Prevent influx by manual and automatic monitoring of mud weight in order to ensure correct mud properties and volumes for loss/gain control. Continuously monitor drilling parameters and trends in order to detect abnormal conditions (change in ROP, drill pipe torque, bottom hole pressure). Ensure proper communication and understanding between mud logging company and drill crew.	PS– Well Control
	Control kick	Well Monitoring	Detect and confirm kick through monitoring of active volumes and performing flow check.	PS – Well Control
		BOP	Close annular preventer, space out and monitor shut in pressure in order to shut in well and prepare for well kill.	PS – Well Control
		Emergency Well Control	Circulate out kick according to chosen method and degas the mud in order to remove gas from the well. Kill well according to preferred method depending on situation.	PS – Well Control
	Prevent HC to surface	Emergency Well Control	Divert hydrocarbons with LP and HP diverter systems in order to avoid exposure to the rig.	PS – Well Control
		BOP	If the situation cannot be controlled, seal off the well and prepare to relocate.	PS – Well Control
	Prevent exposure of rig	EDS & LMRP	Emergency Disconnect System (EDS) disconnecting the Lower Marine Riser Package (LMRP) from the remaining BOP Stack	PS – Well Control
		Positioning Systems	In order to prevent hydrocarbons from exposing the rig, move the rig away from location by manual operation of the positioning system, following the rig move procedures.	PS – Positioning Systems
		Main Power Generation	Upon moving rig from location, the main power system is essential for successful operation.	PS – Main Power Generation & Emergency Lighting

When establishing barriers for managing risk it is important to demonstrate the link between hazards, hazardous event, barriers and requirements. In operation it is important to evaluate how barrier degradation and failure influence the risk picture. This relationship can effectively be communicated by using barrier matrixes as illustrated in Table 5-2 in the barrier strategy.

Table 5-2: Example of barrier matrix showing links between performance standard, barrier function and hazardous event for a specific area

Drilling area		Hazardous event				
Performance standard	Barrier function	Topside blowout	H2S release	Shallow gas blowout	High energy collision	Loss of structural integrity
Well planning	Control kick	x				
	Prepare for H2S		x			
	Prevent unexpected shallow gas			x		
Well control system	Control shallow gas			x		
	Control H2S in well flow		x			
	Control kick	x				
	Divert hydrocarbons	x		x		
	Prevent ignition	x		x	x	
	Prevent unexpected shallow gas			x		
	Seal off well	x		x		
Secure the well					x	x

5.3 Performance requirements

After identifying all barrier elements in the barrier analysis, each element should be grouped under safety systems categories (see sect. 3.3). The next step is then to establish performance requirements necessary to ensure that barrier elements perform their required functions as means for either preventing or mitigating the chain of events.

Facilities regulation, Section 8

"Requirements shall be stipulated for the performance of safety functions".

Comments:

In this context, safety functions may represent barrier functions.

For guidance on how to establish the requirements the following standards can be used:

- NORSOK S-001
- ISO 13702
- IEC 61508
- Norwegian Oil and Gas' Guideline No. 070

Other relevant standards are, but not limited to:

- DNV-OS-A101 Safety Principles and Arrangements
- DNV-OS-D202 Automation, Safety, and Telecommunication Systems
- DNV-OS-D301 Fire Protection
- DNV-OS-E101 Drilling Plant

The performance requirements will mainly be based on those stipulated by regulatory bodies, corporate governing documents, or recognized industry standards. In addition, installation specific requirements identified in reliability-, maintenance criticality-, risk- and safety- studies may apply. The requirements may cover the capacity, reliability, accessibility, efficiency, ability to withstand loads, integrity and robustness.

The complete list of performance requirements for safety systems is commonly referred to as the system's *Performance Standard* (PS). The PS is outlining the capacities to which barrier elements are expected to perform. The objective of the PS is to add supplemental safety requirements in addition to those specified by authority requirements, class rules and standards. The PS shall be based on the barrier strategy documents and these should be read in conjunction with each other [Adapted from NORSOK S-001]. The specific safety performance standards shall ensure that barriers elements and functions:

- are suitable and fully effective for the type hazards identified,
- have sufficient capacity for the duration of the hazard or the required time to provide evacuation of the installation,
- have sufficient availability to match the frequency of the initiating event,
- have adequate response time to fulfil its role,
- are suitable for all operating conditions".

An example of how the first page of a PS may look is given in Table 5-3.

Good practice 9

For each barrier element (as defined in 0), establish the following performance requirements:

- **Function** - *The functional criteria will include appropriate definition of requirements to the relevant functional parameters of the particular barrier; i.e. the essential duties, capacity or response that the system/function is expected to perform to manage the major accident hazards (ref. ISO 13702).*
- **Integrity** - *The integrity criteria will include appropriate definition of and requirements to the relevant reliability and availability parameters of the particular barrier; e.g. probability of failure on demand, failure rates, demand rates, test frequencies, deterioration of system components, environmental impairment etc. (ref. ISO 13702).*
- **Survivability** - *Criteria determining how a barrier can withstand accidental loads and will remain functional after a major incident, i.e. under the emergency conditions that may be present when it is required to operate (ref. ISO 13702).*

Comments:

It is important that performance requirements cover all barrier elements.

Table 5-3: Example of PS first page

PS Active Fire Protection					
Installation			Performance standard (PS) ID		Document number
Issue No.	Revision request no.	Date	Prepared by	Verified by	Approved by
1		04.10.2013	EKO		
Some Barrier elements commonly categorized under “Active Fire Protection”					
<p>'The equipment associated with this performance standard comprises:</p> <ul style="list-style-type: none"> - Fire pump systems; - Fire water ring main and distribution pipework; - Fire hydrants, hoses and fire water monitors; - Water spray/ foam deluge systems - Water mist systems; - Helideck and refuelling fixed foam system; - Dual agent skids for the helideck (powder and foam); - Aragonite extinguishing systems 					
PS Hierarchy					
<pre> graph TD Root[Extinguish fires and provide protection to structure and equipment] --> B1[FW pump systems, ring main & distribution pipework to provide required amount of FW to fires] Root --> B2[Other means of fire fighting] B1 --> B1_1[Fixed FW systems with automated initiation] B1 --> B1_2[Manual application of FW to fires] B1_1 --> B1_1_1[Deluge systems] B1_1 --> B1_1_2[Sprinkler system] B1_1 --> B1_1_3[Foam systems] B1_2 --> B1_2_1[Monitors] B1_2 --> B1_2_2[Fire hoses] B2 --> B2_1[Portable foam systems] B2 --> B2_2[Argonite systems] B2 --> B2_3[Dual agent systems] B2 --> B2_4[Waterfog systems] </pre>					
Typical examples of “Role of barrier elements”					
<p>The role (barrier sub-function) of barrier elements is to provide quick and reliable means of extinguishing fires and to limit potential escalation. This includes:</p> <ul style="list-style-type: none"> - Extinguishing fires; - Controlling the spread of fires and preventing escalation by cooling structures and hydrocarbon containing equipment; - - Reducing explosion overpressures. 					
Relevant hazardous events from Bow-Tie			Prevention / mitigation		Bow-Tie
Shallow gas blowout			Mitigation		XX
Etc.			Etc.		Etc.
Interface & interactions with other safety systems			Function and reason		PS number
Fire detection			Start of fire pumps upon confirmed fire		XX

Etc.	Etc.	Etc.
References documents and basis for requirements		
The basis for the PS' requirements is derived from the documents in the reference list.		
External	Internal	
Source	Doc. nr.	Doc. Name
DNV MOU Part 4, Chapter 6		

An example of one requirement to the firewater distribution system is given in Table 5-4. In addition to the information given in this table, the requirements can also be linked to checklists containing assurance and verification activities. The assurance activities may consist of both measures, criteria and frequency for execution, while verification activities may include verification check points. Establishing assurance and verification activities are further described in chapter 5.7 and 5.8.

Table 5-4: Example of one performance requirement for active fire protection

Safety (sub-) system	Role	Requirement Reference No.	Sub-element	Performance requirement	Regulation codes, standards and internal requirements
FW pump systems, ring main & distribution pipework	Provide required amount of FW to fires.	F 1	FW pumps and FW ring main	<p>The FW supply shall be sufficient to cover area with the largest FW demand plus the adjacent fire area with largest demand. The FW demand shall include supply to two hydrants.</p> <p>The maximum firewater demand arises from a fire that triggers the deluge system in the process, manifold and KO Drum areas simultaneous with deluge in the drilling area, requiring 35,063 litres/min (2,103 m³/hr.).</p> <p>Firewater shall be available ...</p>	<p>NORSOK S-001, rev. 4, 20.4.2</p> <p>NORSOK S-001, rev. 3, 10.7.2</p>

Good practice 10

Document the performance requirements in performance standards.

Comments:

Performance requirements should preferably be established as an integrated part of the design and construction process, as the decisions on what safety systems to install and what specifications they should meet are made during this phase.

When performance requirements are established for rigs in operation this may be carried out as a facilitated process, with involvement from relevant personnel. Regulatory requirement can be used as a starting point before adding the rig specific requirements. In any case, reference should be given to the regulation, or other documentation, that is the basis for establishing the requirement.

In order to facilitate follow-up of the established requirements during operations the performance requirements should be linked to assurance and verification related information. A good way of doing this is to include the assurance measures and criteria and verification activity (see sect 6 for details) with frequency in the performance standard document. The columns included in the PS may correspond to the bullet points below.

Performance requirement:	Assurance related information:	Link to barrier analysis:
- Role/function	- Assurance measure No.	- Comments
- Barrier Element	- Assurance measure	- Applicable for Bow-Tie No.
- Req. ID	- Assurance criteria	- Corresponding barrier function
- Performance requirement	- Assurance frequency	- Equipment group fulfilling this barrier element
- Ref.	- Responsible party	
	Verification related information	
	- Verification activity No.	
	- Verification activity	
	- Verification frequency	

5.3.1 Performance requirements for operational barrier elements

Performance requirements for operational barrier elements are not as easily obtained as for technical barrier elements. The main objective with managing operational barrier elements is to increase human reliability and reduce human errors, by ensuring performance according to established performance requirements.

As with technical barrier elements, a pre-requisite for managing operational barrier elements is that they are identified. If some sort of barrier analysis has been performed they may include operational barrier elements or give indications of barrier functions in which operational barrier elements performs an important function. Bow-Tie's often just describe operational barrier elements using brief task descriptions or references to relevant procedures. If so, a more detailed review of the tasks involved in operational barrier elements should be obtained.

Task analysis is a well-established method for task description (Kirwan & Ainsworth, 1992). It basically refers to a set of techniques used to understand tasks by breaking operational goals into a set of tasks and sub-tasks or actions. The operational goal, in barrier terms, translates to the role or function of one or more operational barrier elements. There are different ways of documenting task analysis – some of the most common are task hierarchies, task tables or as process flow diagrams. A task analysis captures both cognitive and manual actions required to perform a task. Describing the cognitive (i.e. mental) actions is necessary to further understand how manual actions are performed. This is illustrated in Figure 3-3, and refers to actions such as detection and diagnosis of events, as well

as decision-making on how to handle the situation. An example of a coarse task analysis for well control is given in Table 5-5.

Table 5-5: High-level task analysis of secondary well control

Tasks	Task No.	Sub-tasks
1. Monitoring Influx Indications	1.1	Monitor return flow rate
	1.2	Monitor changes in mud pit volume
	1.3	Monitor standpipe / pump pressure
	1.4	Monitor rate of penetration
2. Diagnosing Influx Indicators	2.1	Check for increase in mud return flow rate
	2.2	Check for mud pit gain
	2.3	Shut down mud pumps
	2.4	Space out drill string
	2.5	Slow down or stop drill string rotation
	2.6	Route mud returns to trip tank
	2.7	Perform flow check
3. Shut-in Well	3.1	Close upper annular preventer
	3.2	Open subsea choke and kill line valves against closed surface choke valves
	3.3	Read SIDPP and SICP
	3.4	Adjust annular closing pressure to casing pressure
	3.5	Close upper pipe rams and equalize pressure prior to opening annular preventer
	3.6	Hang off drill pipe on dedicated pipe ram
4. Perform Well Kill	4.1	Perform well kill calculations
	4.2	Open adjustable choke
	4.3	Establish initial circulating pressure (ICP)
	4.4	Continuously monitor standpipe pressure and SICP while circulating the influx out
	4.5	Monitor SICP and SIDPP to ensure both pressures remains constant
	4.6	Circulate kill mud down drill string while adjusting the choke to maintain constant Bottom Hole Pressure (BHP)

The task analysis itself is mainly a method for obtaining sufficient task descriptions allowing for further evaluations. It is commonly used as part of a larger assessment, such as workload assessments, human reliability assessments, human error identification, and HMI reviews. An excellent task analysis method which fits the need for barrier management is called *Safety Critical Task Analysis* (SCTA). Guidance for SCTA can be downloaded free of charge on <http://www.energyinst.org/home>.

Good practice 11

Perform a (safety critical) task analysis to identify and describe operational barrier elements.

Comments:

- Review Bow-Tie's, risk analysis, safety studies, procedures, or other relevant documentation to identify operational barrier elements (and other safety critical tasks) per area on the rig.
- Describe operational barrier elements in sufficient detail and include or refer to these descriptions in relevant documents (e.g. performance standards, barrier strategies).
- Document link between operational barrier elements, other barrier elements, barrier functions, hazards, hazardous events, rig areas etc., for example through the barrier analysis.
- Not all operational barrier elements needs be analysed in detail. It is therefore useful to establish a set of criteria for which operational barrier elements should be subject to task analysis. Examples of criteria can be:
 - **Task criticality**, such as importance for barrier function performance or consequence of human error on accident prevention or mitigation.
 - **Task complexity**, such as number and sequence of task steps, durance of task, equipment involved, amount of information to be processed, number of people involved etc.
- For highly critical tasks, human errors and unsafe actions should be identified so that they can be systematically managed and reduced.

Task analysis is often based on descriptions of major accident scenarios. As a start, the question is often "what does operators have to do to prevent or mitigate this event?". Several sources of information can be used, but it should always include input from the end-user actually performing the task. Walk-through-talk-through, workshops and observations are good arenas for data collection.

The next step is to use the task analysis, or other available task descriptions, for establishing performance requirements for operational barrier elements.

Good practice 12

Establish performance requirements for operational barrier elements.

Comments:

Performance requirement categories for operational barrier elements can be the same as for technical barrier elements (i.e. function, integrity and survivability). Topics to be addressed can include, but is not limited to:

- Criteria for taking action (e.g. alarms, trends or other key indicators)
- Response and execution time from detected abnormality
- Frequency, sequence, and accuracy of task execution (e.g. for BOP or EDS activation)
- Operating philosophies, or overriding principles, for dealing with doubt (e.g. if in doubt, shut in well)
- Involvement of required personnel and communication between different parties

Task performance is never a product of individual or team capabilities and limitations alone. Humans should not be considered as “cogwheels” in large machinery, which can be programmed or machined to perform consistently. Instead their performance is always affected by performance shaping factors (PSFs). See Appendix A for examples on PSFs mapping for a well control scenario (note: this is a fictive example). PSFs may have both negative and positive effects on tasks. Poor PSFs may induce human error and inefficiency, while good PSFs increase efficiency and human reliability.

A pre-requisite for managing operational barrier elements successfully is to identify and manage factors that have a significant influence on performance. This way attention can be devoted to the most important elements in terms of safety and risk.

Good practice 13

Using task analyses, or other task descriptions, identify performance shaping factors which have a significant influence on operational barrier performance.

Comments:

Performance shaping factors can be identified by asking “what does the operator(s) need to perform this task?” and “what may cause the operator(s) to not execute the task as planned?”.

Avoid trying to capture everything. This adds unnecessary complexity and makes follow-up and improvement processes inefficient. Instead identify specific factors of greater importance and focus on these.

When performance shaping factors have been identified, performance requirements need to be established. Some of these factors can be managed directly, while others indirectly. For example, stress and task complexity can be reduced through proper training, good procedures and collegial support. Thus, performance requirements are established for those factors that can be managed directly.

Examples of requirement topics for PSFs are given in Table 5-6. Note that other PSFs may also be relevant.

Table 5-6: Example of topics relevant for identifying performance requirements

Performance shaping factors	Requirement topics
Procedures	<ul style="list-style-type: none"> - Accuracy (e.g. step sequences) - Relevancy of content (e.g. exclude irrelevant information) - Availability (e.g. marking/labelling, location) - Updating (e.g. revision control, MoC) - Owner (e.g. authorization to modify and distribute) - Usability (e.g. support with drawings, figures, tables) - Frequency of use/familiarity (e.g. level of detail) - Use of highlighting (e.g. critical information)
Competence and training	<ul style="list-style-type: none"> - Formal certificates (e.g. for certain tasks) - Verification of competence (e.g. before task or job assignment) - Documentation of training needs (e.g. for competence development) - Follow-up of personnel in operations (e.g. seniors coaching junior staff) - On-the-job (OJT) training (e.g. for normal operations) - Simulator training (e.g. for rare or abnormal events)
Human-machine interface (HMI) and equipment	<ul style="list-style-type: none"> - Marking of equipment and controls (e.g. clear labelling) - Consistency (e.g. use of colours and symbols) - Availability (e.g. access to panels and displays) - Familiarization (e.g. knowledge about controls) - Visibility (e.g. of system status, such as overrides) - Fault tolerance (e.g. avoid unintentional activation)

Good practice 14

Establish and document performance requirements for performance shaping factors.

Comments:

In addition to the task analysis, requirements can be collected from different sources:

- Regulatory requirements (e.g. PSA)
- DNV GL Class rules (mostly for technical PSFs, such as HMI)
- International standards (e.g. ISO, NORSOK. Mostly for technical PSFs, such as HMI)
- Already existing internal requirements (e.g. from procedures, manuals and operating philosophies)
- Crisis Intervention and Operability (CRIOP) method

Some high level requirements can apply to performance shaping factors across all operational barrier elements, such as requirements about mapping of training needs. More detailed requirements may only apply for specific operational barrier elements, such as location or marking of certain equipment.

Careful consideration should be made for how and where to document the performance requirements. One solution is to document detailed requirements together with Performance Standards for associated technical barrier elements. For example, requirements for competence, procedures and HMI specifically associated with well control can be documented in a performance standard for "Well Control Systems". More general requirements which can be applied to several operational barrier elements can be gathered into one dedicated performance standard.

Figure 5-2 summarizes the Good Practices for identifying and establishing for operational barrier elements. Note that the same approach can also be used for and include other safety critical tasks.

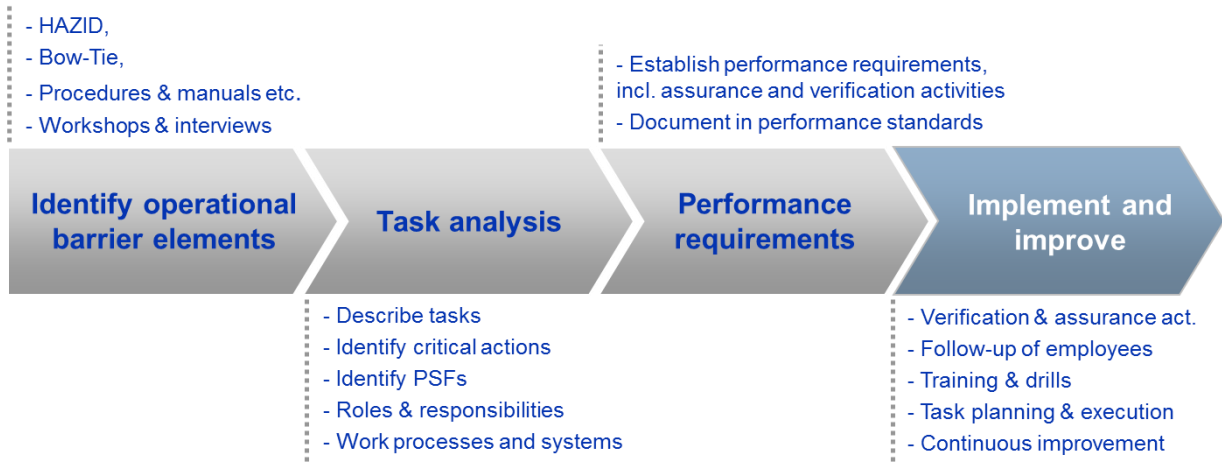


Figure 5-2 Process for establishing operational barrier element performance requirements

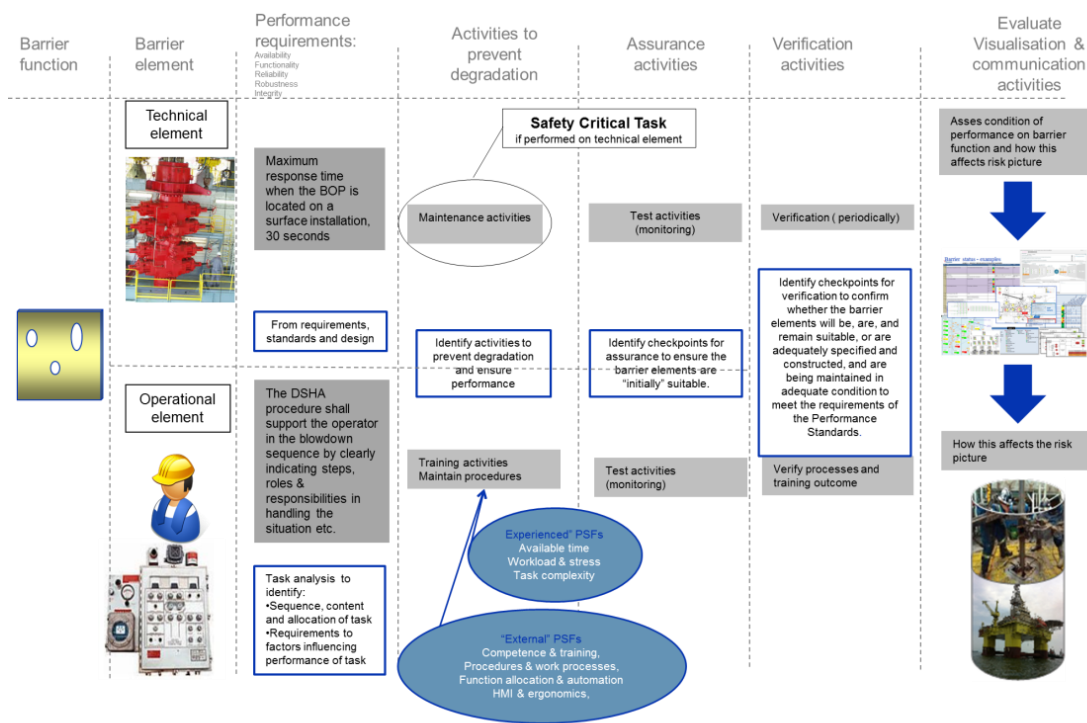
5.4 Prevent degradation of barrier performance

Barriers are designed to prevent and control major accident risks. Requirements to performance of barrier and barrier elements should be established in the performance standard. Barriers will always be subjected to deterioration and unsafe acts causing holes in the barriers. Activities to ensure performance must be managed in a systematic way. This management is shown in Figure 5-3 and described in this chapter.

Before establishing activities to ensure performance critical degradation and safety critical failures must be identified. Acceptance criteria for deterioration of barrier functionality must be established. To prevent failure and degradation efforts must be made to maintain barrier condition and performance throughout the lifetime of the installation.

For technical barriers this is done partly by choosing the right maintenance strategy and establishing a maintenance program based on the Failure Mode and Effect Analysis (FMECA) and associated analysis as Reliability centred maintenance (RCM) Risk based Inspection (RBI). Based on output from these analysis a maintenance philosophy should be choose to state activities to be performed and interval (see chapter 05.5).

For operational barriers a Human Reliability Analysis (HRA) can identify and give input to safety critical procedures, training needs, workload issues and other performance shaping factors which have influence on task performance (see chapter 5.6). For barriers to function as required and when needed, activities to ensure barrier elements to fulfil performance requirements must be in place (see chapter 5.7) and also verification activities to ensure processes to manage barrier performance are in place and performed as intended (see chapter 5.8) must be in place.



2

Figure 5-3: Management of barrier performance

Technical barrier elements may degrade and fail due to underlying mechanisms such as corrosion and erosion, extraneous loads and vibration, overload, wear and fatigue. Similarly, operational barrier elements may fail in case misinterpretation of information, faulty decision making, incorrect actions etc., caused by operator fatigue, stress, lack of training, poor procedures and HMI, among other things. Barrier degradation and failure may result in functionality, reliability or the integrity no longer being as intended in design or as expressed in the performance requirements.

To monitor status and prevent deterioration beyond acceptable limits of barriers and barrier elements, it is necessary to identify safety critical failures for the barrier elements identified (see section 5.1). Further it is recommended to establish acceptance criteria for each failure mode.

Good practice 15

Identify safety critical failures for the identified barrier and barrier elements and define quantified acceptance criteria for barrier elements:

- *Active/functional technical barrier elements (failure modes)*
- *Passive/structural technical barrier elements (degradation mechanisms)*
- *Operational barrier elements (human errors / unsafe actions)*

Comments:

Unsafe actions represent the holes in the Swiss Cheese model caused by human error. As for technical barrier elements, the most critical human failures should be identified so risk reducing measures can be implemented and followed up. This can be achieved through well-established methods such as:

- Safety critical task analysis (SCTA)
- Human error identification (HEI)
- Human reliability analysis (HRA)

The information above are to some extent expected to be found in existing documentation such as FMECA and reliability assessment for technical elements. Available sources for historical failure rates can be found in e.g. OREDA (www.oreda.com) considered to be most relevant for offshore related equipment. Other sources are presented by NTNU on their page <http://www.ntnu.edu/ross/info/data>

When establishing acceptance criteria, the historical values should be consulted to establish realistic values. In addition to the above, data either used or resulting from other documentation, such as risk assessment, emergency preparedness assessment, emergency procedures etc. may form basis for the criteria. Typical safety critical failures for technical elements are shown in Table 5-7. Examples of unsafe actions for operational barrier elements are described in Table 3-3.

Table 5-7: Examples of safety critical failures for technical elements

Performance standard	Barrier element/ SCE	Safety critical failure	Acceptance criteria (Target Failure Fraction)
Fire and gas detection	Flame detectors	The detector does not give correct signal to the F&G logic when tested	1%
	Manual call point push button	The F&G logic does not receive a signal from the call point when activated	0,5%
Active fire fighting	Fire water pump unit, start	The fire water pump unit fails to start on signal	0.5 %
	Fire water pump capacity	The fire water pump delivers less than 90 % of design capacity	1 %
Well control	Blow out preventer	Leakage through one of the barrier valves observed by measured pressure loss over time (i.e., if stable pressure then no safety critical failure)	Trend

5.5 Maintenance

Maintenance of technical systems is warranted by Activity regulation and NORSOK Z-008 and/or NMA/Class/Flag state requirements. Maintenance activities are an important part of maintaining the performance of technical elements whether they form parts of barriers or not. This chapter is outlining those maintenance activities or topics that somehow are influenced by or influence itself barrier management. Some recommendations on how to integrate maintenance and barrier management are given here.

Activity regulations, section 45-51 & facilities regulations, section 8

Maintenance management and execution is addressed in the Activity Regulations from section 45-51 covering philosophy, classification, maintenance program, planning and prioritization, effectiveness and special requirements related to specific safety critical elements.

In addition Facilities regulation Section 8, states that "Safety functions shall be tested and maintained without impairing the performance".

Comments:

Some relevant standards are:

- NORSOK Z-008: Risk based maintenance and consequence classification
- DNV-OSS-102: Offshore Service Specification
- IEC60812: Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)
- IEC60300-3-11: Dependability management - Part 3-11: Application guide - Reliability centred maintenance
- NS-EN 13306 Maintenance terminology
- NS-EN 15341 Maintenance Performance Indicators

Maintenance definitions

Tag

A unique identification number of any part, component, device, subsystem, functional unit, equipment or system that can be individually considered as maintainable

CMMS

Computerised maintenance management system

PM

Preventive maintenance, activities carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the function of an item (for more information, see NS-EN 13306).

CM

Corrective maintenance, activities carried out after fault recognition and intended to put an item into a state in which it can perform a required function (for more information, see NS-EN 13306).

To be able to prioritize, maintain and monitor barrier elements a proper tagging code needs to be established in the company's Engineering Numbering Standard (ENS). The ENS codes equipment in a technical hierarchy. This hierarchy describes how equipment carrying out a specific task, performs a sub function and how this is linked to an overall main function. A level indicator in the mud pit will have the sub function "Indicator" and the main function will be "Mud pit level".

In order to realize synergies for automatic generation of status reporting for technical barrier elements, it is suggested that relevant barrier elements are mapped to the technical hierarchy (part of the maintenance planning). This link should be identifiable, both in field, the CMMS system, in other technical and operational documentation and drawings. Example: Link "mud pit level indicator" to barrier element "monitoring of drilling parameters" and identify safety critical failure modes for this function.

Good practice 16

Apply the following approach for linking equipment to technical barrier elements:

- *Map link between barrier elements found as part of the barrier analysis (ref Sect. 5.1) and corresponding element/sub-function in "technical hierarchy".*
- *On the sub-functions and element level a cross disciplinary safety and asset team should evaluate if the sub-function/element have a role in the barrier performance. E.g. the battery charger in the lifeboat does not have a role in the performance standard "Rescue, Escape and Evacuation".*
- *For common systems on the rig e.g. fire dampers, location or system code may also be needed to evaluate relevance for performance requirements.*

To be able to priorities and prevent degradation of barrier functionality, safety critical failures should be identified. This can be done by FMECA and RCM analysis for mechanical and instrumented system, and RBI analysis for static mechanical equipment and load bearing structures. These analyses will identify failure modes, -mechanisms, and failure frequencies.

From these analysis failures threatening the barrier functionality should be addressed and maintenance activities and frequencies to prevent failures should be established. Predefined activities to maintain

barrier performance and assurance activities should be identifiable in the maintenance system to create awareness.

To facilitate an efficient monitoring of barrier performance, identification of safety critical failures for each barrier element, should be considered by a further breakdown than traditionally done in the criticality assessment as part of the RCM development (see section 0 for further details).

It is recommended to distinct between critical- and non-critical failures to be able to prioritize maintenance activities on the barrier elements. E.g.

- a) Critical failure - Clogging of impulse line to the sensor is a critical failure which needs immediate repair,
- b) Non-(low-) critical failure – A loose tag sign or damaged paint which is not an immediate threat to functionality of the element.

The CMMS system should be set up to easily read the number of test and failures and notify if the different barrier element groups are within the acceptance criteria's. If for status and reporting (like RNNP) manually work by go through individual work orders is required this will be very time consuming and prone to error.

Good practice 17

Maintenance program should include:

- *Proper identification of barrier elements with corresponding criticality*
- *In the CMMS tags with a barrier element with performance requirements should be identifiable*
- *Identification of safety critical failure for equipment performing a barrier function*
- *Assurance activities should be identifiable*
- *Reporting of results from assurance activities should be possible*
- *Historical information about failures should be stored*

5.5.1 Consequence classification

According to Activity regulation section 46 all equipment shall be classified with regards to health-, safety- and environmental- consequences of potential functional failures. Classification of all main equipment functions and sub-equipment with regard to consequence of failure is done for several reasons:

- to be able to choose maintenance activity with frequency when establishing the maintenance program
- to be able to prioritize between different maintenance activities in operation
- to be able to evaluating the need for spare parts in operation

NORSOK Z-008 describes a methodology for consequence classification of equipment. By following this standard it will not be possible to differentiate whether a failure will have impact on occupational- or major accident-risk since all risks are combined in one category called "HSE". A good practice will be to split this category so sub-functions impacting on major accident risk can be distinguished from occupational risk. Then a search for High on major accident risk in the CMMS all equipment with a barrier function will be identified. Another solution will be to use other labels CMMS with fields for barrier function, barrier element and performance standard.

Good practice 18

There are two different solutions on how consequence classification and identification of technical barrier elements can be combined:

- *Solution 1 is applicable to already existing consequence classification. It is to introduce the class VH (Very High) on HSE for all equipment that can be linked to a technical barrier element.*
- *Solution 2 is more compressive and will be relevant for newbuildings. The solution is a result from establishing a best practice from the NSAs Asset integrity forum autumn 2013. The consequence category HSE should be split into occupational risk, major risk and environment.*

5.6 Managing operational barrier elements/safety critical tasks

After having established performance requirements for operational barrier elements and performance shaping factors, a plan must be established and implemented for how to manage the barriers accordingly. Most companies already have systems, routines, procedures, and philosophies in place which are relevant and suitable for this purpose. The challenge is to adapt existing practices, find the missing pieces, and tie everything together in a system capable of managing operational barrier elements and performance shaping factors. Different types of operational barrier elements may require different management strategies, as shown in Table 5-8.

Kick, or pit drills may rely mostly on training sessions, with personnel actually simulating required actions (e.g. roughnecks installing stabbing valve). Other types, such as checking mud weight regularly, can be followed up through buddy checks and coaching.

Good practice 19

Identify, adapt and utilize existing systems, processes, and arenas for planning and execution of operational barrier elements and other safety critical tasks.

Table 5-8: Suggested systems and processes for managing operational barrier elements

System/processes	Type of operational barrier element
Training and drills (Emergency preparedness exercises, well control drills, etc.)	Training and drills can be useful for tasks which; <ul style="list-style-type: none">- are highly critical,- have little or no time for planning,- must be performed within a relative short time frame,- are rarely required
Task planning and execution (Tool-box-talks, SJA, risk assessments, etc.)	Task planning and execution is useful for tasks which <ul style="list-style-type: none">- involves multiple steps, many people,- require several procedural checks,- time and resources for preparations is available,- can be executed without time restrictions
Follow-up of employees (On-the-job training, coaching, buddy checks, mentoring, etc.)	Follow-up of employees can be useful for tasks which; <ul style="list-style-type: none">- part of normal operations,- are performed relatively frequently,- does not necessarily require manuals and procedures,- rely mostly on operators competence and experience

5.6.1 Training and drills

Some important operational barrier elements are part of the expected responses of the operators to accident initiators, commonly triggered by alarms and other detected abnormalities. These are relatively rare events which imply that certain operational barrier elements are not subject to regular on-the-job practice. This is particularly true for operational barrier elements which are part of mitigating barrier functions, such as tasks part of secondary well control (e.g. BOP activation, choke & kill etc.), emergency disconnect, search & rescue, and firefighting. To compensate, different types of training and drills can be effective means to ensure that operational barrier elements perform as intended when needed.

Good practice 20

Implement a training program for operational barrier elements.

Comments:

The training program should take the following topics into consideration (ref. also **Table 8-1**):

- Identify which operational barrier elements require training to meet performance requirements, e.g. by reviewing the barrier analysis (if performed).
- Develop learning goals to reflect and define purpose of the training.
- Learning goals should include technical as well as interpersonal/social skills (e.g. teamwork).
- Perform training evaluations to measure learning effects and achievement of learning goals.
- Evaluations should include, but is not limited to, performance measures related to response time, accuracy, execution sequence, deviations and errors, incl. their causes.
- Measures of performance should be made against performance requirements, including a set of clear and pre-defined criteria.
- Systematically update and improve training program based on training evaluations. Key success factors should be reinforced.
- Ensure sufficient realism when performing drills, e.g. by use of scenario based training and simulator centres.
- Scenarios should reflect the area specific barrier strategies
- Consider frequency of training/drills against complexity and criticality of task (operational barrier element).

Note: Many companies already perform several types of drills (e.g. pit, kick & choke drills) and emergency preparedness exercises. To avoid introducing overlapping training initiatives, a GAP analysis can be performed to examine whether relevant operational barrier elements have been covered. Also, existing training should reflect the barrier strategy, and links to barrier functions and hazards should be made clear.

Note: The International Association of Oil & Gas Producers (OGP, 2012) has issued an excellent report on recommendations for enhancements to well control training, examination and verification. Another report on safety critical team skills is due early 2014. This introduces the concept of Crew Resource Management, a well-established training concept in the aviation industry which is already in use by some rig owners. NORSOK D-010 also stipulates requirements and guidance on well control drills.

5.6.2 Planning and execution of safety critical tasks

Some operational barrier elements can be planned for as part of normal operations and may not require drills or extensive training. Instead they can be managed through other processes. Most rig companies have established systems, processes and tools for safe planning and correct execution of tasks. This may include Tool Box Talks (TBT), Safe Job Analysis (SJA), handovers, checklists and others. One example of such a process can be seen in Figure 5-4:

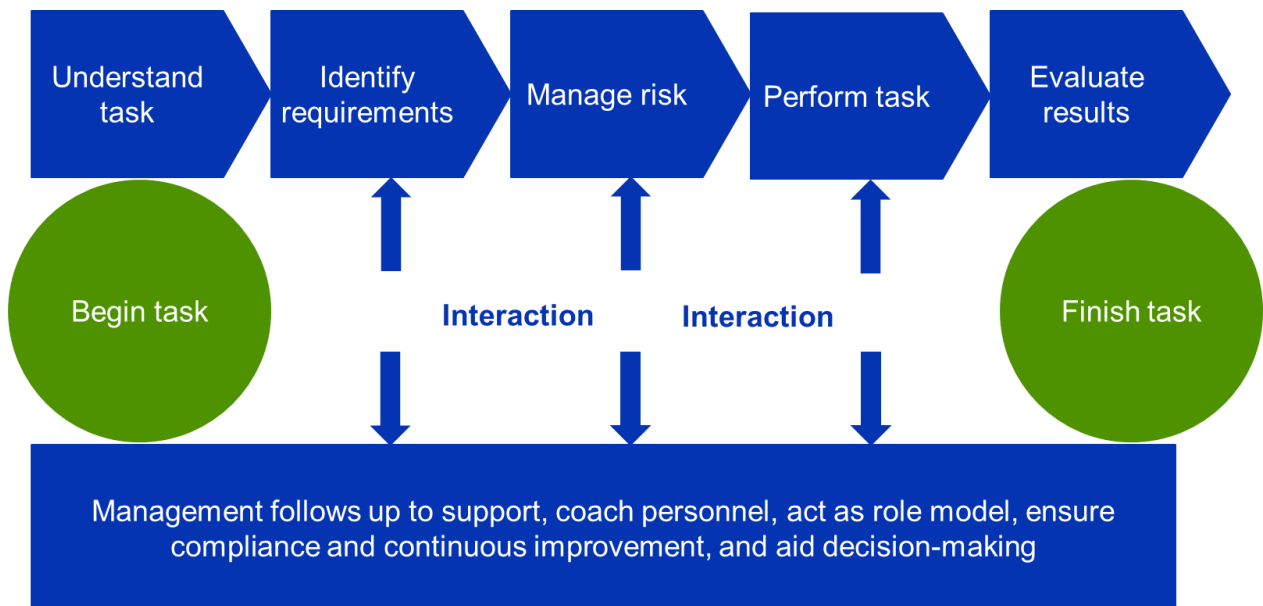


Figure 5-4: Planning, execution and evaluation of safety critical tasks

The purpose of such processes often originates from a need to reduce risk of occupational accidents. However, in some cases they can also be applied to operational barrier elements and other safety critical tasks with minimum adjustments. This assumes that the necessary preparations have been made, such as making information about hazards, barrier functions, barrier elements, performance requirements and easily available. Table 5-9 shows how a process for task planning and execution can be made relevant for barrier management.

Table 5-9: Example of task steps and questions relevant for safety critical tasks

Steps	Questions	Information
Understand the task	<ul style="list-style-type: none"> - Is this an operational barrier element or another safety critical task? - Does the task involve interaction with technical barrier elements? - Which barrier functions do the barrier elements perform? - Is the barrier function preventive or mitigating? - What are the hazards and hazardous events? 	<p>Bow-Tie</p> <p>Performance standards</p> <p>Barrier strategy for area</p>
Identify the requirements	<ul style="list-style-type: none"> - What are the requirements for task execution? - What are the performance requirements for technical barrier elements? - Where can I find relevant requirements? - Which procedures apply? - Are the people involved qualified to perform the task? - Who must be involved and when? 	<p>Performance standards</p> <p>Rig specific procedures</p> <p>Equipment manuals</p> <p>Maintenance reports</p> <p>Barrier strategy for area</p> <p>Operating philosophy</p>
Manage risk	<ul style="list-style-type: none"> - Do we need to perform a SJA or risk assessment? - What are the risks involved? - How does this task influence barrier performance during and after task execution? - Are there other barriers which must work for this task to be performed without reducing the risk level? - What can go wrong, e.g. which critical errors or failures must be avoided? 	<p>Safe job analysis sheet or other risk assessment tool</p> <p>Permit to work</p> <p>Override log</p> <p>Alarm list</p> <p>Area risk map</p>
Perform task	<ul style="list-style-type: none"> - Are we able to execute the task according to plan? - Are there any show-stoppers for not performing the task? - What are the contingencies if something unexpected happens? - How do we monitor risk assumptions? 	<p>Safe job analysis sheet or other risk assessment tool</p> <p>Rig specific procedures</p> <p>Equipment manuals</p>
Evaluate results	<ul style="list-style-type: none"> - Was the task executed as planned? - What is the status of the barrier elements and function compared to before? - Was any barrier failures or degradation introduced or removed? - How and what can we learn from this task? - Is there anything that needs to be reported? - Was the performance requirements met? 	<p>Reporting systems</p> <p>Maintenance log</p> <p>Performance standards</p>

Steps	Questions	Information
Management support (continuously)	<ul style="list-style-type: none"> - What additional information can be provided? - What are the most important performance shaping factors to manage? (e.g. do we have experienced personnel and the right equipment?) - Does the task involve decisions which the operator(s) need support in making? (e.g. unclear or ambiguous requirements and procedures) - In case of dilemmas, what should be prioritized? - What can we learn from previous tasks? 	Performance standards Rig specific procedures Maintenance reports Barrier strategy for area Operating philosophy

5.7 Assurance activities

Assurance activities generally are regarded as identifying “holes” in the Swiss cheese.

Assurance activities

“Assurance” represents the activities performed to ensure barrier elements meet performance requirements.

Comments:

This includes activities in all phases of the lifecycle and may involve activity by the design contractors in the design, procurement and construction phases which the rig owner needs to monitor to ensure the barrier elements are “initially” suitable.

These are day-to-day activities or checkpoints related to maintenance, testing, training and task execution to ensure that the performance requirements are met and the barriers are available. These activities are normally performed by first line personnel at the installation. For technical elements the activities are planned and scheduled in the maintenance system and work orders are periodically generated from the maintenance system. Operational elements are assured in the daily work on updating procedures and work practices and in the competence program.

For assurance activities, it is important that maintenance and operation activities related to barriers are identifiable in the maintenance system to enable prioritisation, analysis and tracing of these activities. The activities and the results of them will give valuable information for evaluating the status of the barriers as described in chapter 6. Examples of assurance activities are given in Table 5-10. The challenge with assurance activities is that personnel executing the work order need to have awareness that this activity is a quality check to evaluate:

1. The availability of the barrier e.g. If the barrier function or elements is present and efficient enough when needed
2. The quality of maintenance process e.g. if the activities to prevent degradation is efficient enough

Since main task for personnel doing the assurance activities normally is to fix equipment, knowledge about purpose of assurance activities and who to handle a failure on a test with regard to reporting is necessary.

Good practice 21

Mark (indicate) assurance activities in CMMS. Then personnel executing the Work Order will be aware of purpose and how to handle a test or inspection when it comes to follow-up and reporting.

5.8 Verification activities

Verification activities with reference to Swiss cheese model is to evaluate if the hazard picture has changed and if the thickness and coverage of the cheese slices are sufficient.

Verification activities

Verification represents the activities to confirm whether the barrier elements will be, are, and remain suitable, or are adequately specified and constructed, and are being maintained in adequate condition to meet the requirements of the Performance Standards.

The purpose of verification is to verify that established processes for managing performance of barriers are working as intended. Subject for the verification will be to look into e.g. design documentation compared to as-is, maintenance program, the setup and results of assurance activities, the coverage of performance requirements. Normally this is performed, either by an independent (3rd) party or a party not directly responsible for the assurance activity. Verification activities may be carried out on a fixed interval basis or on demand. Performance requirements, checkpoints for verification, findings and ranked actions are normally not included in any systems but a simple data base can be a solution.

Good practice 22

Establish a database, or use existing CMMS if possible, for managing performance requirements, incl. related verification activities or checkpoints, findings and actions.

Comments:

As part of the verification, all findings/deviations should be ranked according to the effect it has on the safety level, using a set of predefined grades. The ranking will make it easier to prioritize implementation of risk reducing measures (close findings) and improve safety.

A good way of establishing assurance and verification activities or check points is through well prepared workshops with relevant personnel from the company; system responsible, asset and HSE. Technical experts on safety systems and class requirements should also be represented. Relevant input data will be Performance requirements, maintenance program, technical hierarchy, procedures and competence matrixes. The assurance activities should comprise frequencies and responsible unit/manager in order to create a clear link to the maintenance programme. The assurance criteria should be formulated to clearly determine a pass or fail of the performance requirement and the instruction on what and how to report should be stated. Examples of verification activities are given Table 5-10.

Good practice 23

Follow 7 success factors for verification activities:

- **Establish "common ground":** *Clearly communicate background and objective of the assessment.*
- **Ownership:** *It is important with commitment and involvement from management and local unit.*
- **Quality:** *The results of the verification relies on the quality of the performance requirements and checkpoint in the PS.*
- **Competence:** *High quality level in the survey team.*
- **Added value – increased safety:** *Clearly define findings, and practical risk reducing measures to be implemented.*
- **Co-operation:** *A transparent process between survey team and personnel from the asset being object to verification.*
- **Learning:** *Exchange of knowledge and experience.*

Table 5-10: Example of assurance and verification activities

Barrier element	Type of requirements	Performance requirements	Typical assurance activities and test method	Design capacity & information source	Actual installed capacity (& info source)	Typical verification activities
Active fire fighting Fire pump	Functionality	Fire water system shall be able to provide water (from any section of the ringmain) in sufficient quantities to the largest user on the installation plus the adjacent area with the largest demand plus to two hydrants.	Check fire pump capacity head by portable flow meter and pressure gauge at pump head.	2,103 m ³ /hr & 16barg @ main deck elevation	2,200 m ³ /hr & 16barg @ main deck elevation	Check test results and maintenance record.
	Integrity	Inhibits and overrides shall be registered and an overview shall be available in CCR. Enabled inhibits and overrides shall have constraints relevant to activity and duration.	Check that instructions /procedures for use and control of inhibit and overrides are in place and adhered to.			Check that inhibits and overrides is registered and that an overview is available in CCR.
	Survivability	All active firefighting equipment shall be protected against dimensioning explosions and fires.	Verification of automatic start-up sequence of the fire water pumps			Check that firewater and centralized foam pumps is fire resistant in accordance with standard

6 MONITOR BARRIER PERFORMANCE

Part of managing major accident risk is to capture early warnings about deterioration of barriers and the effectiveness of other systems in place to manage risk. This early warnings can be used to implement measures to improve the barriers or to adjust the activity level and operations in accordance with the deteriorated barrier performance.

With reference to the Swiss Cheese model this early warning means to identify the condition or the status of the barrier; where the holes are and how big they are. When identified the holes can be fixed or the activity level can be adjusted so the hazard does not penetrate a hole.

Management Regulation, Section 5

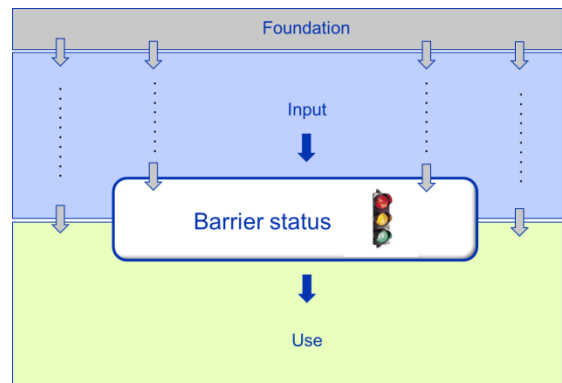
"Personnel shall be aware of which barriers are not functioning or have been impaired."

The requirements stated here gives challenges and opportunities in the organisation;

- Information relevant for assessing the status of barriers must be identified
- A process for evaluate and communicate the status must be in place
- The purpose and use of information about barrier status must be identified related to planning, operating and maintaining the asset.

Systems, work practice, competence and preferably tools must be in place to meet these three requirements. A simplification of this approach is illustrated in the figure with the attached text:


- 1) **Foundation:** To achieve relevant information with good quality there need to be the right baseline, e.g. detail level and the structure of the CMMS and the competence and organisation (recourses) available for evaluation.
- 2) **Input:** To be able to evaluate the status, information relevant for assessing the status needs to be identified. Several types of information and information sources can be relevant to establish a good overview of barrier status.
- 3) **Use:** To have overview, prioritise and decide based on knowledge about the barrier status, the information needs to be used and communicated. The rig owner should therefore clarify what the information should be used for, by whom and when.



Management Regulation, Section 10

"The operator or the party responsible for operation of an offshore or onshore facility shall establish indicators to monitor changes and trends in the major accident risk and environmental risk."

Traditional indicators, such as Loss Time Injury (LTI), are not relevant for measuring major accident risk. Since the frequency of major accidents is extremely low, a number of underlying indicators which are significant for assessing the changes in major accident risks should be followed up. The status of barriers can be seen as relevant indicators for major accident risk, but it is important to understand that status of barriers only tell something about "how many holes in" or the condition of the barriers.



This is not equivalent to the risk picture. Because of the complexity of major accidents the risk picture can among other factors be derived from the status.

Recognizing the complexity in the major accident risk picture it also recognized that establishing a single indicator to show the effect of barrier status – and its associated effect on the major accident risk picture is challenging / impossible. As of today it is seen a range of different indicators, monitoring regimes and to some extent software solutions available to show barrier condition or status. In common for these is that the results are in various degree presenting “historical” values rather than “online” or “as of now” pictures. In addition some of the indicators are generating new/additional reporting routines “on top” of already existing routines/systems. In common for the indicator systems is the focus on the technical condition and not extensively inclusion of operational elements and performance shaping factors.

When establishing a monitoring system, a recommended approach is to map already available information in existing reporting monitoring system(s) and evaluate how this can be utilized directly or be made available with a minimum of modifications.

It is believed that there are synergies in combining the development of PS- hierarchy and technical hierarchy (maintenance planning) and associated criticality ranking. Alignment of these may facilitate automatic reporting of status of technical barrier elements from CMMS. In addition systems/processes monitoring temporary reductions in capacity/availability can be taken from PtW, override/inhibit logs, Non conformity logs etc. Other systems like CRM may facilitate input to indicators for operational barrier elements.

It should be noted that monitoring activity of barrier status is one of several parameters to consider within major accident risk management. Other factors like activity type and level and/or operational mode needs to be considered together with the barrier monitoring activity. As an example, criticality of a failure (degraded functionality) is not constant over time – failure of propulsion/manoeuvrability is not critical if the rig is anchored on location or berthed in harbour, but critical when the rig is en route.

The set of indicators established should be included as decision support on the different levels in planning of activities (See Figure 7-1) considering both the condition and criticality of the different barrier and barrier elements. Some examples of indicators are identified in sect. 6.1.

Good practice 24

Establish a set of indicators that represent a picture of the condition including a functionality of a dynamic criticality to present a “true” criticality of the status.

Indicators should present an “online” picture of the status. Enable decision support in all levels of activity planning.

6.1 Identify input data/indicators

The rig owner should identify information that has relevance for early warning about deterioration and impairment of barrier functions. In most cases this information or indicators are already available and collected in other processes in a rig organisation. Dependent on the structure of the CMMS most modern systems can extract reports about test results for safety critical equipment. Together with acceptable failure rates these test results are to certain extend valuable information about status of barriers.

Examples of relevant input data are given in Table 6-1.

Table 6-1: Example of input to and indicators for barrier status

Barrier elements	Input/Indicator	Comments
Technical elements	Override log	Should be easily available in control room
	Open corrective maintenance (CM) for safety critical equipment	This is the most explicit input to the status of barrier elements. It should be the total amount of CM with safety critical failures. This should not only be backlog of CM.
	Test results for safety critical equipment groups with hidden failures, e.g. BOP, Gas detectors, Emergency generators	The previous results (even if equipment is fixed after failure) are relevant information regarding the availability of the system/equipment group. Required input to be send to PSA, ref. RNNP
	Inspection results	Same as above, but for systems that needs to be inspected to identify failures (e.g. structures and passive fire protection) cracks, corrosion etc.
	Backlog Preventive Maintenance (PM) for SCE	Backlog of PM only indicate an uncertainty regarding the status of the barriers.
	Relevant open findings and/or actions from audits/verifications	There could be findings that indicate weaknesses in the systems which are not covered in the CMMS.
	Reported well incidents (well kick and loss of well control)	Well incidents could be followed up as indicator the same way as typically LTI. Required input to be send to PSA, ref. RNNP
	Incidents with SCE failure	Can be relevant to following up in addition to test results.
Operational elements / performance shaping factors	Competence (Competence matrix)	Should be competence related to defined operational barrier elements and other safety critical tasks influencing barrier performance.
	Training/drills on operational barrier elements.	Similar to test results for technical elements. Results and evaluations of training against set criteria. Tasks could e.g. be those associated with well control, marine operations or emergency preparedness.
	Backlog on training/drills (training matrix), OJT or other forms of competence development plans and follow-up.	Similar to backlog for PM for technical elements. Measure against competence PSF specifically related to operational barrier elements and other safety critical tasks with significant influence on barrier performance.
	Revision frequency of procedures /operational documents	Lack of regular updates or late inclusion of proposed changes to procedures and operating documentation could indicate lack of control on performance shaping factors.

Good practice 25

When choosing input/indicators to reflect the barrier status the operator should clarify the following:

- *Do the input give relevant/important information about the status*
- *Is it possible to obtain the data or is it needed to improve/update e.g. systems to get the data*
- *Are the data reliable*
- *Are data retrievable*
- *Are the data available electronically, e.g. possible for automatic data gathering. If not, do the operator has sufficient recourses to handle this manually*

A success factor for information on test results is that personnel executing maintenance, training and assurance activities report the results on a predefined format. "Test OK" is not a valuable information when it comes to analysing the availability of a barrier. An good report of test can be; "*pressure test of BOP according to test program to 3200 psi. The result of test is 3200 psi and according to acceptance.*"

Good practice 26

When reporting execution of test the following should be included:

- *the result of test in duties*
- *the capacity or response*
- *if the test is according to acceptance.*

6.2 Evaluate and communicate barrier status

If test results are available and acceptance criteria established the status of technical barrier elements can be drawn from this. Since barrier functionality is fulfilled by technical operational elements evaluating status of barriers will be more consistent based on a combination of:

- information about results of tests
- incident register
- information about quality of established processes and systems in place to control the risk like maintenance, management of change, training etc.

Evaluation of barrier status can be done in several ways. It can be online generated based on predefined algorithms and acceptance criteria or it can be assessed by safety systems domain experts within the organisation.

Since information will have different format and come from different sources overview of all information and evaluating the barrier status without a common presentation format can be difficult. For easily access and a common overview a good solution can be to establish a barrier panel fit for purpose.

A uniform methodology for describing status can be useful. This allows the organization to evaluate and interpret the results in a consistent manner. One solution can be to introducing a rating system with predefined tolerance criteria. Rating systems normally exists of colure coding with a general description; see example in Table 6-2. In addition there should be some guidelines or criteria's for the different indicator, see examples in Table 6-3.

Table 6-2: Example of rating system

Rating	General description
	Not functioning/not acceptable
	Degraded or uncertain status
	Good

More than three rating categories can be used if the operator wants a more detailed system, both regarding evaluation and prioritizing for following up.

Table 6-3: Example of rating description for some indicators (ref. indicators in Table 6-1)

	Open CM for SCE, equipment level (or for the equipment group, but then an aggregation system is needed)	Test result, equipment group level (based on 12 last months)	Backlog PM, equipment group + Backlog on training/drills, per defined training/drill activity	Training/ drills Result, per defined training/drill activity	Etc.
	CMMS code "dead"	Above the acceptance criteria	NA	Above the acceptance criteria	
	CMMS code "sick"	Failures, but below the acceptance criteria	Backlog, i.e. uncertain status of the barriers	NA, or define if relevant for particular training	
	No open CM	No failures	No backlog	No failures	

Based on the number of safety systems, equipment (total tags) and indicators this will generate a long list of information. To easily give an overview it can be reasonable to do some kind of aggregation. Different methods for aggregation can be applied, see examples in Table 6-4. Be aware that aggregation introduces some challenges with respect to interpretation of the results. Examples of level of visualization of results are given in Table 6-5.

Table 6-4: Example of possible methods that can be applied for aggregation.

Methodology	Strengths	Weaknesses	Comments
Always show the worst rating at a lower level	Easy system to understand and implement	<ul style="list-style-type: none"> - With a lot of information it will "always" be red. - Several yellows can in some cases be worse than one/few reds. 	With this system it is important to: <ul style="list-style-type: none"> - Always drill down to check the amount at lower level - Communicate in the organization that the total safety system <u>not</u> is red even if it show red, and can be <u>weak</u> even with yellow.
Aggregation rules, e.g. <u>Green</u> : at most 1 yellow, no red <u>Yellow</u> : at least 2 yellow (but not all) and at most 1 red <u>Red</u> : 2 red or more, or all yellow	Easy system to implement	Similar as above, but at better solution regarding this weaknesses	Gives a "better picture" of the overview than the solution above. However, the aggregation rules will never be "perfect" regarding given the right status at the system level.
Manual rating (except for the indicator level)	Gives relevant status information at the different levels	Resource-demanding	If <u>not</u> using this method (or the method below) a similar evaluation can still be done when evaluating the results:

Methodology	Strengths	Weaknesses	Comments
	Get a good understanding of the status		<ul style="list-style-type: none"> - Check the reason for "red" - Evaluate the result if a lot of "yellow" - If always "green" check if the coding, reporting etc. is correct, e.g. reporting of test result "fail/fixed" can be incorrect reported.
Manual rating	As the solution above, but even better	As the solution above, but even worse	For this solution table 4-3 will not be relevant, but can be used as guidance. If identifying weakness in data quality, rating should be given differently.

Good practice 27

When developing a system for barrier status monitoring, the following principles can be applied:

- **Rating system:** *Have clear criteria for the rating categories, with detailed descriptions for each category and for each indicator. This will enhance consistency in the evaluation and interpretation of it.*
- **Aggregation:** *Since aggregation of information not will give the full picture, there should be opportunities for drill down. In addition, information at several levels will be useful for different user groups.*
- **Trends:** *Trends compared to previous period, year etc. gives important information. This can be illustrated with e.g. an arrow downwards for deterioration, horizontal for unchanged and upwards for improvement.*

6.3 The purpose and use of information about barrier status

The main purpose of identifying status of barriers is to assure that risks are being adequately controlled. Different levels in the organization will have different needs of control. Top management in a rig company may benchmark rigs with each other while decision takers in work permit meeting needs to, based on information about a deficiency in a barrier, decide upon permits to be performed and on-going drilling activities. Some information will be useful directly from the original information sources, e.g. equipment out of order or override given in the CMMS or in the CCR. The operator should therefore clarify what the data should be used for, by whom and when.

Information about barriers can be organised and presented in different ways to give stakeholders relevant basis for taking decisions and to manage risk. Examples of different way of organising information and relevant stakeholders are given in Table 6-5

Table 6-5: Example of different way of organising information and relevant stakeholders

Status level	Stakeholders	Comments
<p>Per safety system (PS level)</p>	<p>Onshore management Offshore management</p> <ul style="list-style-type: none"> - Daily operation - Long term <p>Safety system responsible or Performance standard (PS) responsible *</p>	<p>This information can be used by managers to monitor the status of the barriers. Managers should regularly evaluate major accident risk and performance of the safety system for their offshore units. When evaluating the results they should decide if it is a need for temporary mitigating measures or some adjustments or upgrades of the system(s).</p> <p>If used for daily operation, e.g. related to the work permits process, safe job analysis and drilling program, the information should be given per area.</p> <p>* It is not required to have Performance Standards responsible, but it is a good solution to have dedicated persons responsible for the different PS's who understand the system, has a continuous overview of the systems weakness and improvement potential.</p>
<p>Per equipment group</p>	<p>Onshore management Offshore management</p> <ul style="list-style-type: none"> - Daily opr. - Long term 	<p>When managers evaluates the results, it is important to not just following up with regular maintenance (repair or replacement), but also identify if there is some repeating failures which indicate a need for decreased test interval, changing of components, upgrading of components/systems etc.</p> <p>The result of analysing the data can also lead to increased test interval.</p> <p>In addition analysing data can also identify weaknesses in the tag structure, recording practise etc.</p> <p>If used for daily operation, the information should be given per area.</p> <p>This example of "status level" does not cover operational and organisational aspects.</p>

Good practice 28

To ensure use of information regarding barrier status the operator should:

- *identify and specify who and when it is going to be used (work processes).*
- *linked use to specific decision processes or arenas.*

7 BARRIER MANAGEMENT FROM DAY-TO-DAY

Main role of Operator's "management system" is to facilitate safe and efficient operation. As part of the overall major risk management, barrier status and performance is regarded valuable input as decision support for short and long term planning of activities on the rig.

Several predefined onshore and offshore meeting arenas or decisions points are set up to handle uncertainty, give flexibility and to exchange information see Figure 7-1. Several of these decisions points needs or provides information relevant for barrier management as shown in Table 7-1. This chapter will describe some of these meetings and give examples on how information relevant for barrier management can be communicated.

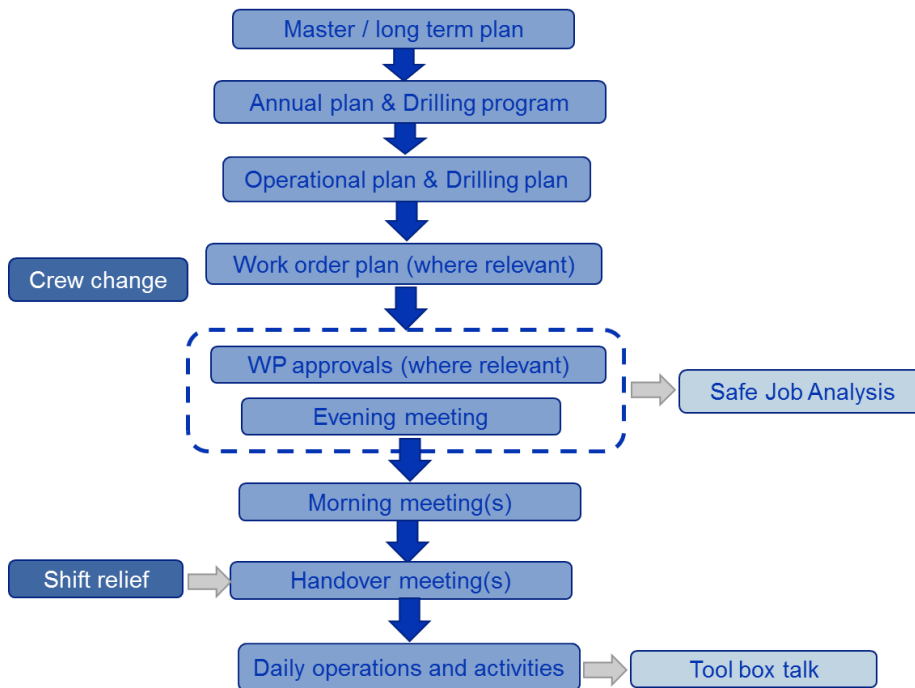


Figure 7-1: Example of decision points in a rig company

Table 7-1: Examples of how decisions points needs or provides information relevant for barrier management

Decision point	When	Who	What	Relevance for barrier management
Drill-well-on paper	Before start-up and when needed	Company OIM Driller	Identifies all risks and obstacles in the next drilling sequence.	Needs to have an overview of risk picture and status of barriers
WP approval/ Evening meeting	17 o'clock	Department supervisors, OIM	Discuss and agree on all activities next day. Approves all work permits for next day. Discuss any issues between drilling, maintenance and other activities	Needs to have an overview of risk picture, status of barriers on an area level, overrides and isolations on safety systems. Decides measures to improve the barriers and compensating measures
SJA	Before executing	Department workers	Risk management in activity	Needs to consider barriers that will be influenced by the job and barriers important for eliminating risk in the job
Issue WP	07 o'clock	CCR	Overview of all WP will be from CCR	Needs to have an overview of status of barriers on an area level
CCR	Contentiously	CCR	Overview of all activity, overrides, WP isolations	Needs to have an overview of status of barriers on an area level Gives input to overrides and isolations on safety systems
Activate WP	After 07 o'clock	Area or system responsible		Needs to have an overview of status of barriers on an area level and override and isolation in area.

7.1 Work Permit (WP) approval

This meeting takes place in the evening before execution of work and relevant participants are: OIM, Toolpusher and maintenance manager. The purpose of the meeting is to coordinate activities taking place next day with regard to drilling, operation and maintenance. Some of these activities will be daily routines not addressed by the work order system e.g. a routine check of lighting fixture, some activities will be addressed by the work order system, e.g. preventive maintenance on the mud pump and some of the work orders need to have a work permit.

The work permit system is based on the principle of internal control. This means that several independent roles are involved in the approval, control, coordination and management of activities. On a rig equipment and control of work activities is "owned" by operation/area/system responsibility while required work to be performed is "supplied" by the respective executive department. In this way a WP is considered a contract between two parties.

When deciding work and activities to be performed three questions are relevant to possess:

1. What need to be done to fulfilling requirements?
2. What cannot be done according to risk picture?
3. What can be done according to risk picture?

When approving work orders barriers status should be known and also information about deficiency in performance of the barriers should be used as basis for considering whether a work order can be approved, or if an additional measure needs to be put in place. This information on an area level together with the potential risk picture given deficiency in barriers will give valuable decision support and be a good tool for communicating risk related to work orders and work permits.

The work permits are delivered from the CCR and the execution teams often do a toolbox talk before start working. Area responsible or system responsible is the one activating the work permit. This role coordinates all the work permits and work orders taking place in an area or on a system. This person is a key resource when it comes to overview on activity and he must know the status on barriers in his area, isolation valves, overrides and other information relevant for understanding the risk picture in the area.

Good practice 29

When choosing input/indicators to reflect the barrier status the operator should clarify the following:

- *Do the input give relevant/important information about the status*
- *Is it possible to obtain the data or is it needed to improve/update e.g. systems to get the data*
- *Are the data reliable*
- *Are data retrievable*
- *Are the data available electronically, e.g. possible for automatic data gathering. If not, do the operator has sufficient recourses to handle this manually*

7.2 Continuous improvement

Management of change (MoC)

A process detailing method how changes shall be proposed, reviewed and approved for proper implementation, giving full consideration to occupational -, major risk- and environmental concerns, operability and cost savings.

Non- conformity

Any state or condition that is not compliant with requirements, in this context this corresponds to any form of deviation, non-compliance.

If non-conformities are detected during activities related to operation, maintenance, assurance or verification this should be handled in a non-conformity process. Results of a non-conformance process can be temporary changes with an exemptions or permanent change. Permanent changes should be handled in a management of change process.

Temporary and permanent changes and exemptions on safety systems should be traced and communicated related to barrier status.

There might be situations where barriers are subject to modifications or alterations. This could be a result of optimization, changes in design, operational conditions, or to fulfil new requirements. All these issues need to be handled in a management of change process.

Good practice 30

The performance standard shall reflect the current design and operation of the installation. In order to ensure this, the update of the PS should be a part of the MoC.

Comments:

This implies that the PS should be a living and formal document which is updated when there is e.g.:

- Major modification on the installations design where new/updated company/regulatory requirements must be adhered to. Changes in production e.g.
 - Higher/lower pressure,
 - Higher/lower temperatures,
 - Composition (e.g. introduction of H₂S in production)
- New knowledge, change the existing basic design basis
- Changes in environmental conditions e.g. higher waves

7.3 Reporting and incident investigations

Rig companies have comprehensive reporting systems for unsafe conditions, near-misses and incidents. In addition, incident investigations are carried out for more serious events. While the majority of unsafe conditions and incidents reported are related to occupational safety, the systems should be set up to capture major accident hazards and barriers. This is an important part of continuous organizational learning beyond what is measured and followed up in verification and assurance activities.

Good practice 31

Ensure that systems for reporting and incident investigation are set up to capture the complexity of major accident hazards and barriers.

Comments:

Contributions to major accident risk and barrier performance can be identified in the barrier analysis, barrier strategies, and performance standards. This includes, but is not limited to:

- Hazards, hazardous events, and consequences (for areas)
- Barrier functions and barrier elements
- Barrier failures, including latent failures
- Performance shaping factors

The reporting system should make it obvious to the user whether what is being reported affects barrier performance. Using the same terminology in the reporting systems and incident investigation secures learning across reporting systems and creates awareness about major accidents and barriers.

Much of what is reported would fall under the category of latent failures or performance shaping factors. For example, it should be possible to report procedures which contain errors or are past due for updates. Another example could be negative circumstances concerning testing or the condition of barrier elements, which may deserve attention beyond what is possible to achieve through other reporting systems (e.g. maintenance logs).

For organizational learning to be successful, some key principles apply:

- Personnel must be encouraged to report
- Personnel must receive feedback on status of report (e.g. follow-up measures)
- Reports must not be used to sanction personnel
- It must be possible to perform statistical analysis and trending
- Improvement measures must be followed up to verify that they are correct and implemented according to plan

Experience transfer between company stakeholders, e.g. between rigs and between the onshore and the offshore organization.

8 KNOWLEDGE ABOUT BARRIER MANAGEMENT

Successful and sustainable implementation of barrier management in operations require a specific set of competence (i.e. knowledge and skills) among personnel on different levels in the organization. The management system and social interactions defines how competence is distributed in the organisation, both onshore support and offshore.

This chapter suggest how competence distribution can be made (see Table 8-1)

Competence

Competence is about knowledge and skills.

- *Knowledge is the theoretical understanding; how we know things*
- *Skills are the practical understanding; how we do things*

Building competence involves some prior elements and stages;

- before we can understand we have to remember,
- before we can apply or do it we need to understand,
- before we can analyse we need to apply,
- before we can evaluate we have to be able to analyse,

These stages can be referred to as competence taxonomy. Different level in an organisation and different situation in a value chain needs to possess different level of competence taxonomy when it comes to risk e.g. the OIM needs to understand the full risk picture continuously while risk is managed through the work permit system and the Safety Job Analysis for the mechanics doing preventive maintenance on a mud pump.

Table 8-1: Competence distribution on major accident risk and barrier management

Topic	Offshore			Driller and Department workers
	Onshore	OIM and department management	CCR/ area or system responsible	
Risk understanding		<p>All levels in a rig organisation needs to understand that risk is a combination of probability and consequence of an unwanted event.</p> <p>Personnel must understand how they can reduce probability, reduce consequence or directly reduce risk.</p> <p>Awareness about main contributors to probability and consequence and how can I affect this must be understood in all parts of the organisation.</p>		
Barrier management framework		<p>All employees should have understanding of why barrier management, what is a barrier and how barriers should be managed in operation.</p> <p>They should also understand which barriers are in place and the role of the barriers.</p>		
QRA/ safety case	<p>Understand the company's risk management system and their role and responsibility.</p> <p>Understand contributors to the probability part and the consequence part of the overall risk picture.</p> <p>Understand the assumptions and limitations to the risk picture.</p> <p>Understand areas and activities with highest contributions to the risk picture.</p>	<p>Same as for onshore rig management and CCR/ area or system responsible.</p> <p>OIM to understand how he/she is responsible for ensuring that risk picture is acceptable according to the QRA results.</p>	<p>Understand contributors to the probability part and the consequence part of the overall risk picture.</p> <p>Understand how he/she is responsible for assumptions and limitations to the risk picture.</p>	<p>Understand area risk map (if available).</p>

Topic	Onshore		Offshore		Driller and Department workers
	Rig management	OIM and department management	CCR/ area or system responsible	Driller and Department workers	
Barrier strategy		OIM to understand how he/she is responsible for ensuring that the strategy is followed in operations and management of the rig. Know which operational barrier elements they are responsible for.	Understand the strategy for barriers in place to handle hazards in area. Know which operational barrier elements they are part of performing.	Know where to locate the barrier strategy Know that the barrier strategy contains information about hazards and barriers for each area. Know which operational barrier elements they are part of performing.	
Performance standard	Know how to appoint and follow up owners or performance standards. Understand how different processes influence barrier performance requirements.	Know which safety systems (performance standards) they are responsible for. Know the requirements and the background for the requirements. Know how deviation from performance requirements affects risk picture, i.e. how barrier failures and degradation in barrier elements affect barrier functions. Understand how to assure and verify that performance requirements are met.	Know and technical barriers they are responsible for.	Know where to find necessary information and tools (e.g. procedures) for carrying out task so that barrier performance is assured.	

Topic	Onshore		Offshore		Driller and Department workers
	Rig management	OIM and department management	CCR/ area or system responsible	Driller and Department workers	
Barrier status	<p>Understand their responsibilities for following up and improving barrier status. This includes improving processes and systems affecting barrier performance and condition (e.g. maintenance, MoC, training etc.).</p> <p>Understand how to use information about barrier status to prioritize in decision making.</p> <p>Know where to find and how to use information and data about barrier status.</p>	<p>Understand how to use information about barrier status to identify risks.</p> <p>Understand how to implement necessary improvement measures.</p> <p>Understand how to use information about barrier status to prioritize in decision making.</p> <p>Understand his/hers responsibility for ensuring that the necessary input about barrier status is reliable and valid.</p>	<p>Know the status of barriers they are responsible for (interact with). E.g. overrides, non-conformances, tests, etc.</p>	<p>For driller, know the status of barriers they are responsible for (interact with). E.g. overrides, non-conformances, tests, etc.</p>	
Permit to work		<p>Understand how information about barrier status, operations/activities and other parameters (e.g. weather) can be used to manage risk through the PtW system.</p> <p>Understand how permit to works shall be communicated and enforced.</p>	<p>Understand how to communicate risks when coordinating PtWs.</p>	<p>Understand how changes in planned work can increase risk and when to communicate with other parties (e.g. CCR).</p>	

Topic	Onshore		Offshore		Driller and Department workers
	Rig management	OIM and department management	CCR/ area or system responsible		
Management of change	Understand how management decisions can influence (positively or negatively) the established barrier strategy. E.g. how technical or operational changes may affect barrier performance and should be subject to MoC.	Know when and how to identify MoC necessary to ensure barrier performance.			
Safety critical tasks		Understand how to identify safety critical tasks. Understand how to follow up execution of safety critical tasks using different tools (e.g. safety talks). Understand which performance shaping factors have significant influence on performance of safety critical tasks, and know how to manage them.			Understand whether tasks are part of maintenance or assurance of barrier performance according to performance standard. Understand how different tools (SJA, TBT, risk assessments etc.) can be used to avoid barrier degradation and failure.
Maintenance		Understand how to identify equipment and structures (tags) categorized as barrier elements. Be able to prioritize maintenance activities according to barrier strategy and performance standards.			



Topic	Offshore			Driller and Department workers
	Onshore Rig management	OIM and department management	CCR/ area or system responsible	
Major accident hazards		Understand how barriers and barrier status are taken into consideration as daily decision support	Evaluate the effect of an activity on the barrier elements and risk picture	

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APPENDIX A: MAPPING AND EVALUATION OF PERFORMANCE SHAPING FACTORS

This is a fictive example

Performance Shaping Factors	PSF mapping and evaluations	Input to PSF requirements
Available Time	<p>Available time is defined as the amount of time available relative to the time required to complete the task. During a well control event, it is always recommended to detect and shut-in the well as soon as possible so that the volume of influx, hence SICP, is minimized. If the well is shut in too late gas may reach the riser and will rise to surface where it has to be diverted.</p> <p>It is however, not common to shut-in the well within a defined time frame. This depends on how quickly the influx is detected. Note: Rather than defining a required time to shut-in a well, drillers are given the advice or authority to shut-in the well when unsure. After having shut in the well the driller has a certain time available to circulate out the kick before gas rises to levels where increased pressures may damage the well integrity. This depends on the size of the influx, formation/well integrity, well depth, among other parameters.</p>	<p>The driller must be trained in early kick detection and safe circulation of the well. This includes interpretation of kick indicators, correct use of procedures, and operation of controls.</p>
Stress / Stressors	<p>Stress used in the context of a well control situation refers to undesirable conditions and factors that have detrimental effects on the driller's monitoring and decision making process, which may result in incorrect actions.</p> <p>Stress can be due to the following factors:</p> <ul style="list-style-type: none"> • Competence & Experience; • Management Culture; <p><u>Competence & Experience</u></p>	<p>1. A driller working in an economically oriented (as opposed to safety oriented) environment will be exposed to higher stress when he decides to shut-in the well. Under these circumstances, pressures from management will be detrimental to the drilling's judgment of the situation. Increased competence of the driller will be critical during interpretation of real time drilling parameters and flow check results under these situations (Interdependence with "Experience / Training" PSF). Secondly, promoting a</p>

Performance Shaping Factors	PSF mapping and evaluations	Input to PSF requirements
	<p>Unexpected situations during drilling operations e.g. drilling into an unexpected high pressure formation will lead to confusion and uncertainty. Unexpected pressures usually occur in exploration wells where the formation pressures are unknown, resulting in a level of uncertainty prior to drilling.</p> <p>During well kill operations, especially when exposed to high SICP i.e. increased safety risk to personnel onboard, the driller is subjected to high stresses, especially when he has to perform monitoring and operation tasks simultaneously. This increases the probability of errors. A competent or experienced driller might experience less stress under these situations.</p> <p><u>Management Culture</u></p> <p>Drillers, being the “first line of defence” are often given the authority to shut-in the well whenever he is unsure. However, it is important to highlight that this will vary with company and crew.</p> <p>Shutting in a well would mean a stop in drilling operations. This means that productive time is being lost. At rig rates of 500,000 USD/day, shutting in a well will not be economical to the company. Whether or not the driller is given the authority to shut-in the well is highly dependent on the company’s safety and management culture. Support from the crew will also affect the driller’s decision and judgement.</p>	<p>safety first culture will be effective in reducing the risk (Interdependence with “Work Processes PSF).</p> <ol style="list-style-type: none"> The driller could also consult the toolpusher or the drilling supervisor. This is a potential stress reducer on the driller as there is a second person who will provide operational support and judgement (Interdependence with “Work Processes” PSF i.e. management support). The operator should provide the driller with important information on the well and the risks he is exposed to e.g. prior to penetrating high pressure formation. This could be performed on a daily basis during pre-shift safety meetings.
Complexity	<p>Complexity refers to the difficulty of performing the task. Human error is directly proportional to complexity.</p> <p>Monitoring of the drilling parameters and the procedure for performing a flow check is relatively straightforward.</p> <p>Complications arise during well kill operations as simultaneous operations are required to be performed.</p>	<ol style="list-style-type: none"> During well kill operations, support from pump operator, choke operator, tool pusher and drilling supervisor will reduce the potential for mistakes (Interdependence with “Procedures” PSF). Increased competence / experience of the driller imply that he has the ability to understand any complexities during operations and / or when exposed to unexpected

Performance Shaping Factors	PSF mapping and evaluations	Input to PSF requirements
Experience / Training	<p>Most companies require the driller to undergo well control training and obtain a certification by a recognised training company. For example, drillers will undergo well control training certified by the International Well Control Forum (IWCF) which trains the driller on well control procedures, equipment and hands-on well control drill. At the end of the training course, the driller has to sit for an exam. This training course needs to be attended every 2 years. Note that the driller will be trained to perform independent well kill calculations in these training courses.</p>	<p>situations (Interdependence with “Experience / Training” PSF).</p> <p>Refer to Stress / Stressors, Complexity and Procedures PSFs.</p>
Procedures	<p>The following 3 procedures are relevant to this drilling scenario:</p> <ol style="list-style-type: none"> 1) Flow check procedure; 2) Shut-in procedure; 3) Well kill procedure i.e. driller’s method. <p>Flow check procedure (see tasks 2.3 – 2.7) and interpretation of the flow check results is relatively straightforward.</p> <p>Shut-in and well kill procedures are listed by tasks 3.1 – 3.6. and 4.1 to 4.6. respectively. These procedures have been used in the oil and gas industry for many years and have been proven to be effective during well control events.</p> <p>Human errors usually are derived from mistakes during the application of these procedures for example, wrong interpretation of the flow check results, making wrong well kill calculations, and making operational mistakes during well kill operations.</p>	<p>Flow checking, well shut-in and well kill procedures have been established and proven to be effective during drilling and well control events. Human errors are often a result of mistakes during application of these procedures. The human risk could be reduced by providing the driller with training</p> <p>Refer to Experience / Training PSF and operational support (Work Processes PSF).</p>
Ergonomics / HMI	<p>Ergonomics refers to the equipment, displays, controls, layout, quality and quantity of data obtained from the instrumentation, and operator / equipment interaction.</p>	<p>It is typical that the drilling rig / platform is equipped with 2 sets of sensors placed in close proximity to each other. One set of sensors will be provided by the drilling contractor i.e. rig</p>

Performance Shaping Factors	PSF mapping and evaluations	Input to PSF requirements
	<p>The drilling parameters displayed on the HMI are real time and is a result of direct feedback from the strategically placed sensors, hence, it is critical that the sensors are providing the correct data. BOP and choke and kill panel is according to industry standards and familiar equipment.</p>	<p>/ platform and the second set are provided by the mud logging unit. During drilling operations, the mud logging unit independently monitors the real-time drilling parameters feedback from their sensors and will alert the driller if there are indications of an influx.</p> <p>In addition, the driller's HMI i.e. drilling parameters display screen is duplicated in the Offshore Installation Manager (OIM) / toolpusher and drilling supervisor's office. This enables the drilling parameters to be monitored by the OIM, toolpusher and drilling supervisor.</p> <p>Refer to Stress / Stressors PSF for potential stress reduction when interpreting flow check results and decision to shut-in a well.</p>
Fitness for Duty	<p>The driller's degraded fitness for duty could be due to fatigue at work arising from long shift hours (12 hours per shift). Under these conditions, the driller's judgement will be affected.</p>	<p>Working 12 hour shifts are common for drillers. The driller should always alert the toolpusher whenever he feels unfit for duty.</p>
Work Processes	<p>Examples of work processes PSF includes organizational and management culture, safety culture, communication, management support and policies. This varies from company to company i.e. organizational and management and also the geographical location of the well being drilled e.g. communication, language etc.</p>	<ol style="list-style-type: none"> 1. Promote a safety oriented culture. 2. Learn to understand that the driller is the first line of defence and give him the authority and support to perform flowcheck and shut-in on the well whenever he feels unsure. 3. Ensure good communication between the mud logging unit and the driller. 4. Assign responsibilities to the OIM and toolpusher during well kill operations (Interdependence with "Stress/Stressors" and "Complexity" PSFs).



ABOUT DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.