DYNAMIC POSITIONING CONFERENCE
October 17 – 18, 2000

VESSEL EXPERIENCE

FPSO NORNE Close Proximity DP Operations with MSV REGALIA

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Abstract

Dynamically positioned (DP) vessels operate close to fixed structures nearly every day in the North Sea. Operations vary from routine surface operations to large-scale subsea projects. What made the FPSO NORNE and MSV REGALIA operation unique was that it involved heavy lifts over subsea structures while both vessels were in full DP mode. The MSV REGALIA also had to come within 10 meters of the NORNE in order to place the lifts in the desired location. There are several standard forms of risk reduction that are implemented prior to every DP operation; these include trials, pre operation DP checklists as well as hourly DP checklists. Due the unusual nature of this operation and the obvious high level of risk involved, Statoil contracted to have a risk analysis performed on the proposed operation in its entirety. This was done to determine exactly what the risk exposure was and to find out if it was within acceptable limits. This paper will discuss the risk analysis, the solutions proposed to minimize the risks, and what risk reduction measures were actually implemented during the operation.

Introduction

The Norne Field is off the coast of Norway in blocks 6608/10 and 11. The subsea development consists of 5 templates connected through a pipeline/umbilical system to the FPSO Norne. The FPSO is moored to a turret loading system located approximately 160m from the stern. Water depth at the field varies between 360m and 400m.

Statoil required the installation of four pieces of equipment on the FPSO Norne as part of the Norne Gas Export Project. The four pieces consisted of a TEG unit (71.6 tons), port and starboard contactors (60 tons each), and the metering unit (2.6 tons). Rockwater was awarded the contract to perform the lifts using the MSV Regalia.

The MSV Regalia is a DP Class 3 vessel with a very experienced crew. The vessel has performed numerous DP operations in close proximity to offshore structures. The vessel also has a thorough FMEA, a full annual trials program, and DP capability plots. The operational capabilities and experience of the vessel are well documented.

The Norne is an FPSO and therefore no marine certifications are required. It also has never been classed by a marine classification society. There was no FMEA, trials program, or capability plots for the Norne. The Norne is equipped with a spread of 12 anchors to maintain position and five azimuth thrusters, two at the bow and three at the stern. Each variable speed thruster is equipped with a fixed pitch propeller and is capable of generating 49 tons of force. The center of rotation for the vessel is around the turret located 160m from the stern/100m from the bow. The ADP/PM system is used solely for weathervane operations. Since the lift operation was to be done with the system in full DP mode, there was an added risk because the crew had little exposure to operating the vessel in full DP mode.

The risk analysis was to cover any possible problem that may arise during the operation. This included any possible accidental event, the consequence of that event, and the calculation of the risk results. All possible risk reduction measures were also identified, but selection and implementation of these measures was left to Statoil.

Creation of the Risk Analysis

Global Maritime A/S was requested by Statoil to carry out an analysis of the risk relating to the lifting of the four separate modules onboard the FPSO Norne using the MSV Regalia. The baseline for the risk analysis was generated from the lifting procedures that were provided by Rockwater.

There were several key risk reduction items already mentioned in the lifting procedures. One of them was the use of bolts for the seafastenings rather than the traditional welding of seafastenings which required burning or cutting. Each module was to be lifted up and the crane swung into position prior to the vessel moving towards the FPSO. Once the vessel was in position, the crane would then boom out before lowing the module onto the deck. This procedure avoided having the crane and vessel having to move simultaneously and reduce exposure time.

The use of tuggers kept the pendulum motion of the lifts to a minimum. It was difficult to route the tuggers to have coverage in both the longitudinal and transverse directions. Several changes in the routings were made before a finalized plan was agreed upon. Guides and bumpers were also installed on the FPSO to prevent damage to equipment in the landing area. The slings were designed so they could be remotely released from the deck of the FPSO. All these risk reduction procedures were a part of the lifting procedures manual provided by Rockwater.

In order for a risk assessment to be of use, there had to be a base line level of acceptable risk agreed for any scenario. Statoil split the consequences into three different classes. Each class was then given a separate criteria for acceptance. These figures were used to determine if the risk level of the operation was acceptable or not. The following table shows the figures that were used in determining if the operation had an acceptable risk level.

Consequence Class	Acceptable	"ALARP"	Not Acceptable
Class 1 – Very Large Consequences - Loss of equipment or installation - Large environmental damage - Loss of several human lives	< 10-5	10-5 - 10-4	> 10-4
Class 2 – Large Consequences - Damage to be repaired onshore - FPSO in dock - New equipment to be installed - Potential loss of individual human lives	< 10-4	10-4 - 10-3	> 10-3
Class 3 – Remarkable Consequences - Consequences are local - Damage to FPSO or equipment repairable onboard - Limited delay	< 10-3	10-3 - 10-2	> 10-2

After fully reviewing the procedures, several potential accident scenarios were identified. The details of these will be discussed later in the paper. Statistics gathered from experience involving similar operations were used to determine the probability of each scenario. Once the probability was determined, the consequences and risk results were calculated using event trees. Since there was very little documentation on the Norne, two variations of risk figures had to be generated. One set of values was computed assuming the Norne to be a class 2 DP vessel, the other set was with the Norne as a class 1 DP vessel.

Probability figures for DP incidents were derived from the IMCA Incident Database. This database contains over 20 years of data gathered by Global Maritime with the help of many DP vessel owners and operators through DPVOA and IMCA.

In order to be able to determine the risk level, the time of exposure had to be determined. The longer the exposure, the greater the risk, and therefore there is a higher probability of an accident scenario occurring although moving in and out may also increase risk. It was assumed that each lift would last two hours. This time was considered to be from when the module was lifted off of the deck of the Regalia until the slings were released and the Regalia was moving away from the Norne FPSO. The procedures were to have the Regalia move away from the FPSO between lifts to minimize the risk during this period. The lifting procedures however needed several basic assumptions in order to complete the risk assessment. These assumptions included:

- The FPSO is ballasted at maximum draft (or as required for the lift).
- The FPSO is lying on full DP
- The Regalia is some 50m clear of the FPSO prior lifting
- The dedicated Rockwater personnel have been transferred to the FPSO and no more personnel transfer is required.
- Both vessels have carried out DP tests and all reference systems are functioning
- Weather forecast showing acceptable weather window has been obtained. The relative motions between the crane hook and the FPSO have been tested and found acceptable.
- All preparations have been made and the vessels are ready for lifting.

It was also assumed that there would be no helicopter activities or crane operations on board the FPSO and that there would be no unnecessary vessels inside the 500m zone. These assumptions were made in order to minimize the work. Once made, they had to be executed so that the risk analysis did not have to be revisited.

The following consequences for each accident scenario were derived and then compared to the acceptance criteria defined by Statoil. The base case is assuming the Norne to be a DP class 1 vessel. The risk figures for Norne as class 2 are in brackets.

Consequence	Consequence Class	Acceptance Criteria	Calculated Risk	Acceptable
Potential Loss of Lives	Class 2	1x10-4	2x10-6 (5x10-7)	Acceptable (Acceptable)
Riser Damage	Class 1	1x10-5	1x10-7 (1x10-7)	Acceptable (Acceptable)
Anchor Damage	Class 2	1x10-4	1x10-7 (1x10-7)	Acceptable (Acceptable)
Major Damage to FPSO	Class 2	1x10-4	2x10-4 (3x10-5)	ALARP (Acceptable)
Damage to Regalia	Class 3	1x10-3	2x10-3 (7x10-4)	ALARP (Acceptable)
Minor Damage to FPSO	Class 3	1x10-3	2x10-3 (7x10-4)	ALARP (Acceptable)
Project Delay	Class 3	1x10-3	8x10-3 (3x10-3)	ALARP (ALARP)

It can be seen that most of the risk levels were acceptable, but a couple were ALARP, which was still relatively high. The acceptance criterion, however, was the optimization criterion, which was:

- The solution that is selected gives the best results overall. Expected loss due to damage and accidents is part of the life cycle cost.
- A risk reducing measure is implemented when the reduction in expected loss is greater than the cost of the measure.

Throughout the project there were several meetings and discussions that took place between Global Maritime, Statoil, and Rockwater. The first meeting discussing the HAZOP/ preliminary risk analysis took place early on in the project. During this meeting several different ways to approach the operation were discussed.

It was determined by all parties involved that the safest way to proceed was to get feedback from all parties involved in the operation. This way the risk analysis no longer remained a paper exercise for the management; rather it was able to focus in on many of the practical issues that can be easily overlooked when trying to numerically reduce the risk of an operation. This process also allowed everyone to take an active part in the creation of the final HAZOP. This HAZOP later provided everybody with a clear idea of the criticality of the job and gave the opportunity for “buy in” from everybody.

The assumptions that were made with regards to the procedures were also discussed during the several different meetings that occurred throughout the project. All of the procedural assumptions were later implemented during the operation. By doing this, the risk values that were derived from the Risk Analysis were still relevant.

While doing the risk analysis, it was noticed that there was very little documentation regarding the Norne and her capabilities as a DP vessel. One recommendation that came from the risk analysis was to resolve this issue by going to the Norne. Statoil was aware that this lack of knowledge with regards to the Norne increased the risk of the operation immensely. Later the Norne was visited and an abridged series of DP trials and DP performance trials were executed. The findings of these will be discussed in more detail later in the paper.

The Lifts

The port and starboard contactors each weighed 60 tonnes and were 3.5m x 3.64m x 11.2m in size. These lifts required an additional stage as they were transported on the Regalia on their sides. Once uprighted to their vertical position, the Regalia would then be able to preposition the crane and move in towards the FPSO. The lift for the starboard contactor was designed with a 20m clearance between the two vessels. The port one had a static clearance between the two vessels of 10m. Although the vessels were farther apart on the starboard lift, the setdown area was much tighter so there was still a potential for damage to the FPSO. The metering unit was much smaller, weighting only 2.6 tons. The dimensions were 2.8m x 2.4m x 2.6m. This lift possessed the least amount of risk since the set down area was open and the vessels were not required to b closer than 20m.

In order to reduce the amount of redundant work, the risk analysis was based on the most difficult and risky lift, the TEG unit. The TEG unit's weight was 71.6 tons and the dimensions were 8m x 6.0 m x 6.92m. The reason this lift was considered the most dangerous was not merely because it was the largest and heaviest, but because of the location it needed to be placed on the FPSO. In order to place the lift in the desired spot, the Regalia would have to be 10 m off from the Norne on its starboard side aft of midships. The vertical clearance for the lift was designed to be 3m, thus requiring the Norne to be ballasted to her max draft of 18.7 m. At this minimum clearance point, the lift would be passing over two pressurized tanks. The set down area was extremely tight and it was very difficult to route the tugger lines. The tugger lines arrangement was changed several times, ultimately ending up with the tugger line attached to the forward crane. This left the crane operator in charge of compensating for any longitudinal pendulum motions.

Possible Accident Scenarios

From a risk point of view, all 4 lifts were very similar. They all were lifts from one manned DP vessel onto another manned DP vessel. Static clearance between the vessels varied between 10 and 20 meters. The setdown area on the FPSO was tight. The lifts followed the same procedures and preparations. All the lifts were over subsea constructions, namely the mooring and riser systems.

One benefit was that the lifts were separate and could have been carried out independently from one another and during separate weather windows if required. It was preferred to have all the lifts occur in a relatively short time span to reduce the amount of operational down time for the FPSO.

Several possible accidental scenarios were defined for the operation. These accidents included:

Failure of crane or lifting gear	Dropped object	Erroneous ballasting / crane operation	Break of tugger wire	Failure of release system
Jamming of sea fastening	Failure to position / setdown module	Communication	Failure of bumper / guide system	Transfer of personnel between vessels
Regalia loss of position	**Norne loss of position**	**Change in weather**		

All of these scenarios were probable and the probabilities of their occurrence were all calculated. This paper, however, only focuses on the last three.

The probabilities of these accident scenarios were broken down into the following consequences:

- Potential loss of life
- Riser or Anchor damage
- Major damage to FPSO
- Minor damage to FPSO
- Damage to Regalia
- Project Delay

The following statistics and probabilities all refer to the lift involving the TEG module.

The REGALIA

The status of the Regalia was well documented in terms of a comprehensive FMEA, which, in conjunction with the annual trials program, mobilization and pre-work checks, made it reasonably certain that all equipment was working and available. Regalia spends a significant percentage of the year engaged in DP operations, a major part on DP in close proximity to other structures working as a flotel. The lifting duration of the work was also short and experience suggested that DP operators would generally be more attentive and alert because of the uniqueness of the operation.

LOSS OF POSITION

IMCA defines an incident as "**any loss of position to the surprise of the operator**". A loss of position can be further divided into three categories; a DRIVE OFF, DRIFT OFF, or LARGE EXCURSION. Each category was treated as a separate risk.

There are several errors that could occur which would result in an incident. To discuss each error individually would have required an excessive amount of unnecessary work. Rather an overall probability figure was used derived from the IMCA incident Database. Typical causes of incidents found in the database include:

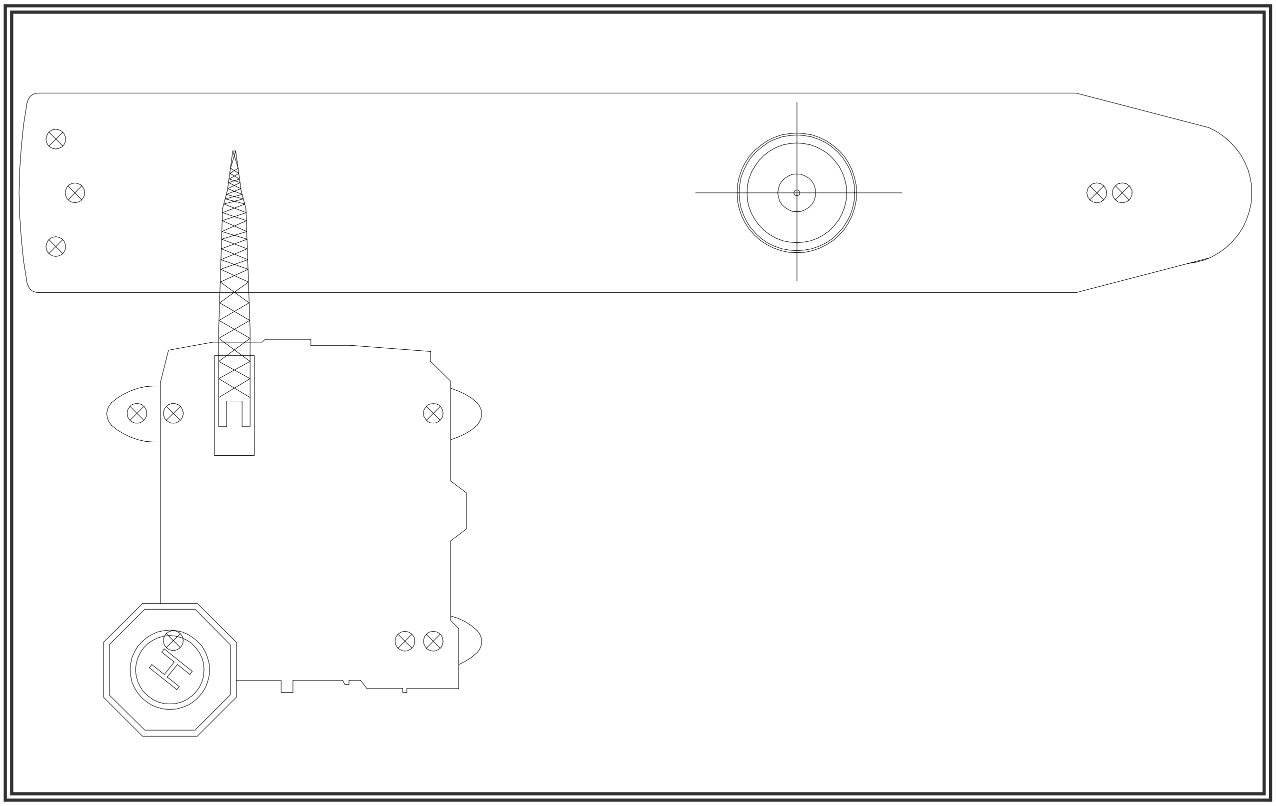
- Computer fault (Hardware)
- Computer fault (Software)
- SDP 531 crash
- UPS failure
- Wrong position / heading input
- Frozen position reference system
- Wind change
- External force
- Thruster control fault
- Governor failure
- Excitation failure
- Position instability
- Fire
- Operator error

There were two special situations that could potentially increase the probability for loss of position. Firstly, Regalia could potentially be exposed to thruster wash form the Norne's thrusters. Secondly, Regalia will generate some pressure between the two hulls due to its thruster wash towards the FPSO. What was done to resolve these issues will be discussed in the findings.

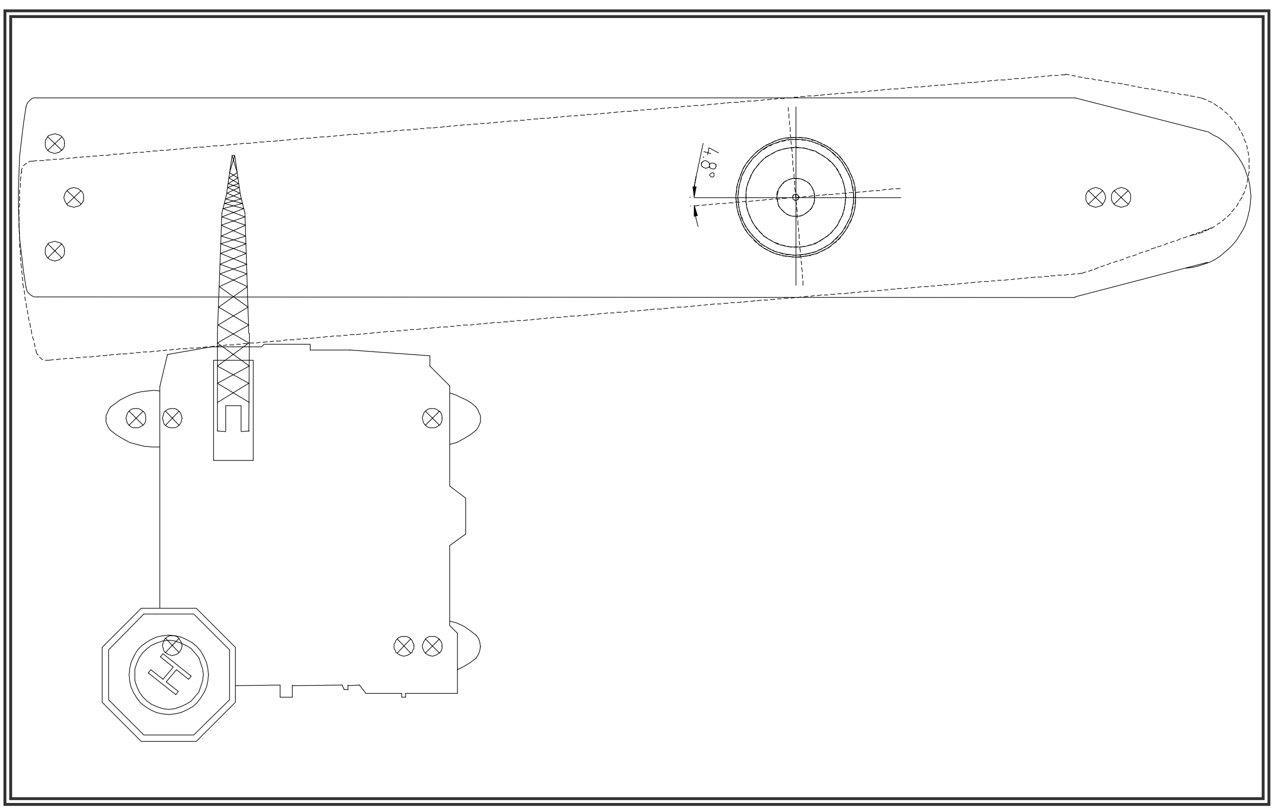
It was determined that if the Regalia lost position, any one or combination of the following could happen:

- Loss of life
- Damage to FPSO
- Damage to Regalia
- Project delay

There was a general agreement that any loss of position would result in collision, especially since the static clearance between the two vessels was going to be only 10m. This was especially true while installing the TEG module, and that was mainly due to the heading sensitivity of the FPSO. It was determined that a loss of heading of 4.8 degrees on the Norne would result in vessel contact. This event by itself most likely would not occur if all things were operating correctly. This changes, however, when the natural motions of the Regalia and the natural motions of the Norne are both taken into account. The vessel motion analysis and footprints presented showed that a collision could occur even without any failures. The only consolation was that since the vessels were so close, the impact velocity should collision occur, would be low and the consequences would have been correspondingly small.



Vessel positioning for the TEG module lift.
Heading control extremely critical.



If a loss of position occurred during a setdown operation, the module could have made contact with the bumpers. Prior to set down, however, the there was a relatively large clearance area above the bumpers so the crane operator would have therefore had sufficient time in most situations to swing the module around to have avoided contact with the FPSO topsides. Because of the tight set down space the most critical period was during the final stages of lowering the module.

DRIVE OFF

A drive off is defined as a move under power away from the wanted position. Drive offs have the potential to occur under full power because the DP system is, in effect, trying to attain or regain the position set point. The IMCA Incident database details a multitude of different faults and errors that resulted in a drive off. This mainly occurs due to false position information or wrong position inputs. The IMCA database assigned broad fault categories such as operator error, DP control failure, and reference failures. These are described as:

- Position reference: Reference system freezes (perfect reference) or poor information is accepted.
- DP control failures: DP computer failure or peripheral system alone, or combined with operator error as a secondary cause.
- Operator error: Operator reacts incorrectly, does not observe fault soon enough, or any situation that could have potentially been stopped if proper action had been taken earlier.

The Regalia is a class 3 DP vessel, so one could argue that no single fault could cause a loss of position. It could even be said that in the majority of the cases the situation could have been recovered by prompt operator action or by the back up computer. Nevertheless, the principal event has been documented to occur on DP vessels. It is considered that a failure to engage the remote backup computer or backup references is a possible operator error, and that these sequences of events are credible failure modes.

Using the data from the IMCA Incident database the total frequency of drive off events believed to be applicable to this vessel in these circumstances was:

$$2.4 \times 10^{-5} \text{ per hour on DP.}$$

Not every drive off will result in a collision. There was only one sector in which it is assumed that drive offs have the potential for vessel collision. Also the potential for successful operator intervention to prevent a collision in this sector during a drive off had to be taken into account. Damage could have occurred if a drive off occurred in any direction while the lift was being lowered between the bumpers. This meant there was a chance that the TEG unit could have impacted upon the pressurized tanks on the deck.

DRIFT OFF

A DRIFT OFF is defined as a deficiency of vessel thrust capability in relation to the environmental conditions, such that the vessel is incapable of maintaining position. There are two main reasons a drift off occurs on a class 3 DP vessel. A drift off could result if the vessel is operating outside the "worst case failure" environmental limits when the failure occurs. The other is because a failure occurs which exceeds the theoretical worst case, generally because of operator error or the hardware redundancy does not operate as designed. The drift off data received from the IMCA database showed the main causes divided into the following general categories.

- Equipment failure – including generators, switchboard, power management and thrusters.
- Operator error – as a primary cause of failure.
- DP control – including computer faults, with or without operator error or poor procedures as a secondary cause.
- External loads – with a further failure, operator or thrusters, as a secondary cause.

Once again by using the data from the IMCA database, the relevant frequencies were derived and the total frequency of drift off occurrences while on DP was computed to be 8.2 x 10-5 per hour.

The external loads generally are weather related and thus the risk is reduced because the operational conditions were restricted to a sea state of Hs 2m. The FPSO was positioned with the bow into the predominant environmental forces. Generally the wind and waves are close to being in line with each other and in such a case the Regalia would have likely drifted alongside the Norne and not have collided. If the winds, waves, and current, however, were not favorable, the drift route could have shifted towards the Norne. An allowance was made for this.
There was a chance that operator intervention on the Norne could have changed the FPSO's heading and moved it out of the drift path of the Regalia, but given the thrust capability of the FPSO it was unlikely that such an action could have been completed in time. Therefore it was assumed that no operator intervention would occur to prevent collision. Given the restrictions on the operational conditions, the drift speed in such an environment was likely to be slow enough to allow the crane operator to lift the module clear of the FPSO topsides. The greatest risk, however, was a failure while the vessel was moving in towards the FPSO, so to reduce this risk a slow vessel speed was used during all maneuvers.

LARGE EXCURSION

The third category for loss of position is the LARGE EXCURSION. This situation refers to a vessel still under control of the DP system but it incurs a temporary larger than normal excursion of position or heading because of a large wind gust, wave, thruster fault, or degraded position information. These excursions are normally defined as excursions in the range of 10m or 10 degrees from the desired position and/or heading.

The static clearance between the two vessels was 10m. When the normal vessel footprints were applied this distance was reduced and allowing for the first order wave motions, the distance reduced even further. With the motions and offsets that were reported, it was determined that a vessel collision could have occurred even with all the systems intact and operating normally.

Large excursions are quite common and often not reported and an allowance for this had to be made and an applicable frequency was determined.

As with a drive off, there was a chance of a large excursion towards the Norne and a chance of successful operator intervention. It was assumed that if the excursion was away from the Norne, there was still a chance that the module would impact the FPSO bumper or topsides.

The NORNE

The risk levels involving the Norne were greater than those involving a standard class 1 or class 2 vessel. This was because there was no DP FMEA and trials performed on the Norne. There was also no record of the station keeping abilities of the Norne or any DP capability plots. This increased the potential for unknown errors that could result in an incident. It was for this reason the Norne was assumed to be a DP class 1 vessel. It decided that the values involving a standard class 1 vessel should be to magnified 10 times in order to reflect this risk. Even with this magnification of risk, the risk level was found to be acceptable or at the ALARP level.

The Norne spends less than 5% of the time in full DP mode, and it was agreed that the probability of DP failure of Norne was higher than for the Regalia. This was also influenced the crew's experience. There was an experienced DPO on board during the operation, but this only reduced some of the risks. It was first thought that the Norne would have limited reference systems, but it was found that the DP desk was provided with two DGPS inputs and one acoustic positioning system input. This reduced some of the presupposed risk that was incurred due to lack of information regarding the Norne.

It was also this lack of material involving the DP capability of the Norne that resulted in the groups involved to carry out verification testing of the DP system. The initial risk analysis results will be presented alongside the findings from the DP verification tests.

Some of the consequences of an incident involving the Regalia held true for an FPSO incident. These were:

- Loss of Life
- Damage of the FPSO
- Damage to the Regalia
- Project delay

Loss of position can involve a horizontal offset from the center and a loss of heading control. It was assumed that the mooring lines will be kept at their normal static pretension and that all lines would have the same pretension.

POSITION LOSS

The most critical aspect of station keeping for the Norne was maintaining heading. A small loss of heading could have resulted in collision.

The problem with a drive off was that a rapid change of heading was possible and the tensioning of mooring lines added an additional component that is normally not part of DP vessel operations. With a drift off there is also a risk of heading change. This could be fast is the Norne was forced to maintain an unfavorable heading. The procedures required that the Norne keep her bow pointed into the predominate forces as much as possible. Similarly, a large excursion in position is not such a problem as an excursion in heading and correct allowances had to be made for those factors. The worst failure mode was the failure of one thruster to full power when positioned athwartships as this would change the heading rapidly and cause a collision unless the operator reacted very quickly to stop the thruster.

The Norne also has to contend with the risk of an anchor line failing. This type of failure will induce a sudden horizontal load on the vessel. The mooring assisted DP system should be able to quickly respond to such an immediate loss of force. The real risk is signal failure generating a false anchor line failure alarm and the subsequent response from the DP system. After computations, it was found that the vessel would offset 6.5m after a mooring line failure, assuming the tension to be 142 tons. A mooring line failure could also result in a loss of heading since the turret is locked. Using statistics and experience from other work, a chain could fail even if it was not under tension. The frequency of failures, however, was lower than the frequency of DP failures.

NORNE DP HAZARD IDENTIFICATION

One of the conclusions from the risk analysis was that there was a need for more information about the Norne. The DP hazard Identification trials for the Norne covered the thrusters/propulsion systems and the DP control system along with its associated back up power supply units and reference systems. Testing was not permitted on any of the main power supply systems. This meant that failures in the power supply system were not proven.

The design of the Norne reflected a class 2 DP set up. By reviewing the information on board, it was assumed that the power supply appeared to comply with IMO class II requirements. Testing showed that this was true in all but one case when main power supply was failed and the display lost power but the computer kept running. The thruster design also complied with IMO class II requirements, but some of the back up equipment was not operational so the redundancy was lost. It was recommended that the back up equipment be fixed prior to operations commencing.

The importance of FMEA testing was brought to light during the testing of the two DP control consoles. A failure in one console should result in command being seamlessly transferred to the other and operations continuing uninterrupted. This is critical for class 2 vessels. All tests except one had satisfactory result. Failing the thruster card in one console resulted in the master control being transferred to the other computer. This was as expected, what was not expected was the complete loss of heading control. The thruster activity increased in such a way that if the vessel had not been moored, a drive off would have occurred. This goes against all class 2 requirements.

As one can see, the tests showed several single point failures that justified the values in the risk analysis reflecting the Norne as a class 1 vessel. These faults could have been found by having a full FMEA performed on the DP system and subsystems. A FMEA of the DP system and subsystems was not performed because it was not required and the vessel is not dependent on the DP system for operations. Under normal operating conditions, a failure in the DP system or a blackout on the FPSO would not result in loss of life or damage to the FPSO. The off loading is done 50 meters off the stern so any failure with regards to station keeping would not immediately jeopardize the shuttle tanker operations. The ADP/PM system is only a tool to assist with installation and then weather vane operations.

Performance trials were also done, but the weather conditions did not match the weather conditions required for the DP lift operation. The best conditions experienced were 10-15m/s winds with accompanying seas, approximately 6 m significant, during the entire test. Thruster 4 was also not available for several of the tests so the results did not reflect the best performance of the system. Even though the weather was rough, the Norne was able to hold heading at +/- 2 degrees from the set heading. Position was held generally within 1 to 2 meters of setpoint with only a few movements beyond 2 meters. Since the conditions were not favorable, it was recommended that further testing be done in weather conditions close to those proposed for the operation.

CHANGE IN WEATHER

Weather conditions in the North Sea are subject to rapid changes and can be quite severe. An environmental conditions study at Norne showed that the winds tend to be out of the Southwest. The lift was planed for a sea state of Hs 2m or less, which approximates to a wind speed of 10m/sec. The weather statistics for Norne were based on three-hour periods, and the lifts were assumed to take 2 hours each. Data showed that for April the average duration for weather below Hs 2m is 49 hours and 69 hours for above Hs 2m. It is for this reason that the probability of having to stop the operation due to weather was ignored. To reinforce this decision the study showed that for the entire year 40% of the waves are less then Hs2m while 64% of the wind is less than 10m/sec. The risk of weather change was therefore included as part of the DP loss of position probabilities and not as a separate risk category.

POSITION REFERENCES

Both the Norne and Regalia were using DGPS and acoustic systems during the Operation. Due to the number of subsea structures the Regalia was unable to use tautwires, so it relied on two DPGS units and two acoustic systems. The Norne also used two DGPS units but only one acoustic system. The risks involved with loss of reference systems were covered as part of the factors leading up to a possible drive off, drift off, or large excursion. The differential providers for the Norne were different from those on the Regalia as well, but that still left the satellites themselves as a common failure point that could affect both vessels at the same time. The frequencies of such an occurrence was computed to be negligible, and the exposure due to the short duration of the operation was small, so this failure was considered as being non-relevant for this particular operation.

Risk Reduction

The risk of the project was within the acceptance criteria as defined by Statoil. Several of the risk reduction measures were geared towards the fact that the vessel motions and footprints suggest that there is a high risk of vessel collision even in a normal operating mode.

Historical data shows that a large percentage of the position losses were caused by operator error or poor procedures. Another major primary and secondary cause is insufficient reference systems. The final one, which could almost be considered an operator error, is working the vessel beyond its safe limits, meaning should a failure occur, position loss would occur. Statoil had already determined that there would be an experienced DP operator on board the Norne during the lifts. This reduced the risks associated with having inexperienced personnel operating the DP console during the critical operations.

The process of moving the Regalia in and then away from the Norne also increased the risk of an incident occurring. In order to reduce this risk, all movements were carried out in a precise and controlled manner. This also meant the crane and vessel were not be in motion at the same time.

In order to reduce the amount of exposure, all the lifts were pre-planned in detail to reduce the amount of time that the Regalia was alongside the Norne. All preparations were to be complete prior to the Regalia moving in for the lift, this included shutting down the production systems and ballasting the FPSO to ensure it is on an even keel.

Onboard the platform, the daily work was also planned in detail to avoid having personnel working underneath the lifted modules. A Hot work permits were issued for the set down areas just in case the lift connections need to be cut off. This was considered very important as there might be gas in the area due to the vent openings on the Norne.

OPERATIONAL ALTERNATIVES

Due to the Norne heading sensitivity, the vessel motions, and the frequency of a vessel position loss, a change in the positioning philosophy was considered. Some alternatives were suggested which showed some reduction in risk in the event trees.

One alternative was to have the Norne offset from the mooring natural position. The idea was to offset the FPSO would be offset towards the Regalia so in the event of a drift off of the Norne the mooring lines would tend to move the Norne away from the Regalia. The thruster wash from the Norne would also be directed away from the Regalia as well. Another factor was the force required to offset the Norne further when in this position. Should a drive off occur, the thrust required to move the Norne towards the Regalia would be quite high and therefore the risk of collision reduced. By offsetting from the center the only major risk remaining is loss of heading control. One of the positioning performance tests done while on the Norne was to see how she positioned with a 5 meter offset from the center of the anchor spread. The results of this helped influence the decision to use a 2-meter offset.

It was eventually decided by general decision that this course of action was to be the one taken. During the operation the Norne was offset 2 meters from the center of the mooring spread, this was considered to give a small and acceptable bias.

Another suggestion was to operate the Norne in heading control mode only. The probability for loss of position would be greatly reduced since one out of two possible scenarios is removed. Heading control is the most critical aspect, and it was felt that the system might be able to maintain better heading if it was not in full DP mode. The only concern would be the second order motions of the FPSO. This idea was rejected because of the fear of longitudinal motions of the FPSO while setting down the lifts in such tight areas. Full control of position was considered better and it gave the chance to use the 2-meter bias.

Fenders were suggested due to the small clearance between the two vessels. Drawings showed that the first point of contact would be at the topside level and not at the waterline. This idea was not followed up because it would have required the installation of mounting brackets and attachments onboard the FPSO.

It was also suggested that the Regalia could be moored to the FPSO with fenders between the two vessels. By doing so the only time risk of vessel collision existed was when the Regalia was first coming alongside and then when leaving after completion. The mooring lines of the Norne were capable of handling the extra loads. This idea was brought up with Rockwater and later rejected because the Regalia was not equipped for mooring lines. In order to moor to the FPSO the Regalia would have had to have mooring equipment mounted on board and it was decided that there was not enough risk reduction to warrant the expenditure and delay.

A table was generated showing the resulting consequences from the recommendations that were made. The target case is included for comparison.

Consequence	Operational Alternatives					
	Target	**Moor**	**Offset**	**Offset + Camera + Fender**	**Heading Control**	**Heading Control + Camera + Fender**
Potential Loss of Lives	2x10-6 (5x10-7)	2x10-7	1x10-6	6x10-7	1x10-6	6x10-7
Riser Damage	1x10-7 (1x10-7)	1x10-7	1x10-7	1x10-7	1x10-7	1x10-7
Anchor Damage	1x10-7 (1x10-7)	1x10-7	1x10-7	1x10-7	1x10-7	1x10-7
Major Damage to FPSO	2x10-4 (3x10-5)	7x10-7	1x10-4	7x10-7	1x10-4	7x10-7
Damage to Regalia	2x10-3 (7x10-4)	7x10-7	1x10-3	7x10-7	1x10-3	7x10-7
Minor Damage to FPSO	2x10-3 (7x10-4)	8x10-8	2x10-3	1x10-4	1x10-3	7x10-5
Project Delay	8x10-3 (3x10-3)	3x10-5	6x10-3	2x10-3	3x10-3	2x10-3

Other suggestions to reduce risk were:

- Camera monitor for Norne DP operators
- Communications between vessel bridges
- Double shifts on both vessels
- Test lifts
- Lift the metering Unit and Starboard Contactor first
- Clarify the use and design of tugger lines
- Check and verify all preparations and equipment prior to start of operation
- Obtain hotwork permit prior to start of operation
- No other operations carried out onboard either vessel
- No helicopter, crane, or offloading activity
- No other vessel within the 500m zone.

Most of these suggestions were implemented, with the exception of the camera monitor for the Norne DP operators.

The Operation

Prior to the operation commencing, there was a final Hazop meeting on board the Regalia. This was done before departure to the Norne Field. All parties were informed of the full scope of work to be done and the final risk reduction measures were gone over. Statoil and Rockwater agreed with most all of the risk reduction measures. Some, however, were not implemented, like the suggestion to put Yokohama fenders alongside the Norne. The decision was made to operate the Norne in full DP mode, as mentioned in the Operations Procedure, but with added recommendation that the FPSO be offset 2m from the center of the anchor pattern. This way the majority of the thruster wash would be directed away from the Regalia.

Prior to arriving in the field the Regalia went over the routine arrival checklist. A full pre-operation check list was completed before the first lift began. The checklists were the Regalia's usual comprehensive ones used on all prior operations. The weather forecast for the next 8 hours was checked and it bode well for completing the entire operation in a single secession and the decision to proceed was made.

As was suggested, the Regalia moved approximately 100 meters away from the Norne between the lifts. The next lift was then made ready and the Regalia moved in again. The crane was not moved while the vessel was moving.

During the operation everything went smoothly. All the crew members had a heightened state of awareness during the entire operation because they were all aware of the potential for incidents. Nearly every exposure to risk had been covered. Several scenarios had contingency plans should problems have occurred. The use of bolts rather than welds dramatically reduced the amount of time the vessels had to be close alongside.

Concluding Remarks

The entire operation took 4 hours. The Regalia arrived in the field at 0800 and the first lift was underway by 0945. The last lift was complete at 1245. The weather was well within the design operating requirements and the entire operation went as planned without any problems. Nothing adverse happened and if something had gone wrong, most scenarios had been fully identified and contingency plans covered. The operation was fully planned and all parties were well trained and capable of performing their required jobs. All aspects of the operation were discussed prior to commencing work. The entire operation was performed by the operating procedures discussed during the HAZOPs over several months prior to the operation.

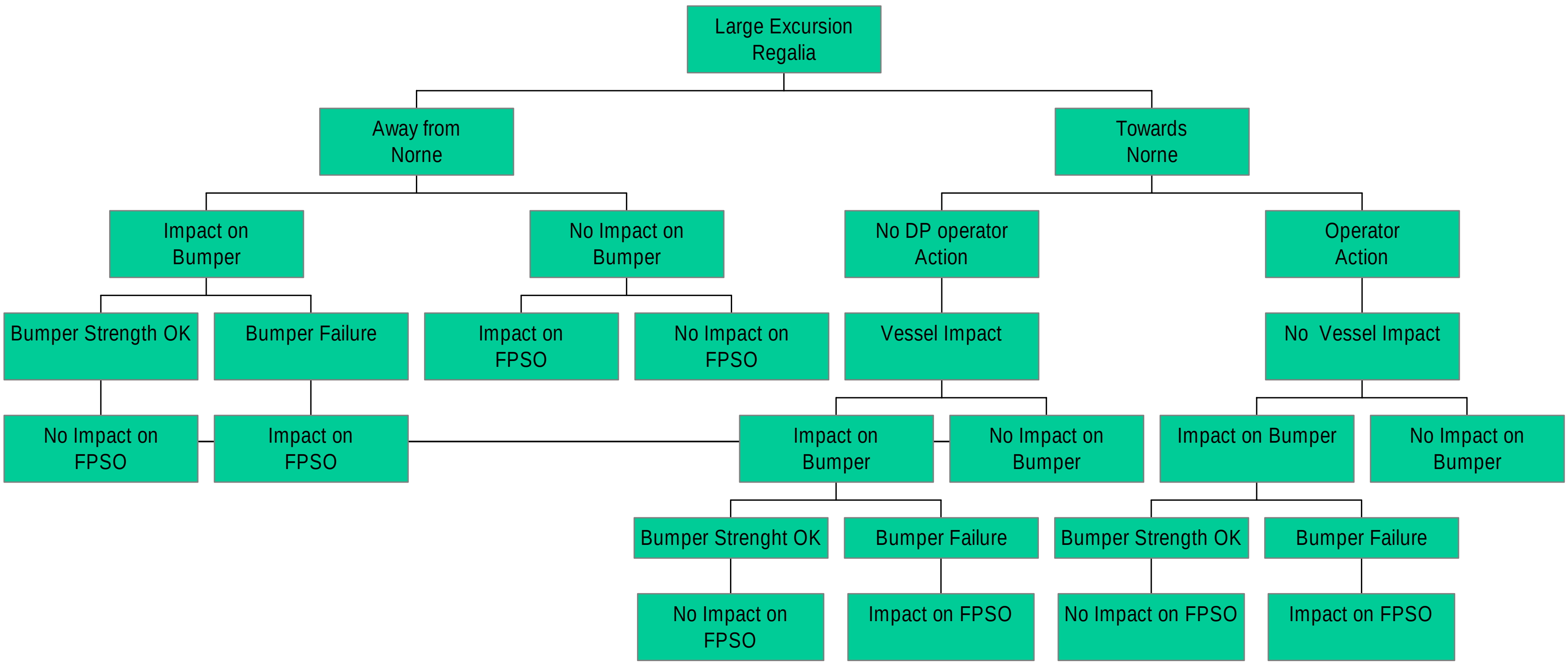
One could argue as to the necessity of going though such an elaborate processes to do a project that only took 4 hours to complete. But it was this process of reviewing the procedures manuals and creating the risk analysis that allowed the job to be completed in 4 hours with low risk. Without all the safeguards in place and all the operating procedures validated, the risk involved would have been far greater and the odds of the job being successfully completed would have been greatly reduced.

The amount of money spent creating the risk analysis was negligible when compared to the cost of the units being lifted, the day rate of the Regalia, the possible additional down time for the Norne, and the cost of repairs for any damage that may have occurred. In all, Statoil acted on the side of safety for not only its personnel, but for the equipment involved as well. Had the results of the risk analysis shown that the risk measures were unacceptable, an alternative plan would have had to have been devised to get the modules onto the Norne.

APPENDIX 1

SELECTED EVENT TREES

REGALIA LARGE EXCURSION



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Drive Off Norne