



Operational safety of FPSOs: Initial summary report

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Operational safety of FPSOs: Initial summary report

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PREFACE

This report presents a summary of some of the observations and recommendations made so far in the research project 'Operational Safety of FPSOs', financed by Esso Norge AS/Exxon Mobil Research Company, Health and Safety Executive and Statoil, and with Navion ASA as a Technology Sponsor. The project is carried out jointly by NTNU and SINTEF, with the Marine Technology Faculty of NTNU as project responsible.

The scope of the research project is to develop methodologies for risk assessment of FPSO vessels with particular emphasis on analysis of operational aspects. This summary report takes a broader view, and considers the use of risk assessment of such installations from an overall perspective. A brief overview is also included of the main characteristics of the FPSO from the point of view of safety prevention and protection against major hazards. Following this brief discussion are some of the main features of the research work carried out in the Joint Industry Project referred to above.

The permission by the companies to publish this summary report is gratefully acknowledged.

SUMMARY

Floating installations in general and FPSO systems in particular, combine traditional process technology with marine technology, and are thus quite dependent on operational safety control. It is essential that scenarios involving potential loss of operational control are assessed at an early stage in the design of new facilities, in order to optimise technical and operational solutions.

The overall objective of the programme is to identify hazard scenarios/events and potential associated human errors and develop models and tools in order to integrate human reliability science into predictive models and tools for analysis of safety of FPSOs. The project is mainly focused on predictive analysis.

The Pre-project phase established the overall risk picture for FPSOs, and has presented an overview of potential FPSO hazards, together with hazard evaluation, resulting in classification of accident frequency, consequence and total risk, including consequences to personnel, environment and assets.

The objective of the first task in the main project is to develop operational hazard models for riser failure due to inadequate response to rapid wind change, analyse risk for case studies and recommend measures to reduce risk for case studies. One swivel based and one dragchain based case study has been considered.

The analysis techniques that are being applied are Task analysis; Error Mode analysis; Fault Tree analysis; Event Tree analysis and Risk Influencing Factor analysis.

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1. INTRODUCTION

1.1 BACKGROUND

Turret moored FPSOs of the mono-hull type have been used in the North Sea for somewhat longer than ten years, so far without serious accidents to personnel. But only one vessel has been in operation for more than 10 years, namely the Golar Nor Offshore owned and operated Petrojarl I vessel. The use of such vessels for field development has increased during the last few years, and nearly 20 fields are currently (mid 2000) either in operation or being developed based on the use of mono-hull vessels for production, storage and off-loading, mainly based on new built vessels. It is likely that quite a substantial number of such installations will be producing oil and gas in the future in the North Sea, in the Far East, off Africa and off South-America.

It could be noted that FPSOs are not new as production units, they have indeed been employed in other parts of the world already for some time, and in quite significant numbers compared to the current North Sea fleet. These vessels have usually been converted cargo tankers with mooring and fluid transfer in the bow of the vessel, sometimes transferred from a loading buoy.

The vessels being installed in the North Sea, Atlantic and Norwegian Sea fields have traditionally been designed for considerably higher environmental loads and often much higher throughput as compared to installations in more benign waters. Without exception, the ones so far installed or under construction for these areas have what is termed 'internal' turret, in the bow or at least well forward of midships, with transfer of pressurised production and injection streams through piping systems in the turret.

Although FPSOs are becoming more common, operational safety performance may still be considered somewhat unproven, especially when compared to fixed installations. Furthermore, floating installations are more dependent on continued operation of some of the marine control systems, during a critical situation. There is accordingly a need to understand the aspects of operational safety for FPSOs, in order to enable a proactive approach to safety, particularly in the following areas:

- Turret operations and flexible risers
- Simultaneous marine and production activities
- Vessel movement/weather exposure
- Production, ballasting and offloading

Accidents are often initiated by errors induced by human and organisational factors (HOF), technical (design) failures or a combination of both. Effective means to prevent or mitigate the effects of potential operational accidents are therefore important for the offshore and marine industries at large.

Predictive risk and reliability techniques have been used in the North Sea offshore industry for almost 20 years, and have contributed to the reduction of the incidence rate of severe accidents. These techniques have traditionally focused more on technical aspects of design, construction and operation, than on human and organisational aspects. Some efforts have also been devoted to modelling of operational safety. These models are mainly descriptive, not predictive, and are thus not very effective in determining how to prevent accidents.

The Joint Industry R&D program called ‘Operational Safety of FPSOs’ was initiated with a pre-project phase conducted from late 1996 until early 1997. The first task of the main project phase was kicked off late in December 1997, and was completed early in 1999. The second phase started in Second Quarter of 1999, to be completed in 2001.

1.2 SCOPE OF REPORT

The general objectives and approach are presented in Chapter 2. The project results will be available as soon as the project is completed. The present report is therefore intended as a preliminary presentation of some of the general aspects of FPSO operational safety.

The main safety features of FPSO concepts and the general safety experience in the North European waters are presented in Chapter 3. This is followed by a brief discussion of the current approaches to consideration of human and organisational safety aspects.

The analysis of operational failures is presented in Chapter 4, followed by the main findings, observations and conclusions in Chapter 5. General conclusions and recommendations are presented in Chapter 6.

1.3 ABBREVIATIONS

APJ	- Absolute Probability Judgment	HOF	- Human and Organisational Factors
CCR	- Central Control Room	HRA	- Human Reliability Assessment
CO	- Crane Operator	HTA	- Hierarchical Task Analysis
CRIOP	- Crisis Intervention in Offshore Production	MP	- Main Project
CRO	- Control Room operator	ODO	- Outdoor Operator
DP	- Dynamic Positioning	PM	- Position Monitoring
FAR	- Fatal Accident Rate	QRA	- Quantitative Risk Assessment
FPSO	- Floating Production, Storage and Offloading	RIF	- Risk Influencing Factor
FSU	- Floating Storage Unit	SLIM	- Success Likelihood Index Method
FTA	- Fault Tree Analysis	THERP	- Technique for Human Error Rate Prediction
HAZOP	- Hazard and Operability study	TTA	- Tabular Task Analysis
HEART	- Human Error And Reduction Technique	UK	- United Kingdom
HEP	- Human Error Probability	VOC	- Volatile Organic Components

2. OVERALL OBJECTIVES AND APPROACH

2.1 OVERALL PROGRAMME

The overall objective of the programme is to identify hazard scenarios/events and potential associated human errors and develop models and tools in order to integrate human reliability science into predictive models and tools for analysis of safety of FPSOs.

The starting point for the project has been the analytical work that has been ongoing for more than a decade related to design and analysis of offshore installations and ships, in particular the overall risk analysis and structural reliability studies.

The Pre-project phase established the overall risk picture for FPSOs, and has presented an overview of potential FPSO hazards, together with hazard evaluation, resulting in classification of accident frequency, consequence and total risk, including consequences to personnel, environment and assets. This hazard evaluation and risk analysis was used in order to identify subjects for the main project phases. A summary of the evaluation is presented in Section 3.3.

A complete programme was defined, consisting of the following part projects:

- MP1: Accident during tank operations, including ballasting, loading and off-loading
- MP2: Tank explosion during intervention
- MP3: Riser failure due to inadequate response to rapid wind change
- MP4: Loss of hydrocarbon containment due to failure during load handling by cranes
- MP5: Organisational reliability study

It was decided to start with the MP3 part project. The next activity that has been initiated (in 1999) is MP1. The MP1 activity is still ongoing (anticipated to be completed in 2001), and this summary report is mainly based on the MP3 part project on riser failures, which was completed in 1999.

2.2 OBJECTIVES - MP3 - RISER FAILURE DUE TO RAPID WIND CHANGE

The objective of the first task (MP3) in the Main Project is as follows:

- Develop operational hazard models for riser failure due to inadequate response to rapid wind change, in order to integrate human reliability knowledge and experience into predictive models and tools for analysis of safety of FPSOs.
- Analyse risk for case studies.
- Recommend measures to reduce risk for case studies.

It was decided that one swivel based and one dragchain based case study should be performed.

2.3 APPROACH

The approach in the study is to carry out a methodology demonstration, whereby different analysis techniques are applied in order to establish which methodology is most suitable and

also to gain experience in such use. The analysis techniques that are being applied are the following:

- Task analysis
- Action Error Mode analysis
- Fault Tree analysis
- Event Tree analysis
- Risk Influencing Factor analysis

The project is mainly focused on predictive analysis. The background is that a relatively frequent activity in Human and Organisational Factors (HOF) analysis in the last few years has been to create classification systems and nomenclature that is suited for post accident analysis. While this is certainly useful in its own regard, it is only one of the building blocks towards being able to determine the contribution from the HOF solutions chosen, in relation to the total system reliability.

2.4 ANALYSIS ENVELOPE

The project in general, considers the total production and off-take system, consisting of:

- FPSO
- Off-loading arrangements
- Shuttle tanker when in off-loading mode
- Supply vessels during transfer for cargo between vessels

The FPSO is the main focus in the project. MP3 considers the FPSO exclusively.

Figure 1 illustrates the difference between the analysis envelope for the project in general, and the analysis envelope for the MP3 part project.

The operational aspects (human and organisational factors) that have to be addressed in the project in general are therefore applicable to organisations within the total analysis envelope. This implies that the operating organisations of both the FPSO and the shuttle tanker when in off-loading mode are within the scope of the analysis for the total project.

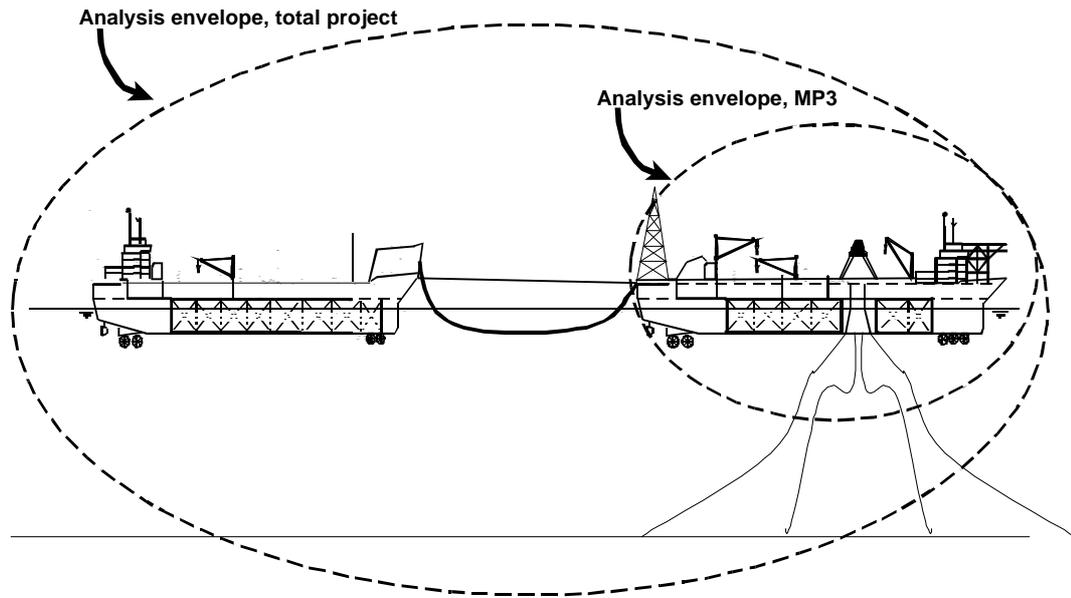


Figure 1
Analysis envelopes

2.5 LIMITATIONS

Only FPSOs with internal, active turrets have been covered in the MP3 project. This implies that the external turret concept (possibly using a yoke or spread mooring loading buoy) has not been addressed, nor has the internal, passive turret concept.

The primary focus of the work is on system induced major accidents. ‘System induced’ failures are such events where a sequence of failures and/or inadequate responses together lead to a major accident. Major accidents may occur due to technical and/or operational failures, the latter may be caused by human and organisational errors. The present work is to a large degree limited to aspects such as man/machine interface, availability and effectiveness of operational procedures, and other factors which directly affect a person’s performance (stress, system understanding, tiredness, etc.). More organisational related factors, such as work organisation, operator training programmes, etc. are to a lesser degree covered. Furthermore, failure scenarios that are initiated by technical failures and which are escalated through operational failures (or visa versa) are also covered.

The primary focus on major accidents implies that there is no particular emphasis on potential causes of occupational accidents. They are briefly addressed, but without making sure that all possible sources for such accidents have been covered.

Risk to personnel is the primary focus, but some emphasis is also placed on risk to the environment when relevant. Risk to assets for an FPSO will largely follow the risk for personnel, as will the environmental risk, when limited to the potential spill sources on the FPSO itself. Spills from subsea production equipment and pipelines are distinctly different, and are not closely related with the FPSO with respect to accidental consequences. Risk to personnel is in conclusion the primary emphasis of the project.

The project is aimed at integration of operational safety aspects into risk assessments for FPSOs. It could be argued that the methodology should enable quantification of the contributions to risk from human and organisational aspects. It was nevertheless decided that quantification would not be attempted during the ‘MP3’ task of the project.

3. SAFETY ASPECTS OF FPSOS IN NORTH EUROPEAN WATERS

3.1 MAIN TECHNICAL SAFETY FEATURES

This section introduces briefly some of the main safety protection features used on the majority of the FPSOs installed in North European waters. Where there are differences in the approaches used, these are briefly noted. The main emphasis in this section is on technical aspects, partly because these can be directly observed, and are therefore quite well known. Differences in human and organisational aspects are not generally known to the same extent. The differences in technical solutions and capabilities will further also determine a significant number of the requirements for operational control and the abilities to cope with abnormal conditions.

3.1.1 Purpose Built or Converted Tanker

The majority of the FPSOs in the North Sea are purpose built vessels, where all features and functions may be tailored to the floating production mode. The use of converted tankers implies that some restrictions are placed on for instance the ability to move quarters and/or other rooms and systems within the hull.

3.1.2 Vessel Layout

The location of the accommodation unit (including main muster area) has extensive influence on safety for personnel. Most of the purpose built vessels have the personnel quarters unit (and the helideck) in the bow, forward of the turret, implying that mustering is available upwind of any source of hydrocarbon release. This is not considered feasible when a converted tanker is used, the quarters has to remain in the stern, where sailing tankers have the accommodation. The bow is that area on the vessel where the motions are the highest, so this location may be the worst with respect to comfort of personnel.

The helideck in the bow implies the most challenging landing conditions for helicopters, during landing in severe weather conditions or darkness.

Furthermore, it has been argued that launching of lifeboats and other escape means may be more difficult when located in the bow as compared to being located at the stern.

The arrangement of other systems, such as the turret, and the flare also becomes more flexible with the accommodation in the stern, but the flare needs to be at a safe distance from the accommodation in any case.

The choice is essentially then between some additional flexibility, everyday comfort and helicopter landing conditions, or improved protection in a major accident involving fire or explosion. Obviously, the comfort level may impact the operators' behaviour in daily running of the vessel and possibly also in handling of emergencies. Most new built vessels in harsh environment nevertheless have quarters in the bow. Hence, the final choice is a complicated issue, which cannot be fully resolved in this brief discussion.

3.1.3 Heading Control and Station Keeping

Many of the vessels in the North Sea have thrusters installed for active heading control, but there are a significant number of vessels without the ability to control heading, thus completely

weathervaning. Mooring systems are installed on the turret for station keeping, typically 8, 10 or 12 point mooring systems. Some of the vessels have main propulsion retained, some do not have this capability.

Both thrusters and main propulsion may be used in order to reduce motions and loads on the mooring lines. These systems may also be used in the case of anchor line failure, in order to compensate for the failed line(s), and thus possibly prevent escalation into multiple anchor line failure.

There are also clear indications that active heading control is advantageous during off-loading operations, in order to reduce risks from these operations.

3.1.4 Off-loading Arrangements

FPSOs in the North European waters have, with few exceptions, off-loading over the stern of the vessel, with an off-loading hose stored on a reel or alongside the side of the vessel.

The distance from the FPSO to the bow of the shuttle tanker is usually in the range of 50 to 110 metres. Two concepts for station keeping of the shuttle tanker are used for maintaining a fixed distance between the shuttle tanker and the FPSO during off-loading:

- Dynamic Positioning (DP) system
- Taut hawser

In the case of DP operated shuttle tankers, these are either DP1 or DP2, the first category having no requirements to redundancy in the DP system, the second category being required to have redundant components for all active systems. Quite often a tanker may be classified as 'almost DP2', if all but one of the components are redundant.

3.1.5 Fire and Explosion Protection

Fire and explosion protection is associated with hydrocarbon handling, processing, storage of crude oil in the cargo tanks as well as off-loading. The fire and explosion protection is in accordance with standard practice for offshore production installations, consisting of:

- Gas detection
- Fire detection
- Emergency shutdown system
- Use of Explosion 'proof' equipment
- Active fire protection
- Passive fire and explosion protection

There are also strict procedures implemented for control of the fire and explosion hazards.

All of the purpose built FPSOs have the process deck elevated some few meters above the tank top, in order to provide separation between process and storage.

Protection against tank explosion is with one exception based on traditional tanker practice, and is by means of Inert Gas purging systems. The use of common headers, venting lines and re-

dundancy in the pressure relieving function does vary. One new FPSO is using hydrocarbon gas for tank purging, for environmental protection (VOC) reasons.

The fire and explosion protection associated with the off-loading systems is integrated in the FPSO's hydrocarbon processing systems, and includes facilities for emergency shutdown and quick release of the off-loading hose.

3.1.6 Escape and Evacuation

Several vessels have an escape tunnel installed along one side of the vessel, usually running from the utility/off-loading area in the stern all the way to the accommodation in the bow. The escape tunnel is usually fire/explosion protected (with active or passive protection) and overpressure ventilated in order to prevent ingress of smoke in a fire scenario. Such a tunnel gives an opportunity for a second, independent escape route from most areas, which is a common requirement by regulations and standards.

Many of the FPSOs have ramp launched free fall type lifeboats, whereas some still use conventional lifeboats. The main evacuation station is next to the quarters, whereas several of the FPSOs also have a secondary lifeboat station in the opposite end of the vessel.

Both the escape tunnel and the lifeboat concept are dependent on whether the vessel is purpose built or converted. Converted tankers usually have conventional lifeboats and escape over open deck space.

3.2 SAFETY RECORDS OF FPSOS

3.2.1 Total Loss

There have been no total losses worldwide of FPSOs, nor any serious accidents for personnel (i.e. with loss of life). Two total losses have occurred for other floating production units, one off West-Africa during tow and one in the Gulf Of Mexico during hurricane. Both these incidents involved converted mobile drilling units and in neither case were lives lost. These two total losses are, however, not considered relevant for the present context of the FPSOs.

In some reports, the converted tanker Lan Shui has been described as experiencing a constructive total loss due to engine room fire, on 21. January, 1990. The fire is described by Lloyds' List as lasting for 29 hours, with extensive damage to engine room, but no damage on process or storage areas, and no pollution. The information further shows Lan Shui remained on location for several weeks, and was later converted for production on the Bongkot field (Thailand) after 1993. The accident should therefore be considered as a severe engine room fire, not as a total loss.

3.2.2 Serious Accidents and Incidents

Two serious accidents without loss of life are:

- Engine room fire on Lan Shui FPSO (South-East Asia) 21. January, 1990 (see Section 3.2.1).
- Overpressure in cargo tank, Uisge Gorm FPSO, 4. April 1999, due to valve in vent line not having been reopened after maintenance. The vessel sustained severe hull damage requiring repair in yard, vessel was back in operation after some 100 days, in mid august 1999.

It may be a coincidence, but it may be interesting to note that both these two accidents occurred on converted tankers, and both were associated with 'ship systems' rather than hydrocarbon processing systems. With only two events however, the number is far too low to draw any firm conclusions.

3.2.3 Less Serious Accidents

There has been an increased focus on safety of FPSOs in the North Sea recently, in association with incidents that have occurred in the period since 1996. Five out of six of these incidents were related to contact between shuttle tanker and FPSO/FSU. None of these impacts was critical and in fact, the consequences have been very marginal. However, they place focus on operational safety aspects. Also the last incident referred to under 'serious accidents' (April 1999), was associated with operational aspects, resulting in structural damage due to overpressure of a cargo tank.

The fact that these incidents occurred without serious effects should not be taken to imply that there is limited potential for serious accidents. There is a significant potential for major accidents from such operational errors, even though the impacts that have occurred during the last few years have been limited. The fatal accident in the North Sea in 1980 on a shuttle tanker, due to a fire during off-loading, may also be mentioned in this context.

The following is a brief overview of incidents that are known from operation FPSOs in the North European waters.

Table 1
Overview of less serious accidents to FPSOs in the North European waters

Accident/incident category	Known occurrences
Fire and explosion in hydrocarbon systems	None known
Fire in cargo storage or off-loading	None known
Other fires	None known in North European waters
Collision and collision threats	<ul style="list-style-type: none"> • Shuttle tanker threatening Petrojarl I on 21. November, 1986 due to partial loss of main propulsion. • Impact by shuttle tanker into Emerald FSU, 28. February, 1996. • Impact by shuttle tanker into Gryphon Alpha FPSO, 26. July 1997. • Impact by shuttle tanker into Captain FPSO, 12. August, 1997. • Impact by shuttle tanker into Scheihallion FPSO, 25. September, 1998. • Impact by shuttle tanker into Norne FPSO, 5. March, 2000.
Environmental impact, mooring failure	<ul style="list-style-type: none"> • Petrojarl I experienced multiple anchor line failure in 50-55 knots NW wind, after being hit by 20-25 m high wave, 30. January, 1994, about 60 miles North-East of Lerwick (Hudson field). The multiple line failure (4 of 8) was gradual, and occurred over a period of approximately 8 hours, initially losing two lines due to the big wave. After that incident, production was shut down, and the vessel kept on station by remaining lines and main propulsion. She was never off station and started reconnecting of the lines the day after. Personnel were never taken off, and the vessel always had the possibility of quick disconnection. • Damage to superstructure by green seas of Scheihallion FPSO on 9. November, 1998. • Damage to Norne FPSO by green seas in March 1998.
Electrical failure	<ul style="list-style-type: none"> • Alba FSU, UK, 31. December, 1994, electric failure. • Uisge Gorm, FPSO, UK, 28.5.96, black out of power in 5-6 hours, production shut down, no other damage. • Other blackouts are known, but no details.

The incidents are few in number, so the possible use of these for risk level prediction purposes is limited. If incidents in other areas are considered, there are also a few others reported, with limited information available in most of these cases:

- Zakir Hussein, FSU, fire in accommodation, 14. November 1991.
- Large Gas Leak, Griffin Venture, W. Australia, 3. January, 1996.

- Nanhai Sheng Li, October 96, south China Sea, minor damage due to typhoon.
- Griffin Venture, 10. November, 1997, W. Australia, engine room fire.

It may perhaps be noteworthy that two engine room fires have occurred, Lan Shui and Griffin Venture. Such accidents are not uncommon for commercial tankers, and may therefore indicate the need for improvement of safety standards when converted tankers are employed as offshore installations.

It is known from FPSOs and FSUs in other areas that some minor impacts by off-loading tankers have occurred, but the details of these incidents are not known, besides the fact that the impact energies have been quite low.

3.3 HAZARD RANKING

An identification and ranking of potential hazards was carried out in the Pre-project phase¹, resulting in the following list of hazards:

Marine and hull related accidents, structural impacts

- M1 Hull failure due to extreme wave load
- M2 Hull failure or marine accident due to ballast failure or failure during loading/off-loading operations
- M3 Leak from cargo tank caused by fatigue
- M4 Accident during tank intervention
- M5 Passing vessel collision with FPSO or shuttle tanker
- M6 Strong collision by supply vessel with FPSO or shuttle tanker
- M7 Other vessels or floating structures operating on the field colliding with FPSO or shuttle tanker
- M8 Collision during offloading
- M9 Rapid change of wind direction
- M10 Multiple anchor failure

Hydrocarbon systems accidents

- H1 Leak that may lead to fire or explosion in process plant
- H2 Leak from turret systems that may cause fire or explosion in turret
- H3 Leak or rupture of riser
- H4 Impacting loads due to crane operations (swinging loads) on a moving vessel
- H5 Dropped object from retrieval of cargo pumps
- H6 Severe rolling during critical operations, such as crane operations (considered as included in other scenarios, therefore not addressed separately)
- H7 "Topside" fire threatening cargo tank

- H8 Emergency flaring with approaching shuttle tanker or during off-loading
- H9 Unintended release of riser
- H10 Work in open air spaces during winter conditions

Auxiliary systems accidents

- A1 Failure of cargo tank explosion prevention function during normal operation
- A2 Fire or explosion in pump room
- A3 Spill from off-loading system.
- A4 Engine room fire or explosion
- A5 Helicopter crash

The ranking of the hazards was based on frequency as well as consequence. The classification of consequence reflects personnel consequences only, but it should be noted that consequences to environment and assets largely follow the same patterns as the consequences to personnel. The following broad categories of risk resulted (starting with the highest):

- Risk category 1: M2, M8, M9, M10, H1, H2, H3, A2
- Risk category 2: M1, M4, M5, M6, H4, H5, H7, H10, A1, A3, A4
- Risk category 3: M3, M7, H8, H9, A5

In addition to the risk categories reported above, two aspects were considered in particular, i.e. the FPSO uniqueness and the importance of HOF. When these two additional ‘filters’ were applied, the list was limited to the following:

- Risk category 1: M2 (ballast/loading/off-loading), M8 (collision during off-loading)
- Risk category 2: M4, (tank explosion during intervention), M9 (wind direction change), H4 (swinging crane loads), H5 (deep well pump retrieval), H10 (work in open air)
- Risk category 3: M3 (working accident during tank intervention)

The majority of these hazards are associated with the cargo storage function directly or indirectly, as follows:

- M2, marine accident associated with ballasting operations during /loading and off-loading
- M4, tank explosion during intervention
- M8, collision between FPSO and shuttle tanker during off-loading
- H5, impact load on process equipment during retrieval of deep well pump
- M3, working accident during tank intervention

3.4 ARE OPERATIONAL FAILURES IMPORTANT?

The production installations in the North Sea have traditionally been either gravity based, concrete structures or steel jackets. Once in place, the integrity of the structures is not dependent

on day-to-day operational control, except if production or process associated incidents or events escalate to scenarios so severe that integrity is threatened. Some of the barriers will be dependent on operational activation and control in these severe circumstances.

With the introduction of floating production concepts, new risks have been introduced. Now there are aspects of structural integrity that are dependent on operational control. Floating structures are often dependent on ballast systems and mooring systems. Experience data from mobile drilling units have shown that both ballast and mooring system incidents are often caused by human and organisational errors. Many of the accidents have been relatively minor, without implications for integrity, but the potential has been present. Sometimes the structural integrity may be severely threatened, (e.g. the capsizing of mobile drilling unit 'Ocean Ranger' offshore Newfoundland in 1982 may be a typical example of such an event). This capsizing was associated with loss of operational control.

The extent of low speed impacts from shuttle tankers into FPSOs in the North Sea has been a concern in the last few years. Human and organisational factors have been critical elements of these incidents, at least to the extent the circumstances are known. Experience from these events shows that an important aspect in these events is the ability to act sufficiently early and extensively in order to avoid contact between the vessels.

This is further demonstrated by incidents involving operational problems related to shuttle tankers and off-loading buoys for crude oil export from fixed production installations. Most of these incidents have resulted in little or no effects (e.g. resulting in ruptured hose and small oil spills).

3.5 CURRENT APPROACH TO HUMAN AND ORGANISATIONAL ASPECTS OF FPSO SAFETY

3.5.1 Modelling of Operational Safety

Human and Organisational Factors (HOF) corresponds to what is often termed 'Human Factors'. The general model for presenting what is included in HOF is based on general industry practices, and includes the following elements:

- People
- Equipment (e.g. hardware)
- Management systems
- Culture and environment

The principle of the model is shown in Figure 2, where the interactions between the elements of the model are shown as intersections between the different elements. Equipment, people and management systems are shown as elements within the framework created by culture and environment. Examples of management systems include:

- Procedures
- Communication
- Training
- Management of change
- Risk assessment

Another aspect of this modelling is that a 'Life-cycle approach' has to be taken, these aspects have to be addressed with respect to design, construction, installation, operation, maintenance and decommissioning.

This approach has however, mainly been taken in research activities, and less systematically in the practical design and during operations phase.

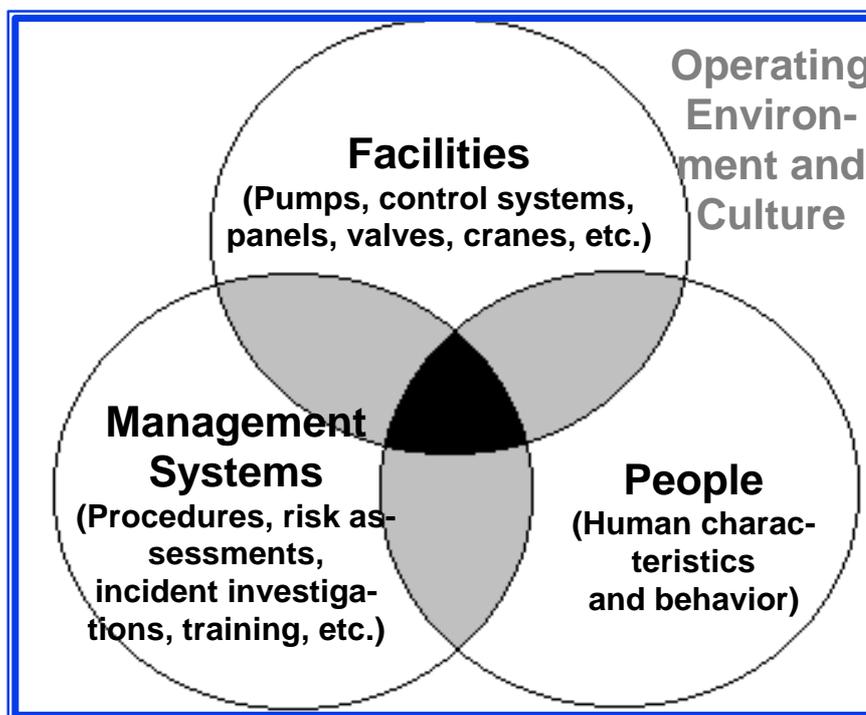


Figure 2
Conceptual model for operational safety/HOF aspects

3.5.2 Approach taken in Design

The current approach to analysing operational safety during the design phase appears mainly to be based on what is identified through the various risk assessments and safety studies. This implies that the depth of the consideration of these aspects is quite dependent on how well the assessments and studies are structured. Risk assessments are discussed in the following section.

Human and organisational aspects of safety can not be considered in isolation from the technical systems. Technical philosophies and specifications are therefore important, in order to present the interface between the systems and the operators.

Panels and control stations in the main control room and elsewhere have usually been designed and laid out based upon human factors engineering. Independent evaluations of these aspects may also be carried out. One example in this respect is the performance of CRIOP analyses (CRIOP = Crisis Intervention in Offshore Production) during late detail engineering².

A total integrated and systematic system approach to human and organisational aspects regarding the control of the FPSO operations in the design phase is not evident from the project risk assessment work.

In most cases, a project is focusing on traditional technical processes and marine solutions to achieve operations control. Personnel with a traditional process control background may have limited experience with the marine control aspects that are involved. Selection and training of personnel for these tasks are therefore important to ensure that process control as well as marine operations are conducted safely.

3.5.3 Approach taken in Risk Assessments

Global risk assessments are usually carried out during field development phases, concept studies and engineering phases. Qualitative as well as quantitative studies are usually carried out. The qualitative studies are such studies as HAZOP studies and scenario analysis. The use of HAZOP studies is often quite extensive for process and selected utility systems, and is not very different from what is done for fixed production installations. Quantitative studies are usually Concept Safety Evaluations and Quantitative Risk Assessments (QRA) studies.

An overview of risk contributions from major hazards, as predicted in QRA studies, was established in the pre-project phase. Table 2 presents a summary of the relative contributions in the different projects which at the time were all in the construction phase. There are some differences with respect to how the contributions are categorised, but there are nevertheless some clear observations that may be made:

- Hydrocarbon associated risk (process, turret and riser systems) is the highest contribution for all FPSOs considered.
- Collision risk represents a significant contribution for two of the FPSOs (all potential collision scenarios are included, but shuttle tanker impact is the dominating contribution).
- Occupational accidents and accidents during helicopter transport were only included for one of the cases.

Table 2
Comparison of relative risk contributions

<i>Hazard category</i>	<i>FPSO i</i> <i>(escape way impairment risk)</i>	<i>FPSO ii</i> <i>(FAR values)</i>	<i>FPSO iii</i> <i>(FAR values)</i>	<i>FPSO iv</i> <i>(FAR values)</i>
Process/turret/riser	46%	64%	90%	80-90%
Cargo tanks	} 10%	7%	low	Low
Marine/structural		} 2.7%	few percent	few percent
Collision	43%]	few percent
Occupational accidents	-	7%	-	-
Shore transport	-	19%	-	-

This table may be taken to indicate that the risk assessments are mainly focused on assessing the same type of hazards for the FPSOs as they are commonly considering for fixed production installations.

There are at least three aspects of risk assessments application in the design phase that have probably contributed to why QRA studies do not thoroughly address the operational safety aspects:

- Quantitative risk assessments infrequently focus on accident causation, predominantly they are focused on accident consequences (event trees/escalation analysis).
- The assessments usually focus on technical systems (not operational systems).
- Risk management in design phases does not normally require assessment of human reliability, due to lack of relevant information or experience at an early design stage.

It is usually considered sufficient at an early design stage to establish frequencies of initiating events based on accident statistics, without considering the potential causes leading to the initial events.

A comparison between what the typical QRA studies have identified as possible accident causes and what was identified in the detailed HOF based analysis in MP3, demonstrated that several failure scenarios had not been identified through the QRA. Some of these failures may occur in normal operations, whereas others may be associated with response to external threats or abnormal conditions (see also Section 4.9.2).

It could perhaps be argued that a study like the present one will inevitably come up with a number of potential issues because so much focus is placed on the operational/procedural conditions. Also, the level of detail in this study exceeds by far that of a traditional QRA for the hazard under consideration. Experience from the FPSO operation in the North Sea has demonstrated that human and procedural aspects of safety are very important. Several of the impacts by shuttle tankers mentioned above have been associated with inadequate operational control, (human errors) often in association with initiating events of a technical nature.

3.5.4 Approach taken in Operation

The approach taken to control operational risk aspects is based on the use of procedures, the operators' own knowledge and experience, and technical redundancy, alarms and operational limitations.

When collecting information for one particular case it was clearly demonstrated that the following situation had occurred:

- The designers (supplier's personnel) intended the operation of the system to be one way.
- The procedures had been written by the operating company for a somewhat different operation.
- When talking to the personnel on the installation, it became clear that they preferred to operate the system in an even further modified way.

The procedures had not been modified in order to reflect the preferred way of operating the system. It was realised that even though the operational manner followed was the easiest in a day to day operation, it could be more susceptible to human error.

Another observation that has been made in the project is that procedures sometimes are relatively functional, without detailed and specific steps to be carried out. This gives quite considerable freedom for the operational staff, which on the one hand may give flexibility for optimisation, but on the other hand also allow unwanted practices to be established. There is considerable variation in this regard, indicating that more detailed procedures may be prepared for some vessels. This is an advantage, from the point of view of preventing unwanted behaviour and error-prone operation.

Operation of FPSOs is relatively novel, and the number of personnel with broad experience is quite limited. This applies to the operating staff of the FPSO as well as the shuttle tankers, and is particularly relevant for operation in abnormal and/or adverse weather conditions. Some of the incidents that have occurred, have shown that experience and understanding of indications, warnings and responses is particularly challenging in such situations.

4. ANALYSIS OF OPERATIONAL FAILURE SCENARIOS

4.1 PURPOSE OF CASE STUDIES

The case studies^{3,4} that were carried out in the MP3 part project in 1998 were directed at potential turret failure scenarios, with riser damage as the worst consequences. The purposes of the case studies are the following:

- Test out the methodology with relevant examples
- Illustrate the use of the methodology
- Consider two typical concept alternatives with respect to how further risk reduction may be provided for these alternatives

The generalised experience from the case studies is briefly discussed in the following, with the main emphasis on the MP3 part project. More general experiences are also mentioned.

4.2 COLLECTION OF DATA, DOCUMENTATION AND EXPERIENCE

The main experience relating to the collection of data and documentation is that a mixture of documentation reviews and personal communication had to be utilised. One of the general observations in this respect, is that the level of details necessary to perform HRA studies, in addition to written documentation, often requires meetings with operations personnel and if possible visits to operating installations. The actual data collection commenced as follows:

- The first case study considered was actually in operation, which did provide a valuable additional source of information for the analysis. A one-day meeting with two operators was conducted initially. During this meeting, a need for observing the actual systems and operations in real life was identified.
- Consequently, a four-day visit to the installation was arranged. Visual observations as well as 'walk-through' and 'talk-through' exercises in the CCR and turret area were conducted by experienced operators. Based on this visit, the analyst documented a detailed procedure for the turning operation, based on discussion with the operating crew. In addition, potential errors and error sources were thoroughly discussed with the operators.

For the second concept, operation had not commenced and the main part of the data collection has been performed by going through written project documentation. In addition, questions and uncertainties were classified through communication with operations personnel.

For the planning of the studies it could be noted that quite detailed input is required in order to perform a dedicated evaluation of possible HOF influenced accident scenarios. This will to some extent complicate the use of such evaluations at an early stage of project development.

Several different types of analyses have been used in order to identify and analyse risk scenarios. These included:

- Task analysis
- Human Error analysis
- Fault Tree analysis

- Event Tree analysis
- Risk Influencing Factor analysis

Each of these analyses is discussed below.

4.3 TASK ANALYSIS

The task analysis was performed based on the detailed procedure established during the data collection phase. The main objectives of the task analysis have been to support the identification of error modes, the criticality evaluation, and the identification of potential improvements by:

- Adding details to the scenario description when needed.
- Specifying the context in which important actions (task steps) take place, in particular the information available to the actors and relevant aspects of human machine interaction.
- Identification of aspects in relation to information, control and co-ordination which may contribute to less than adequate performance and thus are potential areas of improvement.

Hierarchical Task Analysis and Tabular Task Analysis are the two task analysis techniques that have been applied.

Hierarchical Task Analysis (HTA) is, as indicated by its name, a hierarchical approach, describing the relevant task or operation from its overall objective down to individual operations. HTA has been used in this study in order to give a graphical representation of the turning procedure.

Tabular Task Analysis (TTA) was performed in order to specify the context in which important task steps take place and to identify aspects which may be improved. The TTA format applied concentrates on:

- **Cues** which indicate to the operator that a task step can/should be initiated.
- **Feedback** indicating the effects of carrying out a task step.
- **Traces** which indicate to the operator that the task step has actually been performed and finalised successfully.

Table 3 shows a brief excerpt of the Tabular Task analysis for one of the case studies.

4.4 HUMAN ERROR ANALYSIS

Reason⁵ has produced a framework for understanding of human errors, often referred to as the *Slips, lapses, mistakes and violations model*. This framework has proved useful for the type of errors that have been considered in the project.

Table 3
Tabular Task Analysis of vessel/turret turning procedure

Tabular Task Analysis		Task Description: Change of heading		
Task step description	Cues	Feed-back	Traces	Comments / Illustrations
1. CRO notices that the wind and wave changes or has changed direction	- visual observation out through the windows (daytime) - from alarm on heading deviation (>8°) - from different displays showing wind direction	NA	NA	The operator will realise that that the wind changes or has changed direction based on visual cues. Due to maintenance or other operation on the turret, there may be a large deviation between optimal heading and actual heading relative to the wind. The decision of change of heading is largely up to the CRO and can also be based on a request/wish from the connected shuttle tanker (if relevant)
2. The CRO notifies the ODO/CO via radio that he plans to change the heading of the vessel	Input from step 1., i.e. change of wind and wave direction or other input which triggers a decision to change vessel heading	ODO/CO may confirm request	None	This task step is only cued by sequence.

Although the project's main goal has been to focus on errors performed by the operators (active errors), the complex nature of the problem has made it necessary also to include other error types. This has included latent system errors such as errors introduced during maintenance and technical errors such as a sensor failing to respond.

The **Action Error Mode Analysis** technique, resembling the *Human HAZOP*, has been used to identify human errors for each task to be analysed. For each task step, possible erroneous actions are identified using guide words such as 'omitted', 'too early', 'too late', etc. Furthermore, possible abnormal system states are identified, in order to consider consequences of carrying out the task step (correctly or incorrectly) during abnormal system states (e.g., specific hardware failures). The consequences of erroneous actions and to some degrees combinations of erroneous actions and abnormal system states are identified. Possibilities for recovery (i.e. detection and correction of erroneous actions) are also identified and described in order to support criticality ratings.

Table 4 presents a brief glimpse of one of the Action Error Mode analyses of the FPSO turning for the swivel based case study.

Table 4
Action Error Mode Analysis of vessel/turret turning procedure

Scenario description: Turning of FPSO w/swivel		Normal turning conditions		
Description of task steps	Potential human error / abnormal condition	Potential consequences (worst case)	Possibilities of recovery	Influencing / performance shaping factors
1. The CRO notices that wind changes direction	Omits, i.e. does not notice that wind changes direction	Delayed turning of the vessel Wind will come in from the «wrong» direction ⇒ potential problems with flare heat loads	- separate display showing the wind direction relative to the vessel, and/or - DP/PM console display indicating the wind direction relative to the vessel, and/or - can see the wind changing direction from one of the video-screens showing the flare, and/or - visual observation out through the windows (daytime)	Time pressure, tiredness, inadequate layout and/or feedback from signal-givers

4.5 FAULT TREE ANALYSIS

Fault Tree Analysis (FTA) is a top-down approach used both in quantitative and qualitative assessments. It starts with a ‘*top-event*’, which for our case can be damage of riser or a possible contact between shuttle tanker and FPSO. The system is then investigated to define combination of events (human, technical, environmental, etc.) that may cause the top event to occur. A fault tree uses *gates*: ‘AND’ (logical intersection) and ‘OR’ (logical union) gates. FTA is therefore a deductive technique, identifying and representing logically often complex failure mechanisms, some of which may involve human errors.

An advantage with the fault tree technique is the opportunity to combine human and technical errors into one common framework, hence enabling a complete model of the problem. Another advantage in using FTA is that the analyst has to have or obtain a thorough understanding of the interactions and logical dependencies in the system. Hence, weaknesses in the system should be revealed during the construction of the fault tree.

A challenge when using fault trees is to control the tendency of growing with the complexity of the problem, thus becoming large and difficult to follow. Furthermore, a fault tree provides an overview of the potential error conditions that may result in the top event. The Fault Tree lacks the ability to present a representation of any dynamic nature of the operation being assessed. Care should be taken when using FTA to identify the most credible human, organisational and technical errors, due to this aspect.

Another challenge with fault tree analysis is how to treat dependencies between events such as common cause and/or common mode failures.

The following diagram presents the top levels of the fault tree for the potential riser damage failures for on of the concepts considered.

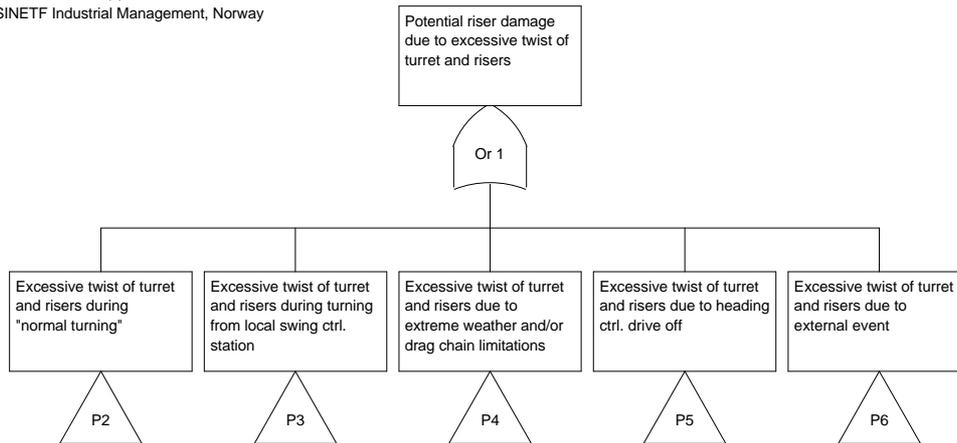


Figure 3
Top level Fault Tree for 'Potential riser damage due to excessive twist', dragchain concept

There are different alternatives for structuring a fault tree, especially for the highest levels. The fault tree shown above focuses on the events which may cause the scenario. The general experience was that this approach was preferable, since it appeared to introduce fewer dependencies between the different branches of the fault tree. Furthermore, it will often be more comprehensible than a structure which reflects the different physical mechanisms by which the accident scenario can occur.

Some of the problems that have been experienced with the fault tree are:

- How to model an operational failure scenario which often develops over time in a fairly rigid fault tree structure.
- How to capture the complex mechanisms and the variety of 'failure paths' which may result in a failure.
- How to capture the effect of different risk influencing factors including their mutual interactions.
- Where to locate the operator errors and in particular the error recoveries, higher or lower in the tree.

In particular the second and third of these questions again led to the attempted influence diagram, see separate discussion below.

4.6 EVENT TREE ANALYSIS

Another alternative may be to combine the use of fault trees and event trees. The causes of failures may in this approach be modelled through a fault tree, whereas the sequences may be illustrated better through an event tree. The event tree can also more easily display influence of several barriers.

Event trees are on the other hand not very suitable for illustrating sequences which may involve loops, nor is it easy to illustrate the detailed timing of the sequences.

4.7 RISK INFLUENCING FACTOR ANALYSIS

An additional approach to using fault trees and event trees is being tested out in the project, based on the use of a Risk Influencing Factor (RIF) diagrams.

Risk influence diagrams and related techniques have proved particularly useful as a systematic approach to *identify and evaluate risk reduction strategies* for a given activity or system⁶. These techniques may be more suitable means of modeling of operational safety aspects of FPSOs, capable of capturing the complexity of the operations. Figure 4 below shows an example of a (simplified) risk influence diagram for the hazard of collision between shuttle tanker and FPSO.

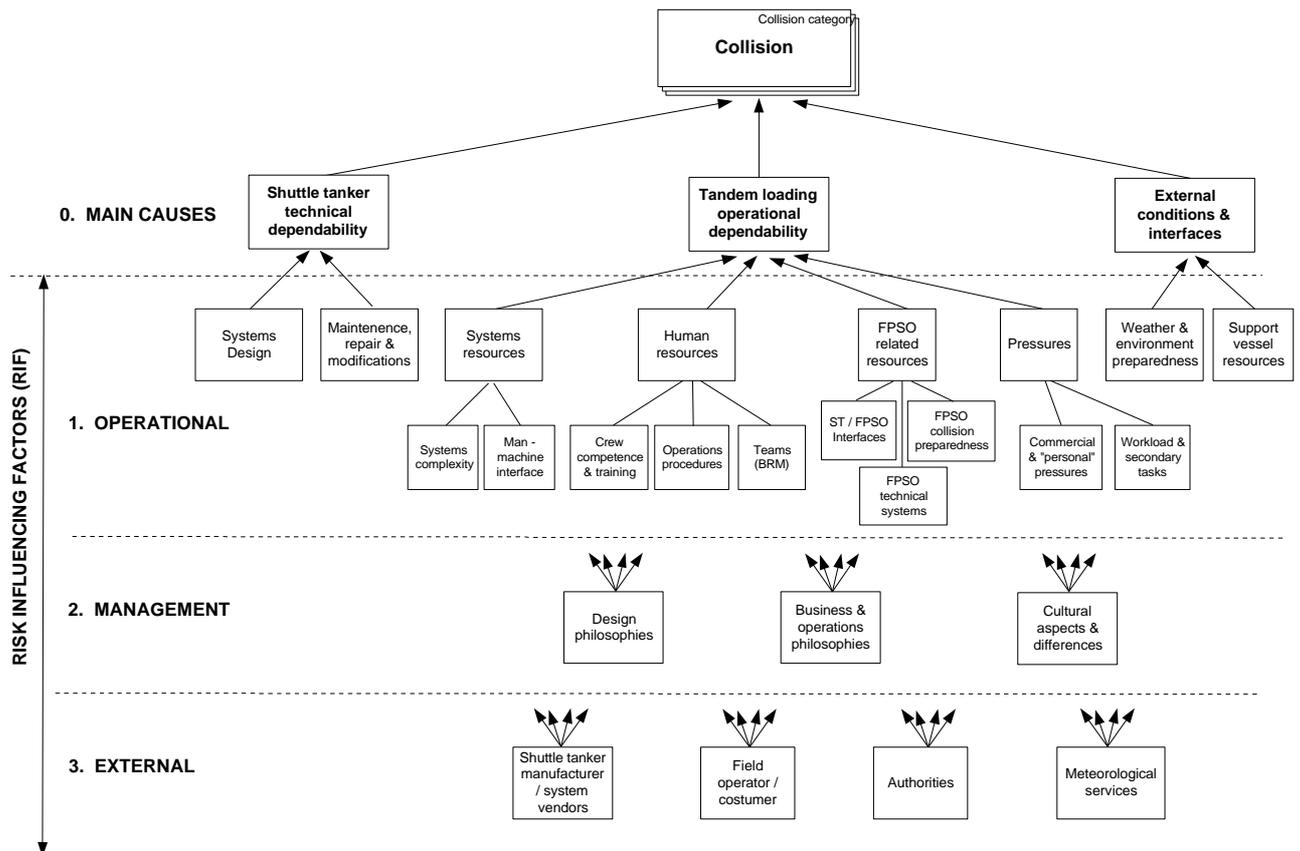


Figure 4
Illustrative RIF diagram

4.8 QUANTIFICATION OF HUMAN RELIABILITY

Generally, limited data on Human Error Probability (HEP) are available from offshore operations, which is equally true for the operation of FPSOs. The ideal source of human error data would be from industrial studies of performance and accidents. The lack of such data may arise for a number of reasons including:

- Difficulties involved in estimating the number of opportunities for error in realistically complex tasks.
- Confidentiality and unwillingness to publish data on poor performance.

- Lack of awareness of why it would be useful to collect such data in the first place.
- Lack of operational experience.

Some HEP data are available from other sources including simulator and experimental laboratory-based studies. Two problems exist with respect to simulator studies, the first being that such simulators are used almost exclusively for training purposes. Hence, personnel on the simulator scene are highly motivated and often familiar in advance with the training context. Secondly, it is not clear how realistic facing an emergency in a simulator is compared with the real thing.

Expert judgement based techniques may be the best solution (such as APJ, Paired Comparisons, HEART, SLIM, THERP). These are extensively described in the literature^{7, 8, 9}.

One of the objectives for the project is to provide an approach to how HOF may be integrated into risk assessment studies. For integration into quantitative risk assessment studies, HOF assessments also need to be quantitative in order to fit into the decision making process. Furthermore, quantification in some contexts also implies a more disciplined and precise modelling. The precision in the estimates and evaluations is important because all other factors will be quantified and (at least interpreted as) precise. Factors that have approximate effects tend often not to be given the same importance as factors which appear to be precisely quantified.

4.9 EXPERIENCE WITH ANALYSIS OF OPERATIONAL SAFETY

The experience with these analyses is discussed with respect to two different aspects:

- Prerequisites and requirements
- Results that are achieved

These two subjects are briefly discussed separately below.

4.9.1 Prerequisites and requirements

Analysis of operational safety requires detailed input, of the technical systems, but perhaps more importantly, of the procedures, practices and instructions. In effect, this implies that the total requirements for input data are more extensive in this case, compared to an analysis of technical systems.

This also affects the timing of such studies, it will be very difficult to analyse operational safety in detail at a very early design stage, before the details of procedures, practices and instructions are available. An exception will be if similar vessels are in operation and experience from these can be extracted.

It will further be essential that the applicable and relevant procedures are used as basis for the analysis. Reference is made in this regard to one of the case studies, where different versions of procedures existed, one from the manufacturer, another from the operating organisation, whereas a third 'version' was being practised on site.

Analysis of operational safety will often make use of expert workshops, with participation of design and operational personnel, in order to achieve the following:

- Fully understand and appreciate how the systems are actually being operated.

- Identify the possible failure modes, including contributions from technical and human errors.
- Identify the potential consequences from errors, from an operational point of view.

It is quite clear from the studies conducted in the project that such expert workshops are time consuming and demanding to organise. The use of workshops should not be abandoned due to these factors, but it will be important to take them into consideration when planning the analytical work.

4.9.2 Results from operational safety studies

The analysis has shown clearly that an analysis which includes human and organisational factors will identify a wider spectrum of potential failure events than what a so-called 'traditional' QRA will do. It has already been mentioned that the events usually focused on in a traditional QRA is, the 'Locked Turret during Extreme Weather' scenario. Other events found in the case studies that may cause severe consequences are as follows:

- ***Heading Control Drive-off*** (vessel unintentionally starts rotating with locked turret).
- ***Emergency Turning*** (desire to turn the vessel as quickly as possible during an emergency situation).
- ***Rule Violation*** (turret is turned, with unintentionally locked turret, without using the turning machinery actively, i.e. it is erroneously assumed that the turret will rotate back passively).
- ***Turret Locked during Turning*** (very remote, not considered further).
- ***Local Turret Turning*** (turret turned from local panel).
- ***Continuous Turret Turning*** (four turret grippers are engaged continuously, two at the time, the turret possibly rotating back freely due to forces in risers and anchor lines being twisted).

5. GENERAL OBSERVATIONS IN RELATION TO TURNING OF VESSEL AND TURRET

This chapter discusses the general findings from the case studies in relation to turning and locking of turret and vessel. Some of the findings and observations are of a general nature, whereas others are more specific. Only the general observations are outlined in this summary report.

A brief overview of concepts for turret turning is first of all introduced.

5.1 TURRET TURNING CONCEPTS

The project has analysed two different turret concepts as case studies, which as discussed above may be characterised as follows:

- Swivel based concept, forced turning
- Dragchain based concept, forced turning

There are a number of different types of turret solutions. If all possible concepts for internal turrets are considered, then the following categories may be used:

- a) **Passive turning** The vessel is totally free to weather vane, no forced turning of vessel nor turret (in relation to vessel).
The passive turning implies that thrusters are not needed for heading control, some vessels may after all have thrusters for convenience. They may then be used occasionally for heading control, under special circumstances.
- b) **Partly active turning** The vessel is turned with thrusters. The turret is rotated passively (relative to vessel) due to anchor line and riser twist forces exceeding friction forces.
- c) **Active turning** The vessel is turned with thrusters. The turret is rotated by active turning machines.

5.2 PREVENTION OF MAJOR ACCIDENT HAZARDS

The following discusses the general observations that can be made from the two case studies, and how it applies to design and operation of the turret in general. Some of the observations may apply only to the designs that have been considered. Such aspects are discussed separately in the subsequent section, in relation to general design solutions.

There are two specific designs that have been analysed:

Case Study 1: *Swivel based concept* with (virtually) unlimited rotation and *normally unlocked* turret. In order to lock (and also turn) the turret, the hydraulically operated grippers must be clamped onto the turret flange.

Case Study 2: *Dragchain based concept* with rotational limitations and *normally locked* turret. In order to unlock the turret, the turret swinger motors' parking brakes must be released.

The differences between these two concepts are briefly addressed in the following discussions.

5.3 IMPLICATIONS FOR INTERNAL TURRET DESIGNS IN GENERAL

5.3.1 Passive Turning

Passive turning implies that there would be no possibility to lock the turret in position. A roller bearing system is often installed in order to eliminate (or minimise extensively) the 'friction breakout angle' (i.e. angle where turning forces exceed friction forces).

A completely passive turning system does not have any locking devices for the turret which in such case, will be free to rotate. One main advantage of this concept is that unintentional locked turret as identified in various forms in the case studies are not applicable. The low 'friction breakout angle' also implies that sudden backrotation of the turret should normally not occur.

On the other hand, there are several disadvantages of a passive turret turning:

- The FPSO has no possibilities without thrusters for compensation for anchor line failures, unless main propulsion could be used.
- The vessel may experience 'fish-tailing' during certain environmental conditions.
- Extra movements may be uncomfortable for the personnel onboard.
- Without the possibility to lock the turret, there may be a hazard to people moving in or out of the turret, if relative movements occur while a person is moving in or out. It may also introduce additional restrictions on maintenance not being able to lock the turret.

These disadvantages could be overcome with a partly active concept.

5.3.2 Partly Active Turning

The background to a partly active system may be a wish to achieve heading control during off-loading operations. Another case when heading control may be wanted is if significant environmental loads occur with different angles, such that the actual heading may have to be a compromise. The partly active system implies that virtually none of the failure modes analysed in the case studies are applicable.

Turret locking (without turning) could be installed as an option to facilitate repair work.

5.3.3 Active Turning

The crucial aspect of the active turret turning is the mechanism installed in order to lock the connection between turret and vessel. The hazards that are considered in the case studies are usually associated with the locking.

The locking mechanism gives the possibility to control completely the movements, and thus avoid abrupt or unintended movements, also during off-loading. This is the 'upside' of the active turning. The 'downside' is the possibility that unintended operations may create hazards.

5.4 POTENTIAL RISK REDUCING MEASURES

Risk reduction options will have to be considered in relation to operation as well as design. The studies will have to be conducted early in the design phase, in order to have full flexibility with respect to implementing design risk reduction actions.

The consideration of risk reducing measures is limited in the work so far, because the main purpose of the work has been methodology demonstration, and the case studies have had somewhat limited scope. The brief discussion of potential risk reducing measures presented in the following is aimed at focussing on some important aspects with respect to operational control, rather than presenting an exhaustive discussion of risk reduction options. The presentations are general and not dedicated to any of the cases considered. Design improvements are not discussed.

It will be important to ensure that operational personnel on all levels throughout the full operations phase recognise the importance of maintaining a high level of awareness of possible errors that may lead to riser failures. This has been shown for potential failures that may lead to riser damage, but is believed to be applicable for all aspects where operational safety is vital. Experience from some of the incidents has confirmed this assumption.

One particular aspect worth mentioning is the importance of the CCR operators at all time being aware of the status of the turret, i.e. whether it is locked or unlocked. In the first case study it was seen that the feedback in the CCR was not adequate in this respect.

A challenge for operational control of major hazards in general is that critical conditions will not occur regularly at all. This is also the case for possible riser damage.

It is therefore difficult to ensure that the operators have adequate competence in dealing with such situations, since these types of situations cannot easily be trained on (except in simulators). It may be argued that this aspect is even more critical in the case of FPSOs. Process control as well as marine systems control may possibly be involved, such as in the case of off-loading to a shuttle tanker while maintaining production, or in the extreme case of a process fire.

Use of procedures and training are addressed briefly below. Others non-design aspects that might also be focused upon are competence, communications and cultures.

5.4.1 Procedures

One of the important aspects is to have effective procedures for the operations in question. During heading change, a large number of the task steps are cued by sequence, i.e. the operators do not receive explicit signals/commands about when/how the task steps shall be executed. Rather, the procedure for change of heading is, largely based on the operator's memory and experience. This underlines the need for detailed procedures, use of checklists and comprehensive training.

Procedures for change of heading and turret turning during 'adverse' conditions should be developed and made available to the operators. More specifically such procedures should include descriptions of:

- Any particular precautions/actions required during turning when a shuttle tanker is connected.

- The exact manner in which change of heading shall be performed when the turret turning is performed in a non-standard manner, such as (if applicable) locally from the control panel at the turret.
- The exact manner in which change of heading shall be performed during a process fire or during a collision threat by an errant vessel.

5.4.2 Training

Some of the aspects of the FPSO are novel and will still for some time be considered ‘new technology’. This will apply to systems such as the turret, which requires new understanding and training. Off-loading to a shuttle tanker over the stem may be another example. Any lack of system understanding is probably more likely to ‘materialise’ during an emergency than during normal operation where the operations and activities are largely covered by routines. Hence, comprehensive procedures and training plans are important.

Additional simulator training related to abnormal conditions could be one effective way to eliminate possible sources of misunderstanding and uncertainty and to test operator situation awareness and competency in low probability/high consequence scenarios.

Some operators may encounter FPSOs which have different systems for turret and vessel turning and locking than what they have been used to. If personnel move between installations, it becomes even more essential that they have a thorough understanding of the various turret operations.

5.5 PREVENTION OF OCCUPATIONAL ACCIDENTS

The main emphasis in the report is on hazards which may expose the flexible risers to significant damage. Some attention has in the first case study been paid to scenarios that may cause injury to individual operators that move in and out of the turret. This is less important for the second case study since the turret is normally locked. Also, a different design of the turret/vessel interface area makes the personnel squeeze less likely for the second case.

One general recommendation to prevent occupational accidents during turret turning, is to provide sufficient warnings to outdoor personnel. This includes visual alarms as well as turning/flashing lights whenever the turret is being turned.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The main findings of the first stage of the main project are briefly outlined in the following, in relation to operational safety analyses and the use of different methodologies.

No serious accidents with consequences to personnel have occurred on FPSOs in the North Sea, but several near misses and less serious accidents have demonstrated a potential for serious accidents. These incidents have also demonstrated that operational safety control is important.

It can therefore be concluded that efforts to control operational failures are important for FPSOs in particular, probably also for Floating Production Systems in general. This implies that systematic efforts in order to manage and control operational safety aspects are important.

Risk assessment studies are required as basis for the identification of actions that may be used to control operational safety aspects. It is therefore a concern that QRA studies for FPSOs do not always appear to capture the differences between fixed and floating production systems, particularly with respect to importance of operational safety aspects. Risk assessments carried out for FPSOs implicitly consider human and operational factors, but do not always look at them in a systematic manner.

The typical QRA study in relation to riser damage is limited to the 'Locked Turret during Extreme Weather' scenario. A number of additional incident scenarios were identified, when the combination of human errors and technical failures were considered. These scenarios need to be identified in the analysis, in order to provide the basis for effective management and control of these risks.

Potential causes of loss of operational control need to be addressed early in the design work, in order to ensure proper inclusion of risk reduction measures in design and operational planning.

The analytical approach that is used should be able to synthesise different failures, circumstances and conditions. The Fault Tree analysis is one approach, which may satisfy this requirement. The Fault Tree analysis may also be used to synthesise inputs of a technical as well as operational nature. Another possible approach is the Event Tree analysis, often in combination with Fault Tree analysis. The ongoing analysis work with shuttle tanker collision risk is done using a Risk Influence Diagram approach.

6.2 RECOMMENDATIONS

When performing risk assessment of FPSOs, care should be exercised such that all failure modes are included in the analysis, i.e. human, technical and environmental aspects.

Human errors need to be included in the analysis of failure scenarios for FPSOs.

Quantitative Risk Assessments generally need to be enhanced - particularly with respect to human and organisational factors - in order to be effective tools in the management of major hazards on FPSOs.

Some important differences in approaches to protection against major hazards have been indicated between FPSOs installed in different areas of the North Sea. It may be worthwhile to analyse these differences in some detail, in order to establish what would be the optimum solutions under various conditions.

6.3 ONGOING AND FUTURE ACTIVITIES

The collision hazard between shuttle tankers and the FPSO during approach, off-loading and disconnection is currently being analysed. During work conducted in 1999, it became apparent that the mechanisms involved are more complicated than anticipated. It is therefore now planned to continue the work with the collision hazard in 2000 and 2001.

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