Operational safety of FPSOs shuttle tanker collision risk summary report

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Operational safety of FPSOs shuttle tanker collision risk summary report

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This report presents a summary of some of the observations and recommendations made in the research project 'Operational Safety of FPSOs', financed by Esso Norge AS/ExxonMobil Upstream 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 Department of Marine Technology, NTNU as project responsible.

The overall scope of the research project is to develop methodologies for risk assessment of FPSO vessels with particular emphasis on analysis of operational aspects. The scope of the last phase has on the other hand been to analyse in detail, using the previously developed approach, the collision risk between the FPSO and its shuttle tanker, during all phases of off-loading operations. This summary report is focused on the analysis of collision risk between the shuttle tanker and the FPSO.

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While Navion's involvement as Technical Sponsor is acknowledged it should be noted that the work of the project team was not focused on the Navion fleet. Scenarios, findings and recommendations are designed to relate to a typical FPSO/Shuttle tanker combination in the Norwegian and UK sectors of the North Sea. The responsibility for these recommendations rest solely with the project team.

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. Further, to develop models and tools in order to integrate human reliability science into predictive models and tools for analysis of the safety of FPSO operations. The last phase of the work has been focused on the collision risk between shuttle tankers and FPSO units.

The purpose of the study has been to consider the frequency of collision between a shuttle tanker and the FPSO in a tandem off-loading configuration, with the main emphasis on contributions from human and organisational factors. The work has been aimed at a demonstration of the significance of human and organisational factors for the FPSO-shuttle tanker collision risk. Further, important Human and Organisational [error] Factors have been identified and evaluated to determine FPSO/Shuttle Tanker collision frequencies.Finally, the objective has been to propose potential risk reduction measures relating to human and organisational factors for the FPSO-shuttle tanker collision frequency, and to indicate qualitatively or quantitatively their importance.

Neither the acceptability of the present levels of risk of collision between shuttle tanker and FPSO, nor the need for improvement of shuttle tanker or FPSO design and/or operation have been addressed during the work.

The project has recommended a number of potential measures to reduce collision frequency. Human and organisational errors contribute significantly to probability of collision between shuttle tankers and FPSO units. As there is a close link between human and organisational factors and several technical aspects, the potential for such failures can also be reduced by various technical improvements, which also are addressed. The risk reducing measures have been classified into three categories, with respect to importance: high, medium and low.

The recommendations are focused on the following aspects:

- Field configuration's importance for mitigation during initiation and recovery phases, following a potential drive-off of the shuttle tanker.
- Human and organisational factors, mainly focused on crew competence on shuttle tanker and FPSO
- Shuttle tanker positioning system
- Man-machine interface on shuttle tankers
- FPSO features and interface with shuttle tanker

CONTENTS

1. INTRODUCTION

1.1 BACKGROUND

Turret moored FPSOs of the mono-hull type have been used in the North European waters since 1986 [Petrojarl I], so far without serious accidents to personnel or the environment. The use of such vessels for field development has increased during the last 5-10 years, and in these waters more than 20 fields are currently either in operation or being developed with FPSO units, mainly new built vessels.

FPSOs are not new as petroleum 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, or sometimes transferred from a loading buoy.

The vessels being installed in the North Sea, North Atlantic and Norwegian Sea fields have traditionally been designed for considerably higher environmental loads and often also 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 well forward of midships, with transfer of pressurized production and injection streams through piping systems in the turret. An overview of an FPSO (Norne, courtesy of Statoil) and shuttle tanker (ST) during off-loading is shown in Figure 1.

Figure 1 Example of FPSO and shuttle tanker configuration

Although FPSOs are becoming common, operational safety performance may still be considered somewhat unproven, especially when compared to fixed installations. Floating installations are more dependent on manual control of some of the marine systems, during normal operations as well as during critical situations. 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 off-loading

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

1.2 PROGRAMME OVERVIEW

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 entire programme has lasted for almost six years, and has comprised of the following phases:

- Methodology development and demonstration (1996-2000)
    - Pre project, definition phase
    - Riser damage, due to inadequate turret operations
    - Pre study: Collision with shuttle tanker
- Dedicated analysis of risk using the methodology developed (2000-2002)
    - Extended study of collision risk

The work up to 1998 has been summarised in OTO 2000:086 (HSE, 2000).

There have been two studies which have focused on collision risk between shuttle tanker and FPSO. The first of these was in the methodology development part, and was limited to focus on recovery from extensive surging.

The last phase has attempted to perform an in-depth analysis of the collision frequency and identify possible ways to mitigate or control this hazard.

1.3 OBJECTIVES – FPSO - SHUTTLE TANKER COLLISION RISK STUDY

The purpose of the shuttle tanker collision risk study has been to consider the frequency of collision between a shuttle tanker and the FPSO in a tandem off-loading configuration, with the main emphasis on contributions from Human and Organisational Factors (HOF). The main objectives of the work have been the following:

- Demonstrate the significance of Human and Organisational Factors (HOF) for the FPSO-shuttle tanker collision risk.
- Identify and evaluate the important factors that from a human and organisational error point of view determine the FPSO-shuttle tanker collision frequency.
- Propose potential risk reduction measures relating to Human and Organisational Factors (HOF) for the FPSO-shuttle tanker collision frequency, and indicate qualitatively or quantitatively their importance.

Limitations are presented in Section 2.4.

1.4 SCOPE OF REPORT

Chapter 2 presents the analytical approach taken in the study and its limitations. Chapter 3 summarises the main safety aspects of tandem off-loading operations in the North European waters, as well as an overview of the incidents that have occurred with tandem off-loading operations.

Chapter 4 presents a condensed summary of the analysis of Risk Influencing Factors (RIFs). The recommendations relating to collision frequency mitigation or control proposals with importance for Human and Organisational aspects is presented in Chapter 5, which also includes overall conclusions.

The details of the analysis are documented in Refs 1, 2 and 3.

1.5 TERMINOLOGY

The definition of Risk Influencing Factor (RIF) is presented in the following subsection 2.1.

The following abbreviations are used throughout the report:

AEMA	Action Error Mode Analysis
BRM	Bridge Resource Management
CPP	Controllable Pitch Propeller
CRIOP	Crisis Intervention in Offshore Production
DARPS	Diffstar Absolute and Relative Positioning System
DP	Dynamic Positioning
FPSO	Floating Production, Storage and Off-loading (unit)
FSU	Floating Storage Unit
HOF	Human and Organisational Factors
MMI	Man-Machine Interface
MP	Main (propulsion) Power
PGS	Petroleum Geo-Services ASA
PRS	Position Reference System
RIF	Risk Influencing Factor
SBV	Standby vessel
SRM	Ship Resource Management
ST	Shuttle tanker
STL	Submerged Turret Loading
TH	Thruster

2. ANALYTICAL APPROACH IN THE STUDY

2.1 MAIN ANALYTICAL PRINCIPLES

The starting point of the analysis is the introduction of Risk Influencing Factors (RIFs). The study is limited to collision frequency, as noted in Section 2.4 below. The key term 'Risk Influencing Factor' needs to be explained first of all.

Risk Influencing Factor (RIF):
A RIF is given as a set of relatively stable conditions influencing the risk. It is not an event, and it is not a state which fluctuates (say from day to day). A RIF represents the average level of some conditions, which may be influenced/improved by specific actions.

The RIFs are organised in the following three levels according to their direct or more indirect effect on the collision risk, see Figure 2.

The RIFs are divided into the following categories:

1. *Operational RIFs*, which are related to running activities necessary to provide safe and efficient tandem loading operation on a day to day basis. This includes conditions or requirements concerning ST technical dependability, state of operational dependability of the compound loading system, and other external conditions and interfaces. *Examples: FPSO design; tanker positioning and control system; tanker crew competence; etc.*
2. *Organisational RIFs (Management RIFs),* defined as RIFs related to the organisational basis support and control of running activities in ST-FPSO off-loading. These are related to philosophies and strategic choices concerning the technical and operational basis as well as support, control and management of running activities in ST operation. *Examples: FPSO (tanker) manufacturers/vendors; FPSO (tanker) operators, etc.*
3. *Regulatory RIFs,* defined as RIFs related to the requirements and controlling activities from authorities. *Examples: Authorities.*

The analysis focuses on the Level 1 RIFs, as these RIFs directly affect and determine the collision risk. However, the status of these is strongly influenced by the status of RIFs on Level 2 and 3. It may be required to impose changes of Level 2 and/or Level 3 RIFs, in order to achieve improvement of the status of RIFs at Level 1.

The arrows in the 'influence diagram' of Figure 2 represent influences. Further, the immediate 'causes' of collision risk can be related to loss of (see level '0'):

- *ST & FPSO functionality and technical dependability*
- *Human/operational dependability*, or
- *External conditions*

These 'causes' can be seen as a grouping of the RIFs at Level 1. There has been a specific focus on RIFs related to Human/operational dependability, but also how these interact with RIFs in the other two groups.

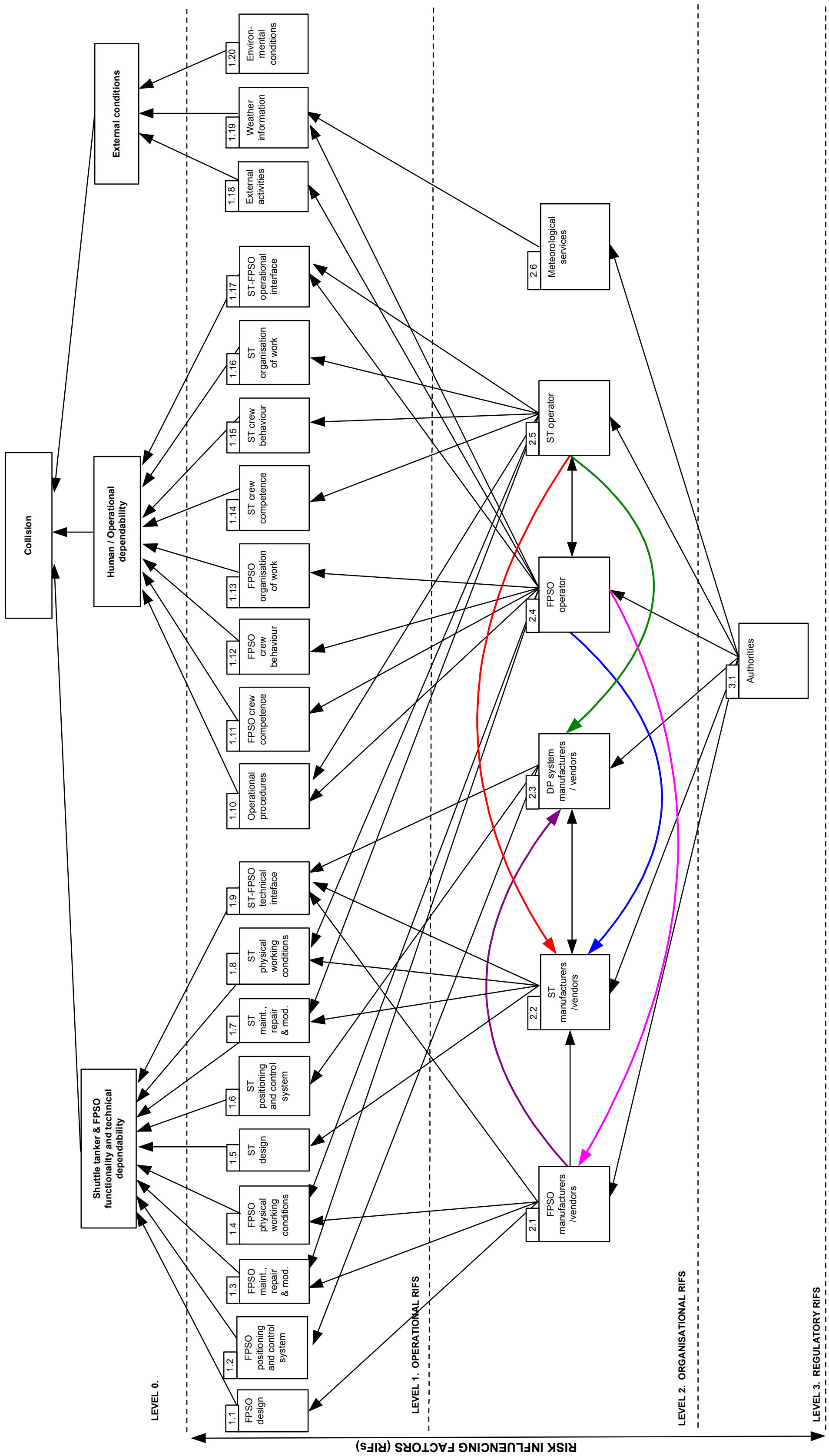


Figure 2 Influence diagram of collision risk between shuttle tanker and FPSO

The structuring of RIFs in an influence diagram, provides a means of handling in a systematic way all the factors and influences that are relevant for collision risk. The study has provided detailed descriptions of the RIFs, a further break down of these, as well as status, problem areas and suggestions for risk reduction.

The importance of the various RIFs has been assessed both qualitatively and quantitatively with respect to the occurrence of ST/FPSO collisions during off-loading phases. A number of expert meetings have been carried out to provide these precise definitions of RIFs, and provide various rankings with respect to their importance.

The HOF aspects have been focused in a CRIOP analysis and an AEMA analysis, as well as STEP diagrams in one of the incident analysis and in the CRIOP analysis. Modelling of human bridge control and human interventions has also been performed. Attention to the importance of the field configuration and the main capabilities was also put through this analysis.

2.2 ANALYSIS ENVELOPE

The project considers the total off-loading system (see Figure 3), consisting of:

- FPSO during all phases of off-loading
- Off-loading arrangements
- Shuttle tanker during all phases of off-loading

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

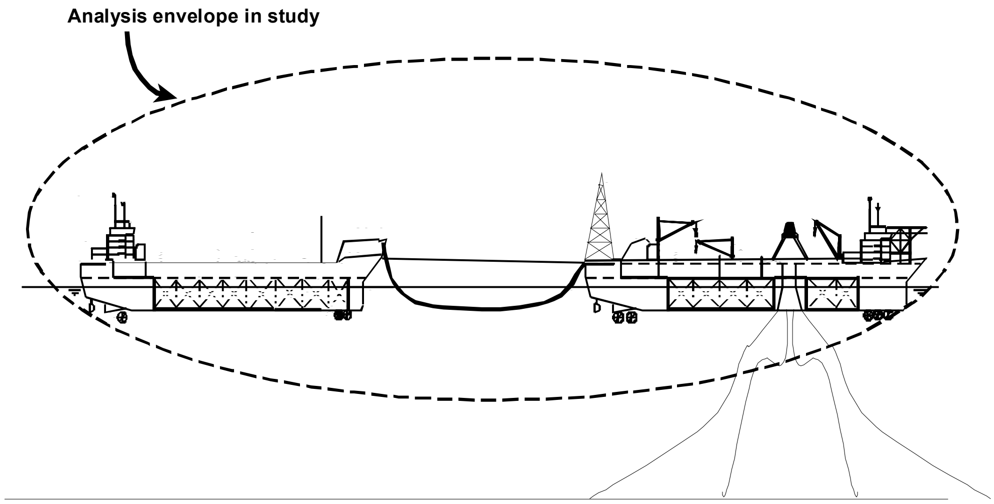


Figure 3 Analysis envelopes

2.3 VARIATIONS COVERED IN THE PROJECT

There are several different collision scenarios that may be considered, relating to different off-loading phases as well as the possible initiating events that may lead to a collision. Table 1 below indicates possible combinations. Also the priorities that were given to these scenarios and phases in the project, are shown in the table.

Table 1 Overview of collision scenarios

	Initiating event			
Phases	**Drive off**	**Drift off**	**Fishtailing / Heading deviation**	**Surging**
Approach and connection Off-loading Disconnection and departure	Highest priority scenarios	Lowest priority scenarios	Medium priority scenarios	Medium priority scenarios

2.4 LIMITATIONS

The term 'risk' involves the probability of accidents or incidents as well as the potential consequences of such occurrences. The study has **not** addressed at all measures to reduce the consequences of accidents and incidents, only measures in order to reduce the probability of accidents and incidents.

The acceptability of the present levels of risk of collision between shuttle tanker and FPSO has not been considered during the work, and acceptance criteria are not considered. The need for improvement of any or all aspects of shuttle tanker or FPSO design and/or operation has not been addressed.

Analysis of RIFs in an influence diagram is sometimes performed on the basis of statistical incident data, given that such data exist in sufficient amount. In the present case, however, there are few incidents (see Section 4.2), and the analysis of RIFs and their importance in Sections 4.3 and 4.4 is therefore mainly based on subjective evaluations performed in expert work meetings.

The analysis has been based on what was current technology and operational practices at an early stage in the work, corresponding typically to some time in the second half of 2001. For instance, the Version 4.0 of the DP software used on the tankers considered, implementing early warning and improved visual display of alarms, was released in November 2002. The study was based on the previous version.

3. SAFETY ASPECTS OF TANDEM OFF-LOADING FROM FPSOS

3.1 TANDEM OFF-LOADING CONFIGURATIONS

The discussion here is limited to off-loading from FPSO and FSU systems. It is taken as a presumption that the off-loading system will be configured such that the FPSO/FSU and shuttle tanker will be at relatively close distance, say in the range (theoretically) from 40 to 300 meter.

One of the particular aspects of tandem off-loading systems is that purpose built and commercially available systems are combined. Hence there are some quite wide differences between configurations applied for comparable situations.

The FPSO may be termed 'purpose built'. When an FPSO is a new build for a specific field, then it may be perfectly tailored to the needs and requirements. Conversion of commercial tankers to FPSO may often be the main option in some areas where the environmental conditions are quite benign, and where the challenges in off-loading are more limited.

However, conversion is also adopted in the North Sea and other areas where the environmental conditions may be severe, and where the challenging tandem mode for off-loading has to be adopted. This implies that there are quite considerable variations between system configurations.

Shuttle tankers are used for off-loading purposes from FPSO/FSU units, in largely the same manner as from fixed installations, i.e. from fixed, floating or subsea buoy systems. These tankers are usually not built only for one type of service, but the capabilities of the tanker may imply the type of services that it is suitable for.

Table 2 illustrates some of the variations that may exist, in relation to some of the aspects that are important for avoiding collisions between the shuttle tanker and the FPSO. The base case analysed in the project is also shown in bold font.

Table 2 Variations in FPSO/FSU field configurations

Characteristic	*Variations (Base case in bold)*
FPSO station keeping capabilities	**Internal turret with 8-12 point mooring system**
FPSO heading keeping capabilities	Without heading control **With heading control**
ST heading and station keeping capabilities	Main propulsion (single or twin screw) No DP system DP1, **DP2** or DP3 systems
Off-loading mode	**DP operated** Taut hawser operated
Interface systems	**With hawser connection** Without hawser connection
Distance FPSO-ST	50 –100 meter **80 meter** 150 meter (not used at present, but considered as a sensitivity)

3.2 OVERVIEW OF CURRENT FIELD CONFIGURATIONS

If aspects of vital importance for the collision frequency are considered, quite extensive variations between the different field configurations may be found. Some of these are briefly outlined below.

The distribution of DP-based off-loading, taut hawser and other off-loading modes are shown in Figure 4, for UK and Norwegian sectors.

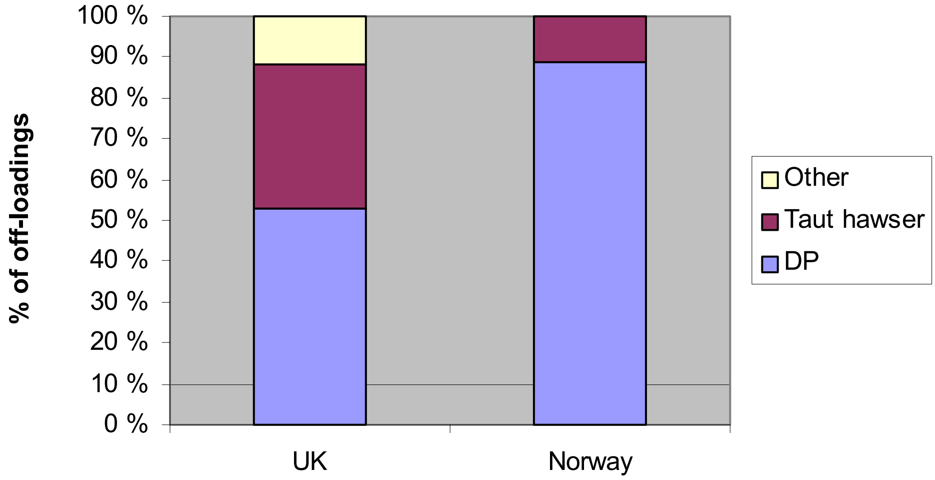


Figure 4 Overview of off-loading modes in UK and Norway

It is shown that DP-based off-loading dominates (about 90 %) in the Norwegian sector, whereas the fraction is just above 50 % in the UK.

The distributions for UK and Norwegian sectors of the off-loading distances between the vessels are shown in Figure 5, which is limited to fields with off-loading based on DP operation, thus excluding fields with taut hawser and pipeline or buoy based off-loading.

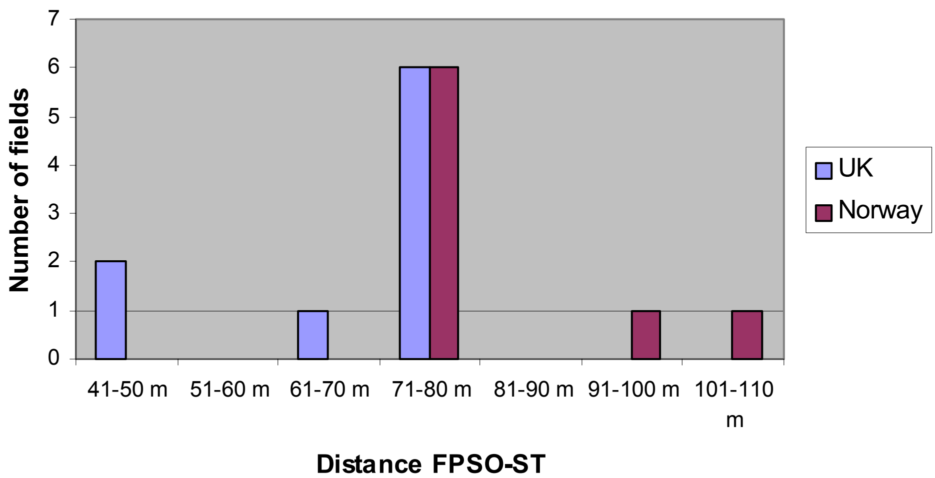


Figure 5 Overview of off-loading distances between FPSO and ST

It is worthwhile to note that the distances range from 50 m up to 75-80 m in the UK fields, whereas they range from 75-80 m up to 100-110 m in the fields of the Norwegian sector.

An assessment of the available extent of thruster capacity on the FPSOs and FSUs has also been performed. There is a tendency that the Norwegian fields have more thruster power installed, but the difference is not as extensive as that seen for distances in Figure 5.

4. ANALYSIS OF RISK INFLUENCING FACTORS

An overview of the RIFs and the structure is presented in Figure 2. The definitions of the individual RIFs is presented in Section 4.1 below. Classification of incidents is discussed in Section 4.2. The subsequent sections summarise analyses of these RIFs.

4.1 DEFINITION OF RIFS

The definitions of the operational RIFs for collision frequency are presented below. The RIFs 1.1-1.9 relate to technical dependability, the RIFs 1.10-1.17 are related to human/operational dependability, and RIFs 1.18-1.20 describe external conditions.

Operational RIFs (Level 1)		
ST and FPSO functionality and technical dependability		***Definition***
1.1	FPSO design	The suitability and quality regarding design of the FPSO (except the positioning and control system) necessary for safe and reliable operation during tandem loading. (Considering collision probability only, consequences of location of topside equipment is not considered.)
1.2	FPSO positioning and control system	The suitability and quality of the FPSO positioning and control system.
1.3	FPSO maintenance, repair and modifications	The quality of FPSO operator's contribution to technical dependability of the FPSO and its positioning system by maintaining it to a defined/intended operational standard.
1.4	FPSO physical working conditions	Quality of physical working conditions that influence the FPSO crew's ability to perform assigned duties/operations at an intended level of safety.
1.5	Shuttle tanker design	The suitability and quality regarding design of the ST (except the positioning and control system) necessary for the safe and reliable operation during tandem loading.
1.6	Shuttle tanker positioning and control system	The suitability and quality of the ST positioning and control system.
1.7	Shuttle tanker maintenance, repair and modifications	The quality of ST operator's contribution to technical dependability of the ST and its positioning system by maintaining it to a defined/intended operational standard.
1.8	Shuttle tanker physical working conditions	Quality of physical working conditions that influence the ST crew's ability to perform assigned duties/operations at an intended level of safety.
1.9	Shuttle tanker – FPSO technical interface	The suitability and quality of the shuttle tanker – FPSO technical interfaces.
Human/Operational dependability		***Definition***
1.10	Operational procedures	Quality of procedures which cover all aspects of handling and operating the ST/FPSO, except maintenance procedures being part of RIF 1.3, RIF 1.7 and RIF 1.9.

Operational RIFs (Level 1)		
1.11	FPSO crew competence	Competence and quality of education related to the skills and knowledge necessary to handle the technical systems, of all FPSO personnel involved in the tandem loading operation.
1.12	FPSO crew behaviour	Attitudes and behaviour regarding the skills necessary to handle the technical systems of all FPSO personnel involved in the tandem loading operation.
1.13	FPSO organisation of work	Quality of organisational working conditions - such as manning, pressure, co-operation and culture -which influence the FPSO crew's ability to perform assigned duties/operations at an intended level of safety.
1.14	Shuttle tanker crew competence	Competence and quality of education related to the skills and knowledge necessary to handle the technical systems, of all ST personnel involved in the tandem loading operation.
1.15	Shuttle tanker crew behaviour	Attitudes and behaviour regarding skills necessary to handle the technical systems of all personnel involved in the tandem loading operation.
1.16	Shuttle tanker organisation of work	Quality of organisational working conditions - such as manning, pressure, co-operation and culture- which influence the tanker crew's ability to perform assigned duties/operations at an intended level of safety.
1.17	ST-FPSO operational interface	The competence, the attitudes and behaviour and the organisation of work related to the shuttle tanker – FPSO operational interfaces.
External conditions		***Definition***
1.18	External activities	The influence on safe and reliable tandem loading from external activities taking place at the field.
1.19	Weather information	Availability and quality of weather information and forecasts.
1.20	Environmental conditions	The environmental conditions at the location of the FPSO, to the extent that these affect a safe and reliable offshore loading.

The definition of the RIFs at level 2 and 3 are presented below.

Organisational RIFs (Level 2) and Regulatory RIFs (Level 3)		
RIF		***Definition***
2.1	FPSO manufacturers/ vendors	The way the FPSO manufacturers/vendors plan and carry out their business in general, to the extent that this has a direct or indirect influence on safe and reliable offshore loading.
2.2	ST manufacturers/vendors	The way the ST manufacturers/vendors plan and carry out their business in general, to the extent that this has a direct or indirect influence on safe and reliable offshore loading.
2.3	DP system manufacturers/vendors	The way the DP system manufacturers/vendors plan and carry out their business in general, to the extent that this has a direct or indirect influence on safe and reliable offshore loading.
2.4	FPSO operator	The way the FPSO operators plan and carry out their business in general, to the extent that this has a direct or indirect influence on safe and reliable offshore loading.

Organisational RIFs (Level 2) and Regulatory RIFs (Level 3)		
2.5	ST operator	The way the ST operators plan and carry out their business in general, to the extent that this has a direct or indirect influence on safe and reliable offshore loading.
2.6	Meteorological services	The way the meteorological service organisations plan and carry out their tasks in general, to the extent that this has a direct or indirect influence on safe and reliable offshore loading.
3.1	Authorities	Quality of national and international rules and regulations supervising and auditing the safe operation of ST/FPSO.

4.2 EXPERIENCE FROM INCIDENTS, NEAR-MISSES AND QUESTIONNAIRES

Table 3 presents an overview of 19 reported incidents e.g. collisions, near misses and 'other' events, for tandem loading with DP tankers in the North Sea in the time period 1995 up to the end of 2002. *Five incidents in italics were not known when the study was completed*. Six of the incidents are analysed in more detail than the other eight incidents.

The project group has performed a judgement of the relative importance of these RIFs (see Section 2.1) to the occurrence of the 6 incidents that were analysed in detail. These judgements based on the incidents reports are of course to some extent subjective, but it seems fairly clear that some of the RIFs have contributed significantly to the incidents/near misses:

- *ST positioning and control system* is a major contributor; this RIF contributes to all six incidents that are analysed in detail.
- *ST crew competence* is another major contributor, contributing significantly to five out of six incidents.
- *FPSO positioning and control system* contributed significantly to two of the six incidents.
- *ST organisation of work* also is a significant contributor in three incidents.

Figure 6 gives a graphical view of the RIF classification for the 6 incidents analysed in detail, utilising the following grouping of the RIFs (RIF numbers according to Figure 2):

- FPSO design and technical dependability (RIFs no. 1.1-1.4)
- ST design and technical dependability (RIFs no. 1.5-1.8)
- Technical and operational interface of FPSO/ST (RIFs no. 1.9 and 1.17)
- Procedures (quality of) (RIF no. 1.10)
- FPSO human/operational dependability (RIFs no. 1.11-1.13)
- ST human/operational dependability (RIFs no. 1.14-1.16)
- conditions external to the FPSO and ST (RIFs no. 1.18-1.20)

Table 3 FPSO/Shuttle tanker collision incidents and near-misses 1995-2002

Year	*Sector*	*Phase*	*Cause*	*Type of incident*			*DP class*
				Near-miss	Collision	Other	

				Type of incident			
1996	UK	Loading	DP failure		X		DP1
1997	UK	Loading	PRS failure		X		DP1
1997	UK	Loading	Operator error		X		DP1
1997	*UK*	*Loading*	*PRS failure*			*X*	*DP1*
1998	UK	Loading	Operator error		X		DP1
1998	*UK*	*Loading*	*CPP failure*			*X*	*DP1*
1999	Norway	Loading	DP failure	X			DP2
1999	Norway	Loading	DP failure	X			DP2
1999	*UK*	*Disconnec-tion*	*FPSO thrusters tripped*	*X*			*DP1*
1999	UK	Approach	DP failure	X			DP1
2000	Norway	Loading	Operator			X	DP2
2000	Norway	Disconnec-tion	Manually initiated drive off		X		DP2
2000	Norway	Approach	DP failure	X			DP2
2000	Norway	Connection	Technically initiated drive off	X			DP2
2000	UK	Connection	Operator error	X			DP1
2001	Norway	Loading	PRS/DP failure	X			DP2
2001	UK	Loading	Technically initiated drive off	X			DP1
2002	*UK*	*Loading*	*Rapid wind change*	*X*			*DP1*
2002	*UK*	*Loading*	*Engine failure*			*X*	*DP1*

The basis of the classification is the incident investigation reports, which have been used without performing any verification of the correctness of these reports. Figure 6 gives the (average) contributions of the various 'RIF-groups'.

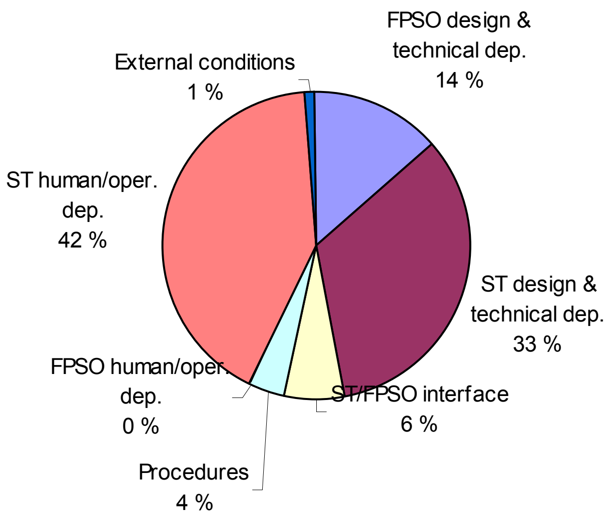


Figure 6 Causal contributions of 'RIF-groups' in the six analyse incidents
(Abbreviations: oper: operational – dep: dependability)

The incidents were also analysed in order to determine the times that had been used for the various stages of recovery actions, where this could be determined from the investigation reports. This resulted in the following:

- Events that resulted in collision:
  - Minimum time for recovery action initiation was 58 seconds
  - Maximum time for recovery action initiation was close to 120 seconds
- Events that did not result in collision:
  - In one case where the time was available, recovery action initiation took 40 seconds.
  - In another case, the total time to stoppage was 72 seconds, implying that the recovery action initiation could not have taken excessively more than 40 seconds.

Also a questionnaire survey was conducted, with reply from 10 captains and 7 DP officers, thereafter analysed anonymously. The estimation of DP operator response time in the drive-off situation is based on estimations of the following three characteristic time intervals:

- Information time – time needed for DP operator to detect the first abnormal signal.
- Decision time – time needed for DP operator to diagnosis and achieve the situation awareness, after detection of the first abnormal signal.
- Execution time – time needed for DP operator to formulate recovery tasks and execute them, after achieving situation awareness.

The survey results produced a few likely first abnormal signals which may prompt operators' attention. Based on estimations of when these signals may happen, a representative information time is found as 30 seconds. The decision and execution times are directly provided by the operators. A typical value for decision and execution time was another 30 seconds.

Based on the survey and the incident data, it appears reasonable to conclude as follows with respect to the periods that should be available for recovery actions[1]:

- A minimum period of 60 seconds should be available for detection, decision and execution.
- In order to reduce the risk, a period of 90 seconds or even higher value is preferable.

The periods required for recovery actions as indicated above apply to field configurations with DP2 shuttle tankers and significant capacity for position and heading control by the FPSO or FSU. Increased periods for recovery will be required for field configurations with less capable vessels. Other alternatives are outlined in Section 5.1.

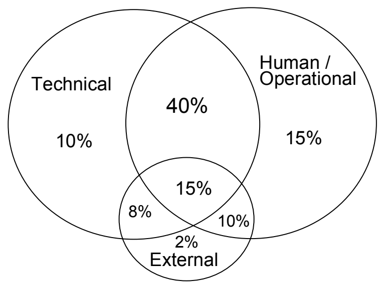
4.3 MAIN CONTRIBUTORS TO COLLISION FREQUENCY, IN DRIVE-OFF

An assessment of the main contributions to collision frequency has been performed, based on incident experience as well as various expert evaluations, see Table 5. The contributions to collision frequency in the table, which also are presented in the diagram, should be considered order-of-magnitude values, rather than exact estimations.

[1] These estimates reflect the technology and practices that formed the basis of the work, see last paragraph of Section 2.4. Improvements adopted recently by some Shuttle Tanker operators may imply that the required times may be somewhat reduced.

Table 5 Ranking of RIF group combinations (expert judgments)

RIF group / RIF group combination	*Ranking*	*Contribution*
1. Technical dep. alone	4	10 %
2. Human/Operational dep. alone	2	15 %
3. External conditions alone	7	2 %
4. Technical *and* Human/-Operational (in combination)	1	40 %
5. Technical *and* External (in combination)	6	8 %
6. Human/Operational *and* External (in combination)	5	10 %
7. Technical *and* Human/-Operational *and* External (in combination)	3	15 %



The combination of technical and human/operational dependability is judged to be the most significant contributor; assessed to cause [in the order of] 40 % of the collisions.

Human/Operational factors contribute alone as well as in combination with other factors. Actually it is assessed that Human/Operational factors, possibly in combination with other factors, may contribute to 80 % of all collisions. This results when all sectors of the "Human/-Operational" circle in the diagram are considered, including the sectors that overlap with other factors.

Similarly, Technical dependability (possible in combination with other factors) is judged to contribute to about 70 %, and External conditions is in total judged to contribute to about 35 % of the collision incidents. The percentages add up to more than 100%, due to the overlaps being counted twice.

There was considerable difference of opinion regarding the factor *External conditions* amongst the experts. One view is that the operation shall be adjusted to external conditions (such as weather). External conditions should then not contribute at all; i.e. incidents due to bad weather are actually caused by erroneous judgments/decisions (or bad procedures) and are as such human/operational errors. An alternative view implies that even if procedures are good and are followed by the crew, there may be sudden changes in weather conditions that may contribute to an incident/collision. Thus, external conditions may actually contribute to accidents, but if the procedures are satisfactory, this contribution is per definition low.

An assessment of the individual RIFs has also been performed, with respect to importance for collision frequency. The ranking is subjective, but it should be noted the experts agreed consistently on the two RIFs with the highest importance.

The ranking does not imply that these factors are unsatisfactory in current operations, just that these factors are very important for keeping the likelihood of collision at a low level. The following were observed from the assessment of individual RIFs:

1. The two RIFs on top are both related to ST:
   1.14 ST crew competence

1.6 ST positioning and control system

2. The four RIFs ranked highest relate to *crew competence* and *positioning and control system*, for ST and FPSO.
3. Amongst the 'ten on top RIFs' there are four RIFs related to ST, two related to FPSO, two to interface ST/FPSO, one to procedures and one related to environmental conditions.

4.4 PHASES, SCENARIOS AND SENSITIVITIES

The assessment presented in Section 4.3 applies to the drive-off scenario during off-loading. The following additional scenarios and phases have also been considered:

- Surging induced collision during off-loading phase
- Fishtailing
- Drive-off during connection phase
- Drive-off during disconnection phase

The results for the additional scenarios and phases are indicated in Figure 7, Figure 8 and Figure 9.

According to the expert judgement we have the same contributions in % for *Fishtailing/heading deviation (therefore not shown)*. However, for *Surging* there is a relative increase in the contribution of *Technical, Human/organisational* and *External conditions,* see Figure 7.

Restricting to the *Drive off* scenario, it is considered whether there are any differences for the three phases: *Approach/connection, Off-loading* and *Disconnection/departure*. The judgements concerning this are presented in Figure 8 and Figure 9.

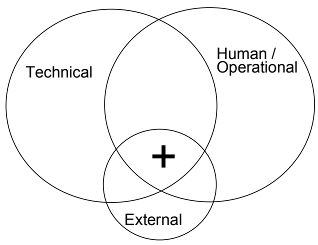


Figure 7 Surging, off-loading phase

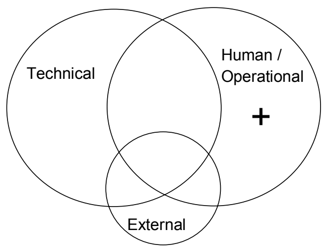


Figure 8 Drive-off, Connection phase

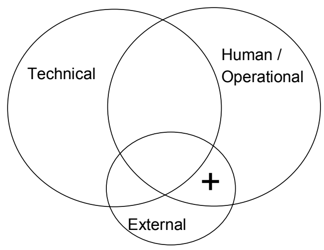


Figure 9 Drive-off, disconnection phase

The contributions to the collision frequency for *connection* and *disconnection* phases are compared to the case for the *Off-loading* phase, and are based on expert evaluations. A higher contribution for Human/operational dependability is considered for the Connection phase. Please observe that this phase requires particular crew skills and alertness.

For Disconnection there is an additional contribution from the combination of Human/Operational and External factors. An explanation is that some disconnections are carried out under harsh weather conditions, when the sea state is increasing up to the upper limit.

The following additional sensitivities have also been considered:

- Distance FPSO-ST: 150 metres (FPSO with heading control)
- FPSO **without** heading control, distance 80 metres
- FPSO **without** heading control, distance 150 metres

Table 6 summarizes the expert judgments for the effect on the collision frequency for different field configurations, compared to the 'base case', i.e. off-loading distance 80 metres and FPSO with heading control.

Table 6 Expert judgement on collision frequency for three alternatives to the base case

Sensitivity case	*Relative collision probability*	*Contributions that are different*
FPSO with heading control, distance FPSO-ST: 150 metres	80 %	Human/Operational dependability reduced Technical and Human/Operational dep. reduced
FPSO without heading control, distance 80 metres	120 %	Human/Operational dependability increased Technical dependability increased
FPSO without heading control, distance 150 metres	110 %	Technical dependability increased

5. OFF-LOADING COLLISION FREQUENCY REDUCTION

This section presents conclusions and recommendations from the study. It was noted in Section 2.4 that acceptability of present solutions is not addressed in the study, thus the conclusions are therefore relatively limited.

The main recommendations for reducing the probability of collision during tandem off-loading are summarised in the following subsections. Only measures related to collision probability/frequency are considered here, not consequence. Human and organisational errors contribute significantly to probability of collision between ST and FPSO. The reducing measures presented below are directed at reducing the potential for such errors to cause collisions.

As there is a close link between HOFs and several technical aspects, the potential for HOF failures can be reduced also by various technical improvements. Thus, probability reducing measures related to various technical factors are also provided.

The reduction measures have been classified into three categories, with respect to importance: 'H' (high), 'M' (medium) and 'L' (low). Measures of categories 'H' and 'M' are presented in this section.

Some of the shuttle tanker operators have implemented several risk reducing measures during the last few years. For those companies where this applies, a 'H' will not necessarily imply a high improvement potential, but essentially point at the need to maintain focus on these issues also in the future. Further, the recommendations may appear to be somewhat redundant, and not all of them may be required in all cases. On the other hand, as many as possible should be implemented in order to achieve a collision risk which is as low as reasonably practicable.

5.1 FIELD CONFIGURATION

The collision failure model in tandem off-loading may practically be structured into the following two phases:

1. *Initiation* phase: shuttle tanker (ST) in drive off position forward.
2. *Recovery* phase: recovery action fails to avoid collision.

The shuttle tanker drift-off forward scenario is considered to have low probability and low consequence in tandem offloading, and it is therefore excluded from the discussions below.

Two parameters are defined to characterise these phases:

- Resistance to Drive-off – in the *Initiation* phase.
- Robustness of Recovery – in the *Recovery* phase.

These two parameters are used in order to identify necessary requirements for FPSO-ST field configuration, which are as favourable as possible in order to minimise or reduce the contributions from HOF aspects to collision probability. Based on these evaluations, the following are recommended in order to reduce risk (H)[2]:

[2] See footnote on Page 16

- Times available for DP operator to initiate recovery action (detection, decision and execution) should be increased, if manual recovery is the main approach, and/or;
- Provision of means for earlier detection and warning, combined with automatic activation of recovery, if not activated immediately by DP operator.

5.2 HUMAN AND ORGANISATIONAL FACTORS

The following are suggested risk reducing measures directly related to the HOFs. These measures are mainly focused on crew competence on ST and FPSO and procedures:

- The education and training program for ST DP operators should be kept current with the technology, (H) e.g.:
  - Use of simulator training for tandem loading (where this is not already required).
  - Improved training on emergency preparedness / collision avoidance.
  - Requirements to the number of personnel on ST having DP competence. In particular require that all tankers at any time have two DP operators (captain not included) on the bridge.
  - A general focus on requirements for DP operators on the ST, regarding recruiting of DP operators, education, updating of their competence, and refresh training.

  This is an area were significant efforts have been made in recent years (particularly on the Norwegian sector); thus giving [for these ST operators] a much lower potential for further improvement.

- The Ship Resource management (SRM) system, (including the Bridge Resource Management, BRM, system) on the shuttle tankers should be evaluated, and courses in this field should be conducted. Sharing of workload and co-operation between operators on the bridge and the engine control, and between engine and bridge should be clearly defined. All should have specific well-defined tasks and work as a team. (M)
- Increase competence of FPSO personnel by (M):
  - suitable training courses and training scenarios, e.g. increasing awareness of having to know about ST off-loading problems.
  - improved emergency preparedness training, including responses to emergencies identified in operation.
  - formal training of technicians on the FPSO in the function and operation of the DARPS and associated equipment.
- The field specific emergency procedures should be described in more detail. More detailed description of shuttle tanker emergency actions in case of drive-off (or drift-off) should be evaluated for incorporation in the procedures. A description of how the FPSO should act in a drive off situation may be described in the procedure. (M)
- The field specific off-loading procedure should in more detail address the FPSO responsibilities to maintain a suitable field environment for the shuttle tanker. (M)

5.3 SHUTTLE TANKER POSITIONING SYSTEM

The following are recommended probability reducing measures for the DP system on the shuttle tankers:

- Continue work to reduce complexity of DP system MMI (Man-Machine Interface), e.g. regarding (H):
  - all intermediate control modes between full DP and full manual control (and changing between these), and
  - ease the understanding of how DP system responds to required inputs (ref. hawser tension/current force).
- Consider further development of 'Tandem loading' software. (M)
- Provide tankers with at least twin main propulsion systems (or single screw combined with retractable azimuth thrusters) and additional redundant thruster facilities. (M)

5.4 MAN-MACHINE INTERFACE ON SHUTTLE TANKERS

The following are suggested probability reducing measures for the Man-Machine interface:

- Improve man-machine interface such that status of thrusters/propulsion can be observed together with other critical DP information (such as position references). (M)
- Consider ST automatic thruster reversal (e.g. in weather vane) when a minimum distance is reached. (M)

5.5 FPSO FEATURES AND INTERFACE WITH SHUTTLE TANKER

The following probability reducing measures are identified for FPSO features and ST/FPSO interface:

- Provide FPSOs with heading control. (H)
- Increase thruster power on FPSOs. (M)
- Provide FPSOs with surge control. (M)
- Consider installation of visual graphics picture of both vessels on the FPSO, to improve FPSOs knowledge on ST behaviour. (M)

5.6 CONCLUSIONS

A number of potential measures in order to reduce the collision frequency between shuttle tankers and FPSO units have been summarised in the Sections 5.1 through 5.5, classified in three categories according to importance for collision frequency reduction.

It was noted on Page 20 above that some of the shuttle tanker operators have implemented several risk reducing measures during the last few years. For those companies where this applies, the proposed measures will not necessarily imply a high improvement potential, but rather emphasize the need to maintain focus on these issues also in the future.

For other companies, that have not yet implemented such measures to reduce the collision frequency, the proposed recommendations will be essential in order to achieve an improved situation with respect to the probability of collision impact by the shuttle tanker into the FPSO vessel.

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