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Shuttle Tanker Operations

Close Proximity Study, Shuttle Tanker Operations

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CLOSE PROXIMITY STUDY

SHUTTLE TANKER OPERATIONS

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Synopsis

The close proximity study was commissioned by the UK Health and Safety Executive and was carried out in spring 1997. Its purpose is to identify the major risk factors associated with the operation of shuttle tankers in close proximity to offshore export facilities. In particular the study addresses the operation of DP shuttle tankers at FPSOs and FSUs. The study considers the many influencing factors affecting the safe operation of shuttle tankers, including hardware and equipment levels, management and organisational aspects, human competency issues, regulatory controls and also cultural considerations. The study identifies problem areas and proposes appropriate risk reduction methods. The study is of considerable importance to the shuttle tanker sector, not only in the UK and NW Europe, but also world-wide.

Project Background

UK Health and Safety Executive (HSE)

The Offshore Safety Division (OSD) of the HSE has the responsibility for the regulation of health and safety on the UK Continental Shelf. The formation of the OSD was one of the many changes in the UK regulatory set up that followed the Piper Alpha tragedy in 1988. The OSD replaced the Department of Energy in the field of safety regulation. Inspectors are based at Aberdeen and Norwich with further policy and legal centres in London and Liverpool. Although principally tasked with wide-ranging regulatory responsibilities for risks directly associated with the exploration and production of hydrocarbons at fixed and mobile offshore installations and for pipeline transportation systems the OSD must also consider other external risks, such as the marine risks posed by attendant vessels, including shuttle tankers.

This study was initiated by the OSD in an effort to obtain an overview of the nature and scope of the risks of shuttle tanker operations, in particular the risks of collision when in close proximity to offshore installations.

Development of the Safety Case Regime

The principal regulations that are now in place in respect of offshore safety in the UK sector are the Offshore Safety Case Regulations, 1992. These regulations heralded a sea change in the offshore safety regime and saw the imposition of the principles of self regulation at the same time as a loosening of the reins of the previous prescriptive regime. The principle that underpins the safety case regime is the reduction of risks presented by major accident hazards to levels of ALARP. In complying with this principle companies must adopt appropriate risk management processes, including identifying hazards and potential magnitude of loss, assessing the likelihood of occurrence and, where necessary, establishing appropriate risk control measures.

This means that the operating companies of offshore installations involved in the export of hydrocarbons via shuttle tanker are required to manage the associated risks in this way.

<u>Increasing Importance of Shuttle Tanker Sector</u>

The past few years have witnessed a rapid rise in the application of the shuttle tanker concept in the UK sector. The transportation of oil by tanker direct from offshore export facilities is not a new phenomenon. The concept has been around for many years; there being many examples of conventional world-wide trading tankers loading at offshore facilities, especially in benign tropical waters. However, the shuttle tanker concept is somewhat different in that it is normally a question of specially dedicated tankers engaged in short trips, shuttling cargo from the offshore production areas to the nearby refinery market. Recent rapid growth in the shuttle tanker sector has been in environmentally harsh areas, such as at exposed locations on the UK and Norwegian Continental Shelves.

The first major export facility at an exposed offshore location in the UK sector was at the Argyll Field in 1975, where a semi-submersible production installation was connected to a single buoy mooring, exporting directly into a conventional tanker tethered to a loading buoy. Similar technical solutions using conventional tankers at single point export facilities were adopted at Shell’s Brent Field, Amoco’s Montrose Field and Mobil’s Beryl Field, etc. By and large the tankers were dedicated and were the first to be considered as shuttle tankers.

It only took a few years for the first DP shuttle tanker to enter into service in NW European waters. This was carried out by Statoil in 1981 at a single point loading facility at the Statfjord Field using MT Wilnora. Initially it was introduced more as an experiment rather than a permanent solution. It was considered at the time as a stop-gap measure to get oil ashore, the intention being, in the long run, to construct a pipeline from Statfjord to shore. However, the results of the 1981 experiment were sufficiently encouraging for Statoil and then, the industry as a whole, to consider exports by DP shuttle tanker as a life of field solution rather than a short term interim expedient.

Since those early experimental days there has been considerable development in the range and type of export facilities. Single point facilities have now been overtaken in importance by ship shaped FSUs and FPSOs and, over the past few years, there has been a marked growth in the size of the shuttle tanker market. There are currently in the region of 20 DP shuttle tankers in the NW European shuttle tanker fleet and there are also a number of non-DP tankers that carry out shuttle operations.

Project Parameters

Project Scope

The overall scope of the project was as follows:

Identify the factors that influence and control the distance of separation between the shuttle tanker and the installation and how the separation is optimised with regard to safety and the principles of ALARP.

In geographical terms the project was to consider shuttle tanker operations on the UK Continental Shelf, i.e. in the North Sea and West of Shetlands. The project also had to take account of the activity in the Norwegian sector, where there is a longer history of DP shuttle tanker operations. In fact the DP shuttle tanker fleet is overwhelmingly Norwegian in all aspects; the majority of shuttle tankers flying the Norwegian flag and almost all owned, managed and operated from Norway with Norwegian crews and largely operating Norwegian equipment. To omit the Norwegian dimension from the study would have eliminated the largest source of relevant information.

In operational terms the scope was to consider the operation of shuttle tankers at the offshore export facilities that are subject to regulation under the safety case regime, including single point mooring systems as well as FSUs and FPSOs. This also included the various arrangements for life of field solutions and temporary production systems such as are required for extended well testing.

Project Objectives

The principal objectives were as follows;

Provide the HSE and other interested parties with a wide ranging objective study of risks associated with shuttle tanker operations.

Provide appropriate material from which guidance, regulations and industry standards may be derived.

In setting these objectives it is acknowledged that the shuttle tanker sector is not without standards. As will be seen later in this paper, however, standards have largely been self generated by the industry and there is evidence that they are not applied in a consistent manner. To a large extent there is little in the form of regulatory guidance to the industry.

Project Schedule

The project ran for a period of three months from April 1997 through to July 1997, when the written report was completed and issued to the HSE in draft form. The project was split into three stages.

Stage 1	Information Gathering	April/May
Stage 2	Report Preparation	June
Stage 3	Acceptance Process	July/August

Project Method

The project was underpinned by an extensive information gathering exercise carried out in three interrelated stages.

Stage 1	Meetings with industry representatives
Stage 2	Literature search
Stage 3-	In-house knowledge of shuttle tankers, DP operations and FSUs/FPSOs

The main information gathering was done at face to face meetings with a wide range of companies all with a direct involvement in the offshore shuttle tanker market. These included six oil companies, i.e. the operators of the export facilities, seven shuttle tanker owners/operators, three equipment manufacturers and two training establishments. Information was obtained in qualitative interview sessions. Results from the oil company and tanker operator sessions were recorded in specially prepared booklets. The booklets covered the following areas.

Offshore Export Facility Operators

Facility Description - location, type, mooring and propulsion system, frequency of exports, cargo capacity of facility, hose and hawser length, nominal separation distance, approach and departure procedures, use of DP.

Facility Management- owner, operator, duty holder. Management responsibility for safe operation of facility.

Support Vessel - role of vessel, size of vessel, fitness for purpose, drills, emergency towing facilities.

Regulatory Regime - identity of regulator, role of regulator, main regulations,

Shuttle Tanker Operators

Tanker Technical Description - main and auxiliary power systems, propulsion systems - thrusters, CPPs, fixed systems, main propulsion units. DP or tethered, level of control redundancy. DP system and sub-systems.

Shuttle Tanker Management - owner, operator, flag state, internal and external DP verification methods, operational limits.

Support Vessel - role of vessel, size of support vessels at different locations, fitness for purpose, drills, emergency towing.

Regulatory Regime - principal rules and regulations, e.g. IMO DP standards,

influence of regulator	equipment levels, class society rules, industry standards and guidelines.
Human Resources - size of facility crew, nationality, language, selection and competency issues.	Human Resources - size of tanker crew, nationality, selection and competency issues, watchkeeping, training of DP personnel, inc. operators, technical staff.
Environmental Factors - design limitations, environmental monitoring, e.g. wave height, operating limits, critical operating limits.	Environmental Factors - design limitations, environmental monitoring, e.g. wave height, tanker operating limits, critical operating limits.
Shuttle Tanker - availability and sources of shuttle tankers, fitness for purpose verification procedures, normal and emergency procedures.	Shuttle Tanker Procedures - approach, connect and departure operations, DP, position references, emergency procedures. DP manning,
Loss Control - records of incidents and accidents, risk based and/or prescriptive approach, areas of concern.	Loss Control - records of incidents and accidents, risk based aspects - Failure Modes and Effects Analyses (FMEA), areas of concern.

DESCRIPTIONS

Export Facilities Descriptions and Assessments

There is a wide range of export facility types. For convenience they can be divided into three different generic types, viz., a) surface single point systems, b) sub-surface single point systems and, c) surface production and storage systems.

Surface Single Point Systems

There are various types of surface single point loading systems, including an articulated loading platform (ALP) and single buoy mooring (SBM). A common feature of surface single point systems is that their upper sections are above the surface and that they have a single terminal offloading point around which the offtake tanker can normally weathervane. The loading hose and, where relevant, the mooring hawser are connected to the bow section of the offtake tanker.

Many of the risks associated with the operation of an offtake tanker at surface single point systems are common to other offshore export facilities but on a lesser scale. Specifically, in terms of the collision risk, the consequences are generally less than with some other arrangements, such as ship-shaped FPSOs and FSUs. Surface single point systems are generally unmanned, have little or no hydrocarbon storage, are less vulnerable to impact damage since they are not fixed installations and normally have a circular profile, which would tend to deflect impact energy in the event of a collision.

Sub-Surface Single Point Systems

There are various types of sub-surface systems, including OLS (offshore loading system), STL (submerged turret loading), TCMS (tripod catenary mooring system), SAP (single anchor production) and SAL (single anchor loading). The OLS, originally known as UKOLS was the first type of sub-surface system and replaced some of the earlier ALPs that had developed cracks. A significant feature of most sub-surface systems is that they are designed for hawserless operations. The loading equipment remains subsurface until picked up by the offtake tanker, so that at times when no export is taking place the main items of equipment remain unaffected by surface environmental forces. In each case there is normally a messenger line and small location buoy left on the surface after departure of the offtake tanker, potentially presenting a hazard to surface ships. The STL, TCMS, SAP and SAL systems are designed for operation with conventional tankers that have had only minor modifications to the bow area for accepting the chain mooring and loading hose. There are advantages in using DP tankers at such systems, generally because the manoeuvring and control characteristics of the DP tankers are superior to non-DP tankers, resulting in a widening of the environmental envelope for offtake operations.

One of the principal advantages of the STL system is that the environmental envelope is considerably more extensive than with other sub-surface systems. STL systems are able to support continued operations in extreme environmental conditions that other systems find untenable. The ability to maintain production in extreme conditions does not significantly increase the risk of damage or loss, since there are generally no surface obstructions presenting a risk of collision. Where there exist environmentally induced hazards, such as extreme wave height or extreme sub-surface currents causing unacceptable excursions or tensions in the mooring system, then the risk of damage can be averted by emergency disconnection. This facility is provided in all systems.

Surface Production and Storage Systems

The two principal systems are floating storage units (FSU) systems and floating production storage and offloading (FPSO) systems. Typically both involve the use of ship shaped vessels secured to the seabed by a number of different mooring systems, such as STL. In both cases the FSU and FPSO are able to weathervane, at some locations without restriction, but at others with only a limited degree of freedom. The normal means of export is by stern loading to an offtake tanker. The generic term for this is tandem loading. The offtake tanker can be either DP controlled or a conventional tanker. There has been a trend for tankers to become more sophisticated with greater manoeuvrability and redundancy, however there are still some shuttle tankers that have conventional propulsion and control configurations.

The greatest single marine risk is that of collision between the FSU or FPSO and the offtake tanker. The hazards are potentially much more severe than other export facilities since, in physical terms, the inherent forces, physical masses and exposure of personnel are greater. Where, as in most cases, the positioning of the offtake tanker is controlled by DP then the reliability and effectiveness of the DP system and its peripherals are of utmost importance. In terms of dynamic interaction the presence of the DP shuttle tanker poses as much of a threat to the FSU or FPSO as does the FSU or FPSO to the DP shuttle tanker. However, apart from a select few examples, the operational risk reduction measures are mainly taken by the DP shuttle tanker.

The better the operational performance and redundancy levels of the DP system then the more remote the chance of collision.

Close Proximity and Environmental Sensitivity Indexing

An effort was made during the project to carry out an objective assessment of all generic types of offshore export facilities and to establish a ranking of each type against various criteria. The criteria included the following, suitability of DP or non-DP tanker application, close proximity sensitivity index, environmental sensitivity index, temporary and life of field solutions.

The following table highlights some important results from that assessment.

Export Type		Close Proximity Sensitivity Index	Environmental Sensitivity Index
ALP	Articulated Loading Platform	2	1
SBM	Single Buoy Mooring	2	1
OLS	Offshore Loading System	3	2
STL	Submerged Turret Loading	3	3
TCMS	Tripod Catenary Mooring System	3	3
SAL	Single Anchor Loading	3	3
SAP	Single Anchor Production	3	3
FSU	Floating Storage Unit	1	1
FPSO	Floating Production Storage	1	1

Close Proximity Sensitivity Index
Key: 1 = most sensitive, 2 = sensitive, 3 = least sensitive

A number of elements were considered in determining the close proximity sensitivity index of each of the export systems. Decisions were made qualitatively but remain consistent with the viewpoints expressed by the participants throughout the course of the project. One of the principal considerations was the dynamic interaction between the offtake tanker and the export facility. It is widely recognised that the most significant dynamic interactions are to be experienced between the offtake tanker and another ship shaped installation, such as a FSU or FPSO, especially when in tandem loading mode. Another consideration was the physical size of the units and also exposure of personnel to potential harm in the event of failure. A rating of 1 is the most sensitive index and indicates that, other things being equal, there is greater risk of collision risk and the potential loss is greater than with other index ratings. For example, a DP tanker that is carrying out an offtake some 60 metre astern of an FSU has a more sensitive close proximity rating than if it were on location at an STL, since not only are the potential consequences much more severe but also the probability of collision is also much higher. The same reasoning applies to a non-DP tanker at these locations, where the rating of 1 still applies to the FSU and lesser rating to the STL.

As can be seen from the table it is only the FSU and FPSO that attract a rating of 1. The other surface based systems, ALP and SBM, have a rating of 2 and the subsea systems have the lowest ratings. It is recognised that a number of subsea systems will attract a higher rating than 3. This will depend on the proximity of adjacent obstructions, such as production platforms and mobile drilling rigs.

Environmental Sensitivity Index
Key: 1 = most sensitive, 2 = sensitive, 3 = least sensitive

Many of the principles used to determine the environmental sensitivity rating are similar in nature to those used in determining close proximity indices. Clearly there are some systems, which are extremely sensitive to environmental conditions, in particular the effects of the wind, sea height, swell, period and current. To a large extent the surface based systems are more vulnerable to the changes in environmental conditions than are the subsea systems.

Single point surface systems such as ALP and SBM are less vulnerable than are FSUs and FPSOs, since, other things being equal, the single point systems are largely unaffected by environment induced movement, such as rotation, rolling and pitching. The tankers that are connected to single point systems are generally free to rotate around a small pivotal area, whereas in the FSU and FPSO systems it is generally the case that the attached tanker and the export facility both adopt environment induced headings, although this is mitigated somewhat where there is heading control.

Results of Assessments

The implication from the results of the above assessments indicated that the FSU/FPSO arrangement has the potential for the greatest risk and greatest loss.

Shuttle Tanker Types and Assessment

Loading Systems

The first shuttle tankers were standard ocean going trading tankers that tied up to buoys using conventional mooring systems, winch equipment and fairleads designed for securing the vessel to a jetty in a harbour. Generally the loading hose was long enough to stretch from the loading buoy to the tankers midships manifold. There are a number of obvious disadvantages with this type of system, e.g., limited environmental envelope, protracted mooring and disconnection times and increased likelihood of personal injury because it was labour intensive.

The tankers were next fitted with a bow loading system. This allowed the tanker to attach itself to the loading station by a single line via a quick disconnect arrangement. A permanent loading line was run from the tanker’s midships manifold to the bow and a system of remote closing valves and a quick disconnect coupling fitted for attaching the hose to the loading line. The bow loading system was a considerable advance in ease of connection and disconnection and also enabled an emergency release to be initiated from the tanker. For tankers operating in the North Sea a standardised coupling design was developed enabling a shuttle tanker to visit all offshore export facilities. As described in the previous chapter there are now a number of different types of offshore loading facilities, all of which have compatible hawser and hose connection systems.

Control Systems

Early shuttle tankers had a simple bridge control system for the main engine speed and propeller pitch. Where fitted, control of the bow thruster was by a single lever controlling the pitch. Control of the main propeller and transverse thrusters were later integrated into a single joystick with heading control.

Dynamic Positioning (DP) systems were then developed for shuttle tanker use. A DP system takes information from vessel status sensors (Gyro compasses, vertical reference sensors and wind speed sensors) and position reference sensors (Hydroacoustic Transponders, Artemis, and satellite position reference systems such as DGPS), analyses this information and adjusts the propeller thrust to maintain position within defined limits. Early systems used a single computer, later systems have utilised a twin computer.

Typical Tanker Configurations

The table below describes typical configurations for four types of shuttle tanker. The types described here are indicative only and, although modelled on tankers that are either currently in service or under construction, they do not refer to specific tankers.

TANKER FEATURES	**TANKER A Early**	**TANKER B 1st Generation**	**TANKER C 2nd Generation**	**TANKER D 3rd Generation**
Main Engine Type	Single slow speed, two stroke Diesel coupled directly to propeller shaft.	Single slow speed, two stroke Diesel directly coupled to propeller shaft.	Two medium speed, four stroke Diesel engines each coupled via a clutch to a gear box and propeller shaft.	Two slow speed, two stroke Diesels directly coupled to propeller shaft.
Main Propulsion	Single main CPP	Single main CPP	Two main CPPs	Two main CPPs
Bow Propulsion	None	Two bow thrusters 2 x 1500hp	Two bow thrusters 2 x 2000hp	Three bow thrusters 3 x 2300hp
Stern Propulsion	None	Single stern thruster 1 x 1500hp	Single stern thruster 1 x 1500hp	Two azimuth stern thrusters 2 x 2300hp
Rudder	Single conventional rudder	Single high lift rudder	Two high lift rudders	Two high lift rudders
Power Generation	3 x identical DGs supplying 440V AC at 60Hz to main swbd.	5 x identical DGs in single ER supplying 440V AC at 60Hz to main swbd.	4 x identical DGs supplying 660V AC at 60Hz to main swbd, plus shaft alternators driven off each main engine	4 x identical DGs, 2 in each ER, supplying 6.6kV AC at 60Hz to main swbd.
Power Distribution	Single main swbd in one section with no bus-ties.	Single main swbd split by auto trip bus-tie. 2 x DGs on port side and 3 x DGs on stbd side of the bus. Main service pumps split between two busses. Bow thrusters supplied from different busses.	Single main swbd in two sections, one in each ER, connected by auto trip bus-tie. 2 x DGs on port side, 2 on stbd side. Main service pumps split between busses. One bow thruster and one stern thruster supplied from each swbd.	Single main swbd in two sections, one in each ER, connected by an auto trip bus tie. 2 x DGs on port side, 2 on stbd side. Main service pumps split between two busses. One bow thruster and one stern thruster supplied from each swbd.

TANKER FEATURES	TANKER A Early	TANKER B 1st Generation	TANKER C 2nd Generation	TANKER D 3rd Generation
DP Control Location	None	Bow Control House	Bow Control House	Navigating Bridge
DP Control System	None	Simplex Simrad ADP100 2 x VRUs 2 x wind sensors 2 x gyro compasses 2 x draught gauges	Duplex Simrad ADP 702. 2 x VRUs 2 x wind sensors 2 x gyro compasses 2 x draught gauges	Duplex Cegelec 902 2 x VRUs 2 x wind sensors 2 x gyro compasses 2 x draught gauges
DP Position References	None	Artemis Mk IV HPR system DGPS/DARPS	Artemis Mk IV Fan Beam Laser HPR System DGPS/DARPS	Artemis Mk IV Fan Beam Laser HPR System DGPS/DARPS

Results of Tanker Type Assessment

Other things being equal the use of high specification tankers is considered as a risk reduction measure. This is especially relevant at export facilities, such as FSU/FPSOs, exposed to the greatest level of risk and greatest potential loss.

THE EXTENT OF THE PROBLEM

Historical Records

<u>Accident/Incident Reporting Regime</u>

There is an absence of publicly available information on accidents and incidents that have occurred in shuttle tanker operations. Information is generally held in-house by oil companies, tanker operators and other industry organisations. There is no sector reporting scheme that provides detailed accident/incident information to interested parties. For example, companies that intend to enter the shuttle tanker or the export facility market have difficulty in finding out about problem areas that have affected existing operators.

The following table provides brief details of the accidents and incidents that were identified during the project.

ACCIDENT/ INCIDENT	CAUSE	DAMAGE	DP OR NON DP	DATE
1	Hawser failure	Fatality Fire Moderate oil spill	Non DP	1980
2	Hawser failure	Loading hose damage Minor oil spill	Non DP	1981-83
3	Hawser failure	Loading hose damage Minor oil spill	Non DP	1981-83
4	Hawser failure	Unspecified minor damage	Non DP	1981-83
5	CPP control system failure	Unspecified minor collision damage	DP	1984-93
6	DP failure	Unspecified minor collision damage	DP	1984-93
7	DP failure	Unspecified minor collision damage	DP	1984-93
8	Human error	Unspecified minor collision damage	DP	1984-93
9	CPP control system failure	None Lost time	DP	1993-97
10	Failure of breakaway coupling during hook up	Minor Lost time	DP	1993-97
11	Inadequate propulsion during final approach	Collision with support vessel	DP	1983
12	Failure of engine control system	Collision with loading buoy	Not Known	1984
13	Not Known	Unspecified collision	Not Known	1988
14	Human error	Collision with loading buoy	Not Known	1989
15	Failure of DP control system	Collision with export facility	DP	1992

In addition to the above known accident/incidents, during the course of the project two accidents occurred at offshore locations involving collision between the DP shuttle tanker and the FPSO. In both cases damage was not extensive, neither were there any personal injuries. The first collision appeared to have been caused by human misjudgement compounding a problem associated with dynamic interaction. The second collision also appeared to have been caused by human misjudgement/error compounding a DP position reference system problem.

Areas of Perceived Hazard

The table below was compiled from the responses made by the representatives of the industry to the question "What area or areas of shuttle tanker operations cause the greatest concern in terms of safety and/or environmental pollution?"

No guidance or further leading questions were given, therefore the responses are totally voluntary and self generating. Brief discussions were held on the current areas of concern and note was taken of the responses, which were later categorised and tabulated in the form shown below. The responses were counted and a criticality rating was given to each category. The criticality rating is based on the number of responses in each category.

CATEGORY	COMMENTS	CRITICALITY RATING
Tanker Positioning and Control	1. Operation and reliability of position reference systems for DP shuttle tankers. 2. Drift movement of NUC tankers following all power loss. 3. Change over from auto to manual control in emergency situations	6
Tanker Human Factors	4. Manning of control spaces, inc. DP control locations, engine room. 5. Cultural differences. 6. Training, familiarisation and competence of tanker crews.	5
Dynamic Interaction	7. "Fish-tailing" 8. "Surging"	4
Tanker Propulsion	9. Operation of CCP thrusters and failure modes that may result in a thruster failing to maximum thrust. 10. Potential failures of main propulsion.	2
Operational Management	11. Commercial pressure in decisions relating to offtake operations, especially in adverse environmental conditions.	2
Environmental Preparation	12. WX and environmental monitoring, in particular accurate measurement of Hs and surface currents, especially in recent development areas, such as the Atlantic Frontier.	2
Support Vessel	13. Support vessel operations and training and familiarisation of support vessel crews	1

The following provides a brief outline of the areas of concern.

Operation and Reliability of Position Reference Systems for DP Shuttle Tankers

Position reference system (PRS) problems are potentially the most troublesome of all systems in a DP system. For example, the analysis of all DP incidents resulting in position loss investigated by the DPVOA in 1993 show that 47% were caused by failure of position reference system failure. Many position reference problems have been overcome in other DP sectors by providing adequate redundancy. Normally, this means that a DP diving vessel operates with three position reference systems on line at any one time. This level of redundancy is not normally available on DP shuttle tankers, many of whom operate with only one system on line. There are particular difficulties with DP shuttle tankers, since the most popular and reliable of DP position reference systems, vertical taut wire, is not an available option.

Risk Reduction Measures

Provide adequate redundancy in reliable position reference systems

Ensure that failure of one position reference system does not result in unacceptable loss of position

Drift Movements of NUC Tankers

This causes concern when risk assessments are being carried out of worst case scenarios, in particular where a tanker may be totally incapacitated without propulsion and with no control of its movements. The worst case scenario must always be considered. Many export facilities are located in congested development areas where there are other offshore installations in the vicinity, typically 1.5 to 2.5km distant, such as production platforms, anchored drilling rigs and accommodation units. Propulsion and control failure present significant risks of collision.

Risk Reduction Measures

Impose sector restrictions on the shuttle tankers

Ensure provision of appropriate emergency towing facilities

Operate shuttle tankers with adequate levels of redundancy

Change Over From Auto to Manual Control

This problem area is also associated with a worst case scenario, which occurs when the tanker is in close proximity to an FSU/FPSO, possibly at a nominal 60 metres horizontal separation. The scenario is that the tanker drives ahead and is about to come into contact with the stern of the FSU/FPSO. There are a number of possible causes for the tanker to drive ahead. For example, it may be as a result of a fault in the main propulsion system which causes a CPP to drive ahead uncontrollably. It may be caused by incorrect data from a PRS. Or, it may be as a result of "surging", i.e. a phenomenon caused by the dynamic interaction between the tanker and the FSU/FPSO.

Risk Reduction Measures

Operate shuttle tankers with adequate levels of security and redundancy in propulsion

Adequate preparation and competency of DP operators

Manning of Control Locations

Manning levels in the engine control room and on the bridge/DP control location when the tanker is in close proximity to the export facility tend to be in line with deep sea trading tanker standards rather than what is normally practised on other DP ship types. For instance, the tanker's engine room may have a class notation, UMS (unmanned machinery space), permitting an unmanned engine room at all times when at sea, including during the offtake period. Therefore, the tanker's engine room may be unmanned during times of close proximity. Also, typical arrangements on other DP ship types, e.g. diving and drilling, are for two DP watchkeepers to be on watch in the DP control area at any one time, one being in control at the console while the other is carrying out some other related duties, the important point being that both are competent DP operators and have hands on experience of that ship. This practice is not always followed on DP shuttle tankers, where, it is acknowledged, that occasionally the master is the only competent DP operator on board.

Risk Reduction Measures

Ensure manning levels meet standards required by other DP sectors
Ensure adequate competency of al DP watchkeepers
Increase awareness of tanker crew of hazards and potential failures

Cultural Differences

Cultural differences are not restricted to shipboard operational situations, such as those indicated above, but extend to the overall management and control of the DP shuttle tanker sector. Different standards prevail between the DP shuttle tanker sector and other DP sectors. Examples are as follows; standards of DP verification and testing, DP documentation and system analysis, identification of single point failures.

Risk Reduction Measures

Increase awareness of tanker management to take account of processes employed in other DP sectors

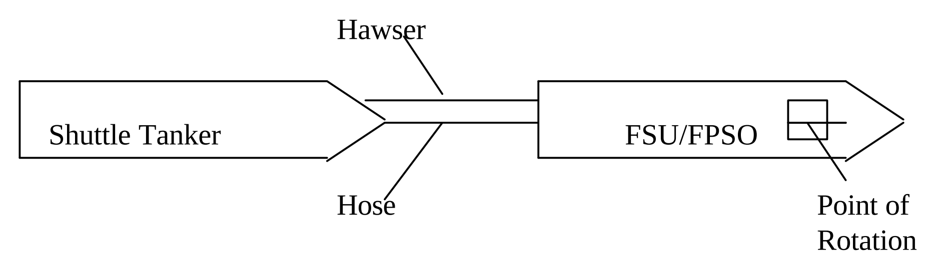
Training, Familiarisation and Competence of Tanker Crews.

There are two strands to this concern, viz., issues related to competency and certification and also issues related to ship specific familiarisation and hands on experience. As far as competency and certification issues are concerned it is apparent that the training centres, courses and syllabi are generally geared up for DP ship types other than DP shuttle tankers. More shuttle tanker specific courses are being developed, more simulator hardware is being installed and the tanker masters and navigating officers are getting effective training. Yet, it is clear that the system caters best for the majority and that means DP operators of dive support ships, drilling units, cable layers, etc. It is also a common feature of DP shuttle tanker bridge management that the master does not delegate DP operational control to other officers and that, frequently, he remains on watch and in charge of the DP console throughout the entire offtake, lasting typically from 18 to 36 hours. This is considered by a number of those who participated in the project as being out of step with current principles of effective bridge management, if not also being inherently hazardous. Operating such a system does not give the master adequate rest.

Risk Reduction Measures
Adopt competency processes that have been implemented successfully in other sectors, e.g. bridge resource management, training and competency of key DP personnel - IMO

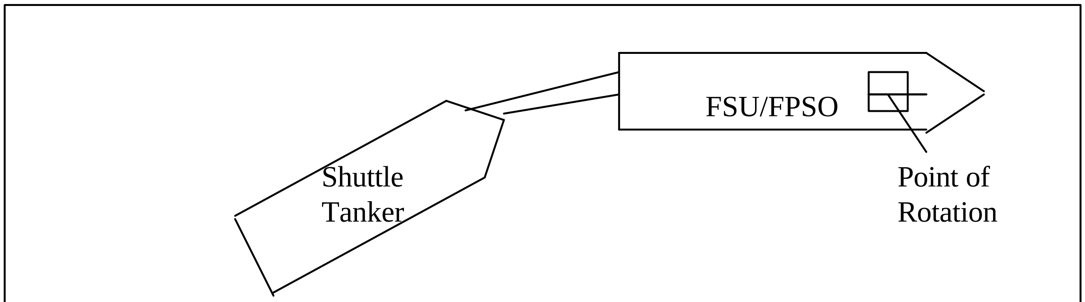
<u>Fishtailing</u>
Currently, the typical control mode for DP shuttle tankers at all offtake facilities, including FSU/FPSOs is to weathervane. The weathervaning heading strategy utilises the stabilising effect of the wind and wave forces on the tanker's hull. In this mode the DP control system seeks to find the tanker heading that offers the minimum sideways force, i.e. minimum sway characteristics, the heading being a function of the transverse forces. The tanker's propulsion is then used to maintain the separation distance between the tanker and the FSU/FPSO. Typically the preferred close proximity tanker-FSU/FPSO alignment is for the bow of the shuttle tanker to point directly towards the stern of the FSU/FPSO. Where the FSU/FPSO has no heading control or DP control itself then the FSU/FPSO is generally free to rotate about its point of rotation and adopt a heading that is in line with the main environmental forces acting on it. Where the FSU/FPSO is in loaded condition with a substantial draft then it is normal for the surface current force to be dominant and for the FSU/FPSO to be predominantly current rode. However, where the shuttle tanker is in ballast condition with reasonably shallow draft then typically the tanker will be more responsive to wind forces than to surface current forces and is more likely to be predominantly wind rode.

Examples of fishtailing are illustrated in the figures below.

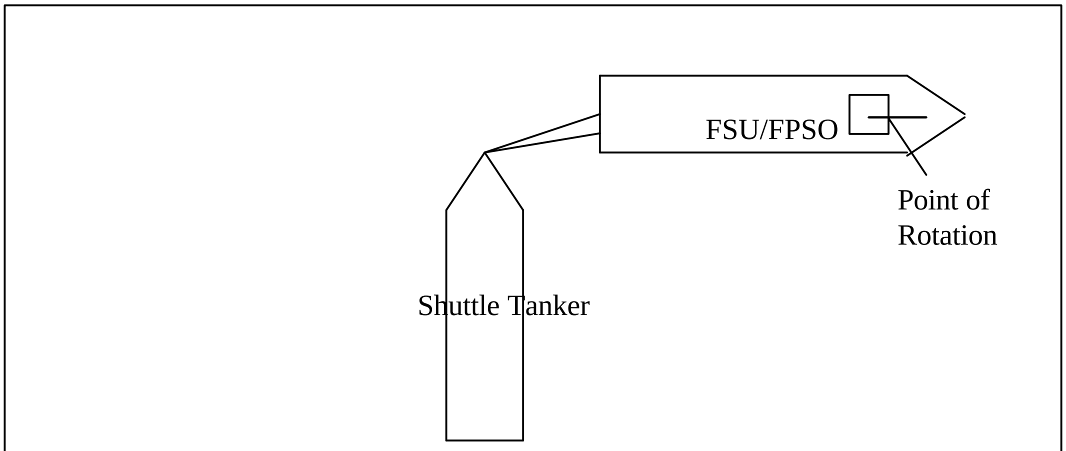


Tanker - FSU/FPSO in Alignment - No fishtailing

Fishtailing generally occurs when the environmental forces are reasonably low in magnitude. It is also principally a phenomenon that occurs when there is considerable dissimilarity in hydrodynamic characteristics between the tanker and FSU/FPSO. As a result the variable factors that contribute towards fishtailing are continuously changing. During the course of the offtake operation the FSU/FPSO becomes lighter and is subject to influence by a different combination of hydrodynamic forces, becoming more under the influence of wind than wave or current. Similarly, the shuttle tanker's condition changes, becoming heavier, tending to be more under the influence of wave and current than wind.



Tanker - FSU/FPSO out of alignment - Typical Fishtailing



Tanker - FSU/FPSO Out of Alignment - Extreme Fishtailing

Operational and Safety Related Problems

- Possibility of the hawser and hose becoming crossed, resulting in abrasion and possible damage to hose and hawser.
- Possibility of obstructions in way of the Artemis line of sight between the tanker and the FSU/FPSO, resulting in loss of position reference signals.
- Less room for manoeuvre when at extreme angles in the event of emergency.
- Reduction in separation distance at the bow and along the length of both tanker and FSU/FPSO, resulting in increased exposure to risk of collision

Risk Reduction Measures

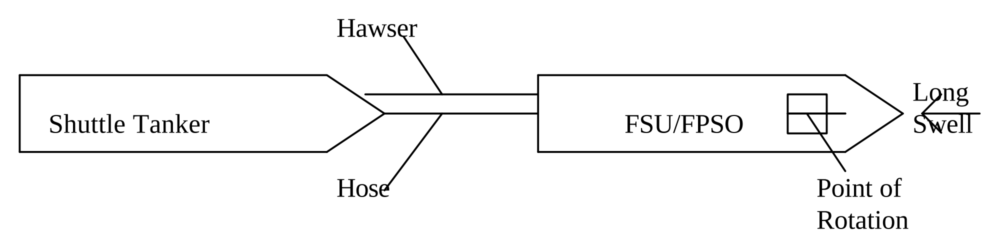
- On the tanker, monitor the heading of the FSU/FPSO and as its heading changes so make minor adjustments to the heading of the tanker and use transverse thrusters to keep the tanker and the FSU/FPSO in alignment.
- On the tanker, where there is no DP control or where transverse propulsion is inadequate, use the support vessel under tow to pull the stern of the tanker in the appropriate direction, thus achieving alignment.
- On the tanker, when it is detected that fishtailing is set to be a problem, apply astern thrust to the main propulsion to exert small amount of tension on the hawser, thus

making the tanker and FSU/FPSO combination one cohesive unit as far as the environmental forces are concerned.

- Apply heading control to the FSU/FPSO so that the FSU/FPSO is not free to rotate in accordance with external environmental forces.
- Where heading control and/or heading monitoring is available on the FSU/FPSO, transmit the FSU/FPSO heading directly to the tanker and use as an input to the DP control system. This means that the tanker is no longer able to operate in accordance with the principles of weathervaning. This requires the DP system to provide control in all three axes, surge, sway and yaw. This principle is applied at various offtake facilities with considerable success.

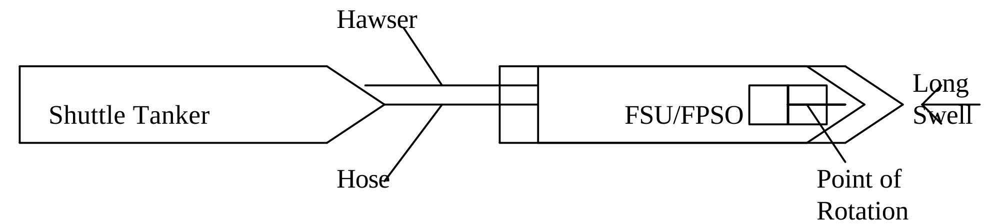
<u>Surging</u>

This is a well known problem during offtake operations, particularly at FSU/FPSO facilities. The shuttle tanker may experience long period waves in excess of 15 seconds frequency with the result that the tanker begins to surf on the crests. This can lead to large alongships oscillations if the fore and aft propulsion is unable to dampen the motions adequately. While the tanker is subjected to such surface influenced fore and aft movement the FSU/FPSO, being secured to the seabed, generally by a chain and wire mooring arrangement, is subjected to different hydrodynamic forces and at different levels. In part much of the fore and aft motion experienced by the FSU/FPSO is dampened by the mooring system. As a result of the differences of the environmental forces the fore and aft motion of the FSU/FPSO may be significantly different from the fore and aft motions of the shuttle tanker, resulting in asynchronous movement. The worst case scenario is where the FSU/FPSO moves astern at the same time as the shuttle tanker moves ahead, thus reducing the separation distance. The movement of the shuttle tanker is not only influenced by the environmental forces. There is also propulsion induced movement caused by DP control system signals acting on the position reference information, so that the DP system acts on changes of the separation distance between the tanker and the FSU/FPSO. The aim of the DP system is to maintain a stable separation distance. There is a possible solution to this problem that is based on a modification of traditional DP control system logic. The following figures illustrate the basic problem of surging and some of the complications.



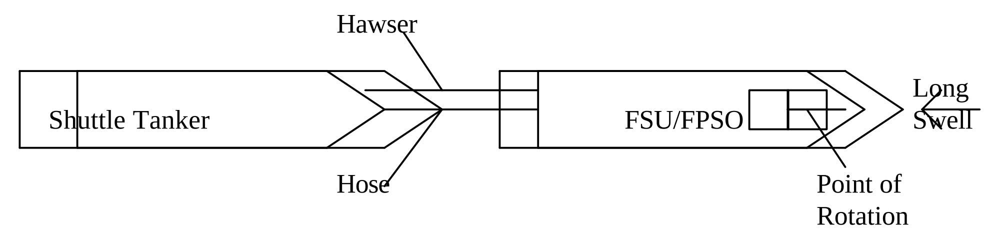
Tanker - FSU/FPSO in Alignment

In the figure above there is a long swell but there is no relative movement between the tanker and the FSU/FPSO. Assume that the separation distance is steady at 70 metres. The hawser is slack.



Tanker steady - FSU/FPSO moves astern caused by long swell - separation distance decreases

In the figure above the FSU/FPSO begins to move astern. The movement is caused by the combined effects of the long swell on the subsea mooring system and on the hull form of the FSU/FPSO. The tanker remains steady. The astern movement of the FSU/FPSO has reduced the separation distance to 60 metres.



Tanker moves ahead caused by long swell - FSU/FPSO still astern of target location -

In the figure above the FSU/FPSO remains steady in position offset some 10 metres astern of its target position. In the meantime the swell has acted on the more responsive shuttle tanker which surges ahead some 20 metres, thus reducing the separation distance to 40 metres.

The combination of movements and the figures used in the examples above are purely indicative and are intended to illustrate in the simplest form possible the potential consequences of dissimilar movements, viz., that of reducing the separation distance. Extreme surging can result in collision.

A number of operational and safety related problems are liable to be experienced during surging. The extent of the problems of movement may be even greater than shown in the figures on the preceding pages. The overall view across the DP shuttle tanker sector is that surging is the most critical hazard affecting offshore cargo offtakes. It is a problem that is associated particularly with long swells, typically in excess of 15 seconds frequency. Although such swell periods may not be altogether common in North Sea areas, the Atlantic Frontier is frequently subject to such environmental conditions. Therefore the problem is likely to be more prominent in that geographical area.

Operational and Safety Related Problems

- Dissimilar fore and aft movements result in rapid changes to separation distance between the tanker and the FSU/FPSO, in turn resulting in rapid engine movement changes from ahead to astern. In the case of some DP shuttle tankers during the entire cargo offtake there are constant ahead/astern movements.
- Failure modes that cause instability in the propulsion movements, e.g. failing to full ahead or astern, can have serious consequences and result in collision.

Risk Reduction Measures

- By reducing the nominal separation distance between the tanker and the FSU/FPSO there is less likelihood of the tension appearing in the hawser when the tanker moves astern on the swell. This practice is exercised by a number of tanker masters, the nominal separation distance being, in some instances, reduced to 30 metres.
- Come out of DP control and maintain small amount of tension on the hawser.
- Appropriate DP control software is under development. The software takes account of the absolute and relative positioning between the tanker and the FSU/FPSO.

NB This paper does not express a judgement on the correctness or otherwise of the above measures.

Operation of CPP Thrusters and Failure Modes / Potential Failure Modes of Main Propulsion Systems

There are many scenarios where serious problems will arise following failure of CPP thrusters or failure of the main propulsion system, if different, resulting in collision and significant loss.

Risk Reduction Measures

Ensure a thorough FMEA is carried out of all critical systems and equipment to ensure that failure modes and consequences are identified and appropriate measures taken to reduce the likelihood of failure and/or increase redundancy.

Pressure to Continue Production

There are occasions when commercial pressures are brought to bear on the senior personnel involved in an cargo export operation. This is seen in the following example.

"Ullage levels on a FPSO are fast disappearing because of continued production. The environmental conditions are deteriorating. The installation asks the tanker to approach, connect up and load only a few hours worth of cargo under explanation that this would relieve the pressure on the installation and provide sufficient ullage to enable full production to continue for a few more days, by which time the environmental conditions should have improved."

This is a realistic scenario and gives rise to occasions when both the offshore installation manager (OIM) and the tanker master feel under pressure to attempt an operation in conditions that are perhaps marginal and deteriorating.

Risk Reduction Measures
Ensure that a decision making process is adopted that avoids conflict between pressure to continue production and the safety of the operation.

Environmental Preparation
It is generally accepted that one of the effects of the harsher environmental conditions will be an increase in downtime and more interruptions to the entire loading cycle than currently experienced in the North Sea. It is this troubled area that causes some concern.

Risk Reduction Measures
Appropriate measures include the following; effective management/procedural controls and accurate forecasting of environmental conditions, increased separation distance and increased technical specification.

Support Vessel
A support vessel is generally in attendance for the duration of the offtake. Apart from a few exceptions its assistance is invariably required at the connection phase and the support vessel remains in relative close proximity to the shuttle tanker during the course of the offtake. For many offshore safety case (OSC) duty holders the close attendance of the support vessel is considered as a major risk reduction measure. However the ability of the support vessel to fulfil its emergency role may be called into question because of a number of factors, inc. the suitability of the support vessel to undertake emergency towing operations in adverse environmental conditions, the training and capability of the crews of the support vessel to carry out such activities.

Risk Reduction Measures
Ensure that support vessel meets all requirements in power, towing capability and competence.

RISK REDUCTION ASPECTS OF DP SHUTTLE TANKER OPERATIONS

> *A DP shuttle tanker offtake operation should be considered first and foremost as a DP operation and be subject to appropriate controls and risk reduction measures that have been proven as successful elsewhere.*

The previous section of this paper dealt with areas of perceived risk and appropriate risk reduction measures designed to tackle these risks. This section of the paper deals briefly with generic risk reduction measures that are available and can be implemented across a wide range of DP operations, including DP shuttle tanker operations. Before proceeding it is important to acknowledge the relevance of the above statement, that, in all aspects, DP shuttle tanker operations are DP operations and should be subject to appropriate controls and risk reduction measures. The following list and subsequent narrative give an overview of subject areas and some appropriate risk reduction measures.

1. Regulatory
2. Technical
3. Operational Management
4. Human Factors
5. Cultural

Regulatory Measures

<u>International Regulatory Authorities</u>
The International Maritime Organisation (IMO) is the principal international body that has powers over flag states in the safe regulation of shipping. IMO has recently been active in issuing and acknowledging standards of equipment and training for DP operations, viz., “Guidelines for Vessels with DP Systems” and “Guidelines for the Training and Experience of DP Operators.” To a large extent, these standards reflect the standards to which the principal countries involved in DP operations have been operating, i.e. Norway and the UK.

<u>National Regulatory Authorities</u>
The Norwegian authorities, NMD and NPD, have been at the forefront in setting standards for the safety of DP operations. Equipment and redundancy levels are established for various types of DP operation; those that carry the highest risk requiring the highest level of equipment and redundancy. The approach of the UK authorities has been less interventionist, the principal publication being the joint UK/Norway guidelines (NPD/DoE) for safe DP operations, the most recent publication issued in 1983. However, neither of the national authorities in the UK or Norway has issued regulation, statute or guidance in respect of DP shuttle tanker operations on the UKCS.

Classification Societies

Classification societies have issued class notations for DP vessels that are based on the levels of redundancy and are consistent with the IMO guidelines. Relevant notations are given in the table below. Only three classification societies have been considered in this report, viz., DNV, Lloyds and ABS, all of whom have considerable experience in the classification of DP vessels. NMD Classification has also been included for the purposes of comparison.

DP CLASSIFICATION EQUIVALENCE TABLE - CLASS NOTATIONS

IMO Class	DNV	NMD	Lloyds	ABS
Class 0	Dynpos Auts	NMD Class 0	DP (CM)	DPS-0
Class 1	Dynpos Aut	NMD Class 1	DP (AM)	DPS-1
Class 2	Dynpos Autr	NMD Class 2	DP (AA)	DPS-2
Class 3	Dynpos Autro	NMD Class 3	DP (AAA)	DPS-3

The IMO Guidelines specify three equipment classes, Class 1, 2 & 3. Class 1 includes non redundant vessels. Class 2 vessels are those that will not suffer a loss of position as a result of a single fault or failure in any active component or system. Class 3 vessels are those that will not suffer a loss of position as a result of any single failure including all components in one fire sub-division and all components in one watertight compartment from fire or flood. Only a few DP tankers have been classed in the manner indicated above. This is in contrast to the number of other DP ship types that are DP classed in this way.

Industry Standards

Without doubt the most powerful and influential standard bearer for the industry has been Statoil, the Norwegian state owned oil company. Statoil operates more export facilities and charters in more shuttle tankers than any other oil company. It is principally as a result of the high standards and the lead set by Statoil throughout this industry sector that the shuttle tanker offtake concept has been so successful in North West European waters over the last two decades. Apart from a few pockets of resistance, Statoil standards are generally accepted throughout the sector. Prescriptive standards have been set for a wide variety of elements related to the safe operations of DP shuttle tankers, including, field support vessel, position reference systems, mooring hawser/separation distance and environmental limitations. However, Statoil do not stipulate the equipment standard for the DP shuttle tanker.

Technical Measures

Consequences of Technical Failure

The direction of the standards that have been designed and developed for ensuring the safety of DP operations has been to improve equipment reliability and robustness at the same time as recognising that equipment or component failure must be considered as a potential hazard. This has resulted in greater levels of redundancy in DP systems. In addition, this has called for an in-depth understanding of the consequences of failure and has resulted in the widespread use of the tool of FMEA (Failure Modes and Effects Analysis) in the DP sector, including the DP shuttle tanker sector.

The FMEA of the DP system is incomplete until proven by trials and testing in operational or simulated situations. Typically, such trials are carried out in all DP sectors apart from the DP shuttle tanker sector, where it has been applied in only a few shuttle tankers.

Operational Management

<u>DP Verification Regime</u>
Standards have been developed for the initial and regular verification of DP systems. The standards require a series of tests and trials to be carried out of the DP system, including annual trials, mobilisation trials and location trials. The trials are hierarchical in nature and incorporate simulated failure modes, operational checks and also status checks. DP verification regimes incorporating these features have been adopted by most DP sectors, other than in the DP shuttle tanker sector, where ,apart from location arrival trials, there is little evidence of wider ranging tests and trials.

Human Factors

<u>Standards of Training and Competence</u>
The principal reference document is the "Guidelines for the Training and Experience of DP Operators." The following provides an overview of principal elements of the training document.

Objectives
The primary objectives are to define minimum standards for;
- the provision of formal training of key DP personnel
- maintaining continuity of vessel experienced personnel on board a DP vessel
- the familiarisation programme for key DP personnel new to a vessel

The achievement of the primary objectives should assist in achieving the following secondary objectives;
- acceptance of an internationally accepted standard for training
- optimisation of training resources
- provision of on board training and familiarisation programmes and simulators

Types of Training
It is recognised that competency in DP is achieved by using a combination of different techniques, including the following;

- formal shore based training
- onboard training under the supervision of an experienced operator
- on board DP simulator instruction and exercises
- ship specific onboard instruction and familiarisation

- supervised operation of the control system
- manufacturers' training courses ashore and on board
- seminars and open discussion on vessel operations
- equivalent approved company schemes

Formal shore based training and certification requirements consist of different phases, from induction to simulator training, augmented by periods spent as trainee and onboard practical hands-on experience.

Experience and investigation show that in the DP shuttle tanker sector there are particular logistical difficulties in achieving compliance with the above standards, particularly in respect of qualifying DP watchkeeping time.

Cultural

Tanker v DP Operation Philosophies

There are contrasting philosophies between conventional tanker operations and the broad spectrum of DP operations. Firstly, there is a tendency on tankers to maximise utilisation of equipment and systems. For example, main engine plants often drive power generators that in turn drive thrusters, thus introducing single point failures into the system, for failure of the main engine can result in loss of thruster capability as well as the main propulsion.

HIGH LEVEL HAZOP

One method of improving safety in DP operations is to carry out hazard and operability studies at a generic level as well as at a project or location specific level. The following provides an outline of such a high level process.

Purpose

The purpose of a high level hazop is to identify the hazards, possible harmful consequences and appropriate risk control and reduction measures.

The hazop requires certain decisions have to be made on a number of aspects of the operation, including the following; selection of tanker type, hawser and/or DP positioning, establishment of nominal separation distance, position reference systems, verification of tanker's fitness for purpose, human competency issues.

In an effort to establish what is reasonably practicable in terms of risk reduction measures, consideration is given to hazardous events that are potentially liable to affect a shuttle tanker in a typical cargo offtake. Consideration is also given to environmental conditions that a tanker is likely to be subjected to.

In carrying out a hazop it is necessary to establish a base case. The base case risks for each hazardous event and condition are identified and are then considered against certain reasonably practicable risk reduction measures. The events and conditions are considered under three separate headings all of which apply inside the 500 metre zone of the FSU/FPSO export facility, viz.,

1. Approach and Berthing
2. Connected
3. Unberthing and Departure

The hazardous events and conditions considered in each case are as follows;

1. Main Propulsion Failure
2. Thruster Failure
3. Steering Gear Failure
4. Main Power or Electrical Failure
5. Position Control System Failure
6. Position Reference System Failure
7. Human Failure
8. FSU/FPSO Dynamic Interaction
9. Adverse Weather and Environmental Conditions
10. Fixed Obstructions, e.g. Pipelines, Installations, Wellheads, etc.
11. Other Marine Activity, e.g. Fishing Boats, Adjacent Rigs, Supply Boats, etc.

An example of a tabulated hazop assessment is given overleaf.

EXAMPLE - HIGH LEVEL HAZOP

TANKER APPROACH AND BERTHING

TANKER APPROACH & BERTHING (from 500 metre zone to FSU/FPSO)			
Hazardous Event/ Environmental Condition	**Description**	**Potential Loss**	**Risk Reduction Measures**
Main Propulsion Failure	During approach the failure of the main propulsion should not be a serious event. However, this will depend on the proximity of surface obstacles, such as rigs, etc. in the vicinity. Main propulsion failure is potentially more serious when the tanker is in final approach to the export facility and, especially when the tanker and the support vessel are in close proximity during the line pick up stage.	Tanker out of control and subject to environmental forces. Collision with export facility or other obstruction.	1. Provide tug assistance. Tug in close attendance during approach and in ready to tow condition. 2. Provide tanker with twin main propulsion, twin main engine, twin screw with separated auxiliaries. 3. Ensure that tanker main propulsion does not fail to full ahead or full astern. 4. Provide tanker with thrusters to provide auxiliary propulsion. Thrusters powered separately from main propulsion to avoid single point failure. 5. Ensure that main propulsion and thrusters, where fitted, are separated as far as possible, so that loss of main propulsion does not result in loss of thrusters.
Thruster Failure	During approach a thruster failure should not be a serious event. There should be sufficient main propulsion capacity to enable the tanker to maintain heading and position control. During the berthing phase and with the support vessel in close proximity the loss of the thrusters could have serious consequences, particularly during the line pick up phase.	Reduction in heading and transverse movement control. Collision with export facility, support vessel or other obstruction.	1. Provide tug assistance, as above. 2. Provide tanker with adequate thrusters fore and aft, grouped so that a single failure mode does not result in total loss of transverse thrust. 3. Ensure that thrusters do not fail to full ahead or full astern.