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NEW APPLICATIONS

Operability Study for DP Vessel Operations at a Deep water Spar-A Decision Support Tool

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1-Abstract

This paper describes the approach and methodology used to undertake an operability and uptime study for a gangway connected operation of a DP vessel to a floating production facility in order to provide support to the construction and commissioning teams.

Traditional operability and uptime studies focus on metocean conditions, vessel motions and vessel's station keeping capabilities. The objective of the study was focused on

- Consider the requirements of the vessel to operate within the established Activity Specific Operating Guidelines (ASOG, project specific).
- Qualify and identify the DP control accuracy for various environmental conditions
- Provide practical guidance in execution planning to operational and project teams

The paper focuses on the approach and the iterative process between the participants to carry out their respective scopes which included

- Project variables and ASOG
- Dynamic Coupled motion analysis of the two bodies
- DP simulation work for relative positioning using production facility motion time traces

The approach adopted delivered results which were used to provide information to support the decision making process of:

- Project teams
- Operational teams during execution

2-Introduction

The DP vessel is a multi Purpose Service Vessel, of 131.7 m in length, 22.0 m in width. The vessel is equipped with the following thrusters:

- Two fixed pitch, Wärtsilä Propulsion Z type, converter driven, variable speed, azimuth thrusters aft, each rated at 3000kW.
- Two CPP, constant speed Rolls Royce tunnel thrusters are fitted forward, each rated at 1335kW
- One CPP, constant speed Wärtsilä retractable azimuth thruster fitted forward, rated at 1200 kW.

The dynamic position control is provided by Kongsberg K-POS DP2 system.

The floating platform is deep water spar moored to the seabed at 8000 feet of water depth with chains and polyester ropes. A bridge will be landing on vessel's landing areas with the bridge originating from the main deck of the Spar.

The DP vessel will maintain station using both relative and absolute position reference systems, when gangway connected with the Spar. Under adverse weather/environmental conditions, the gangway will be disconnected and the DP vessel will move away from the platform.

The decision to disconnect the gangway is made when:

- The gangway predicted motion is beyond the acceptable limits of the landing area on the DP vessel. The limits were predetermined and included in the ASOG granting warning conditions for the operational status. The DPO will follow agreed instructions when these limits were reached. The actions ranged from an advisory status to a complete disconnection. The advantage of this process is the immediate action in response to an operational limit reached.
- The Thruster capacity reached a pre-determined value indicated in the ASOG. These values were calculated using this operational study report and each particular thruster capacity and their combination. This value considered the worst case scenario of loosing power or thruster failure.

The DP system is designed to keep the vessel within specified position and heading limits. In operation the system tolerates transient errors in the thrusters and measurement systems and acts appropriately if a fault occurs. A self adapting Extended Kalman filter estimates the vessel's heading, position and velocities and the disturbances from sea current and waves. The estimator uses an accurate mathematical model of the vessel. Kalman filtering technique using the model prediction together with real measurements provides unsurpassed filtering quality, robustness and station keeping performance. The Kalman filter automatically adapts to the quality of the reference systems as well as their data rates. All accepted reference systems are used at all times with optimal mix to avoid any discontinuity.

In the Auto Position mode, the system automatically controls the position and heading of the vessel relative to a fixed wanted position / heading (setpoint).

In Follow Target mode, the system automatically controls the position and heading of the vessel relative to another moving object (ROV, vessel, moored structure). This mode of operation is preferred when the dynamics of the moving object is significant. Refer to [2] for control aspects on the Relative Positioning. The issue on a “significant” motion of the other object and the consequence for selection of position reference systems is also briefly handled in [3] . DP simulations performed as part of this operability study are all based on “Follow Target” operational mode and a **mixture** of absolute and relative position reference systems. (Absolute systems for vessel positioning and relative for automatic update of setpoints).

A dynamic coupled motion analysis of the two-body for different wave headings was first performed. The purpose of the motion analysis is to calculate the relative motion of the two floating bodies and provide a first-guess of the maximum allowable environment in which the gangway can be connected.

The total ship motion can be regarded as a superposition of a low frequency component (due to the wind, sea currents and thruster forces and moments) and an oscillatory term (the wave induced wave frequency motion, wave period from 3-30 seconds), which represents the effect of the waves. Since the DP vessel’s motions are controlled using relative position reference systems, the gangway availability study disregards slowly varying motions from the total relative motions. It is assumed that the DP system will control the low-frequency motions.

To qualify the DP control accuracy for various environmental conditions, a DP simulation study was performed using the spar motion time-traces. The time-traces are total vessel motion including the low-frequency and high-frequency wave motions. Since DP only considers the slow variations, the motion due to the waves is removed before it enters in the controller algorithm.

Vessel data (hydrodynamic parameters and thruster forces) as implemented onboard the vessel were used for the simulations. The limiting operating criteria can be thus further fine-tuned based on the findings of the DP simulation study.

This study can provide practical guidance to the operational and project teams. It is decision support tool for determining when the DP vessel should be disconnected and safely moved away from the platform.

3-Analysis Method

A dynamic positioning system is a computer controlled system which automatically keeps a vessel's position and heading by using propellers and thrusters. The computer program includes a mathematical model of the vessel which contains information about the wind and current drag of the vessel and the location of the thrusters. This knowledge, combined with the sensor information, helps the computer to calculate the required steering angle and thruster output for each thruster.

In this operability study, a motion analysis was first performed in MOSES to provide the position and heading of the vessel relative to the Spar. Time-domain motion analysis of the DP vessel and the Spar was performed for different wave headings for environmental bin 3-3.5m. The maximum gangway excursions under head, quartering and beams seas are summarized in Table 1, Table 2 and Table 3 respectively. The DP vessel will remain gangway connected with the spar under the allowable weather conditions. Under adverse weather, the gangway will be disconnected and the vessel will move away from the platform.

MOSES analysis model is used in this availability study. The objective of the motion analysis is

- Modelling and Hydrodynamic calculations
- Calculate the relevant hydrodynamic and response parameters of Spar
- Calculate the hydrodynamic and response parameters of the vessel
- Set up a coupled two units system with the Spar moored to the seabed

The distance between the two supports on the vessel and spar is 40m approximately. The gangway is originated from the Spar. The gangway's wheels will roll across deck of the DP vessel. The approximate landing area for the bridge on DP vessel is 12mx7m.

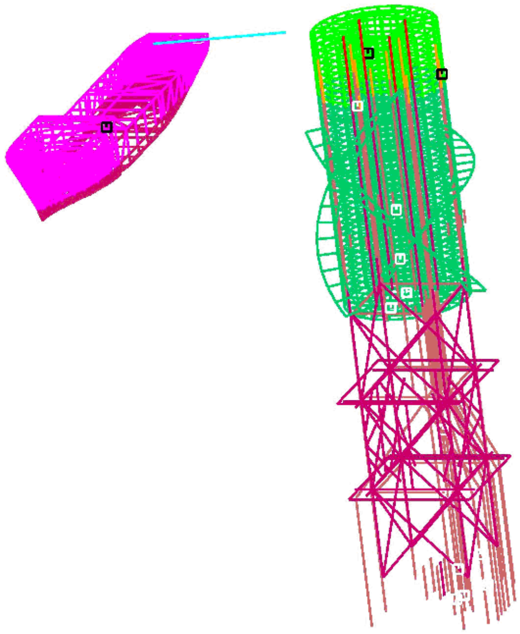

Figure 1: **Hydrodynamic model**

Figure 2: Bridge Details

A DP simulation study was carried out to quality the DP control accuracy for various environmental conditions. The DP simulation work used the spar and vessel motion time-traces calculated from MOSES motion analysis. The position and heading calculated by hydrodynamic model are with two different frequency components. The wave-frequency components of the position signals are reduced as part of the signal processing / Kalman filtering to prevent them from entering the thrusters. The DP was operated in "Follow Target" mode and with medium to high controller gain settings dependent on the environmental conditions.

The results from the DP simulation work provided detail information about motion ranges and thruster demand to maintain station keeping. These values can be used in the ASOG process to accurately determine operational status conditions and establish where the operational contingency and action plan.

4-Results

4.1 Motion Analysis Results

The results are derived via MOSES time domain simulation on the basis of a 3-hour duration.

The maximum fwd-stern gangway movement is 2.9m for wave periods between 6.5 seconds and 10.5 seconds, which is below the allowable movement of 12ft, i.e., 3.7m. However, for the long wave period waves, the maximum fwd-stern gangway movement has exceeded the landing area limit. For these long wave period waves, the allowable Hs is 2.5m. The maximum port-stbd movement is 5.7m with Hs=3.25m and Tp=14.5 sec, which is below the allowable movement of 20ft, i.e., 6.1m, but does not satisfy the tolerance of 0.5m assumed. Therefore, the wave height should be reduced to 3.0m for this long wave period.

Table 1: Heading Sea gangway movement in meter, Hs=3.25m

Head Sea	Max. fwd-stern movement	Max. port-stbd movement
6.5	0.7	0.0
7.5	1.0	0.1
8.5	1.2	0.1
9.5	1.5	0.1
10.5	2.9	0.1
11.5	4.3*	0.1
12.5	3.6*	0.1
13.5	3.8*	0.1
14.5	4.6*	0.1

* exceed gangway limiting landing area. The wave height is lowered to 2.5m for these wave periods. The maximum fwd-stern motion can be reduced to 3.0m.

Table 2: Quartering Sea gangway movement in meter, Hs=3.25m

Quartering Sea	Max. fwd-stern movement	Max. port-stbd movement
6.5	0.5	1.5
7.5	0.7	1.6
8.5	0.7	1.8
9.5	0.8	1.6
10.5	0.7	2.2
11.5	0.7	3.3
12.5	0.8	3.2
13.5	0.8	2.6
14.5	1.0	2.9

Table 3: Beam sea gangway movement in meter, Hs=3.25m

Beam Sea	Max. fwd-stern movement	Max. port-stbd movement
6.5	0.2	2.8
7.5	0.2	3.3
8.5	0.2	3.8
9.5	0.3	3.7
10.5	0.4	4.6
11.5	0.3	4.9
12.5	0.4	4.9
13.5	0.4	5.3
14.5	0.4	5.7*

* exceed gangway limiting landing area. The wave height is lowered to 3.0m for this wave period. The maximum port-stbd motion can be reduced to 5.3m.

The maximum gangway movements for Hs=2.5m are added as part of iterative step to find out the limiting environment condition, after the DP simulation study showed that the thruster load is too high for certain headings and wave periods.

The results for Hs=2.5m are included in Table 4. The port-stbd gangway moments are 2.8m and 3.6m for wave periods 7.5 seconds and 10.5 seconds respectively under beam-sea condition, which are below the allowable movement of 20ft, i.e., 6.1m.

Table 4: Gangway movement in meter, Hs=2.5m

Peak Period (sec)	Max. fwd-stern movement	Max. port-stbd movement
Head Seas		
7.5	0.9	0.1
10.5	2.2	0.1
Quartering Seas		
7.5	0.5	1.5
10.5	0.5	1.6
Beam Seas		
7.5	0.1	2.8
10.5	0.2	3.6

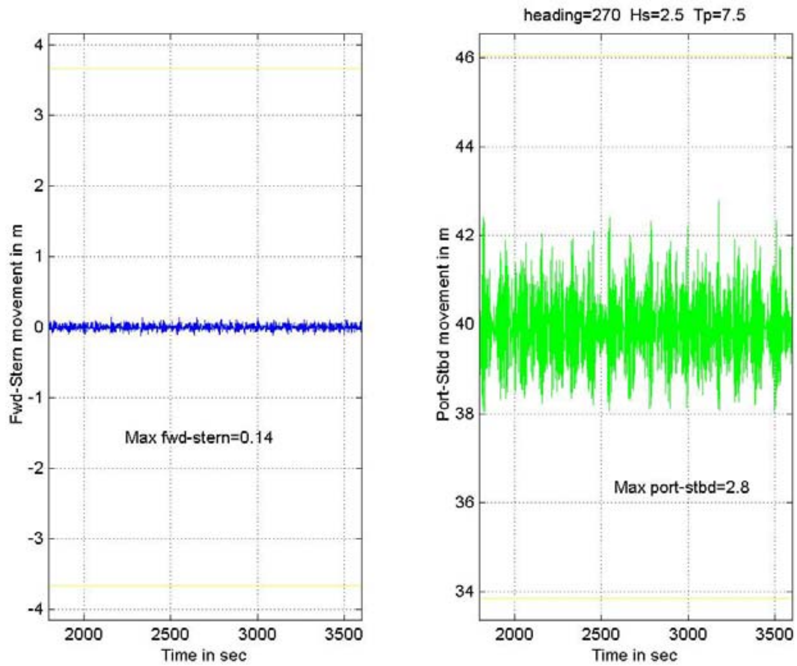

Figure 3: Times series of the gangway movement, Hs=2.5m, Tp=7.5 sec, beam sea

4.2 DP Simulation Results

Twelve DP simulation cases were performed with the following environmental parameters and associated motion time traces:

- Waves: Jonswap Wave spectrum with Gamma 2.0, Wave height and Wave period varied according to table below).
- Wind speed: 17 m/s (API Wind spectrum) or 13 m/s
- Sea Current: 0.35 m/s.

All directions will be collinear and with the direction defined in the table below. The 17 m/s wind is estimated as the "maximum" expected wind speed to occur simultaneous with 3.25 m waves. Utilization of 13 m/s wind for the 2.5 meter wave-height hence gives slightly high thrust utilization. The initial cases 9 were defined for the maximum wind speed and maximum wave height and maximum-average-minimum wave periods. Three additional cases with reduced environmental loads were added for the cases where the first simulations failed the operational criteria for gangway connection.

The decision to disconnect the gangway is made when:

- The gangway will move beyond the acceptable limits of the landing area on the vessel.
- The DP capacity of the DP vessel is over 50%

The results from the simulation are summarized in the table below with respect to whether the criteria for staying connected are met or not.

Table 5: DP Simulation Results.

Case	Wind (m/s)	Wave H_s (m)	Wave T_p (s)	Direction	Position Criterion	Dev[3] (m)	Load Criterion	Load[4] (%)	Thr Nr.
1	17	3.25	6.5	Head	Not OK	4.4 x	OK	23	3
2	17	3.25	10.5	Head	OK	3.6 x	OK	22	3
3	17	3.25	14.5	Head	Marginal	3.9 x	OK	22	3
4	17	3.25	6.5	Quartering	Not OK	8.0 x	Not OK	68	3
5	17	3.25	10.5	Quartering	OK	2.8 x	OK	46	3
6	17	3.25	14.5	Quartering	OK	3.5 x	OK	42	3
7	17	3.25	6.5	Beam	Not OK	8.0 y	Not OK	81	5
8	17	3.25	10.5	Beam	Marginal	6.4 y	Not OK	60	5
9	17	3.25	14.5	Beam	OK	3.5 y	Marginal	57	5
10	17	3.25	7.5	Head	OK	2.5 x	OK	22	3
11	13	2.5	7.5	Quartering	OK	1.6 y	OK	31	3
12	13	2.5	7.5	Beam	OK	4.3 y	OK	35	3

[3] The maximum deviation closest to or exceeding limit for given axis (x-surge, y-sway)
[4] The average load of the most loaded thruster is listed. In all cases where the load criterion not is met, the peak load of one or more thrusters reaches 100%

Significant thruster forces must be used to compensate for wind and current. The wind load is the dominating force for the initial quartering and beam sea simulations, case 4-10. This is the major reason for not meeting the load criterion for case 4, 7 and 8. (The combination of 3.25 meter waves and 17 m/s wind coming from the same direction is however a unlikely situation). By reducing wind speed to 13 m/s and wave height to 2.5 m, the thruster load criterion is fulfilled, see case 11 and 12.

The shortest wave periods (6.5 seconds) combined with the selected wave spectra causes significant variations in wave forces with a period of 90 to 120 seconds. These variations are not accounted for by the “DP current”, resulting in relative position exceeding criteria for cases 1, 4 and 7. It should be noted that wave heights of 3.25 with as short period as 6.5 second is very unlikely according to the presented metocean data. By increasing the wave period and/or reducing the wave height the position excursion criterion is met, ref. case 10-12. The MOSES analysis has been using too high controller gain/regulator stiffness, leading to higher allowable sea-states for short wave periods.

The DP simulation ignores the first order wave motion for the DP vessel, leading to better results than in the 2-body coupled motion analysis, especially for the cases with long periodic waves.

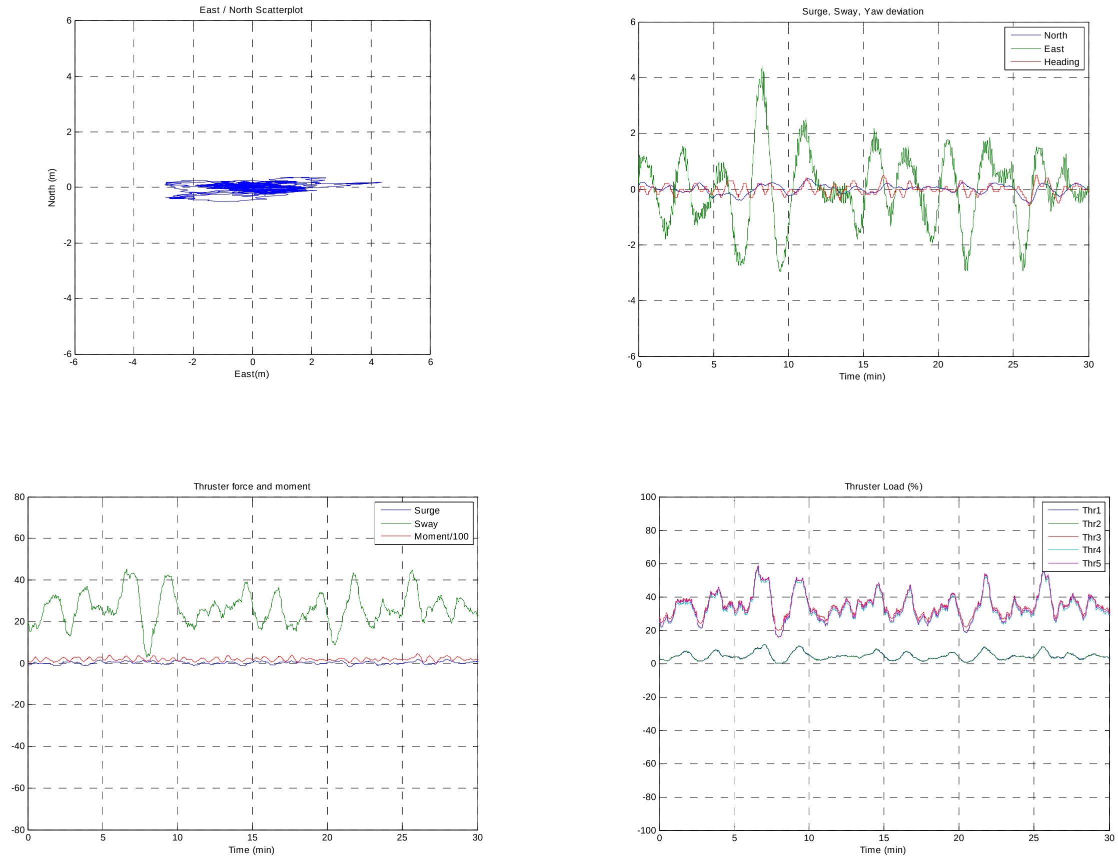

Figure 4: Scatter Plot for Case 12 listed in Table 5 (top left). Position and Heading Deviation (top right). Thruster Force (tf) and moment (tfm/100), bottom left. Thruster Load (top right)

4.3 Gangway Operability

The methodology of assessing operability is to apply the wave scatter diagrams and maximum acceptable environment for different headings to derive the percentage of the operability. It can be described as follows:

- Extract the maximum acceptable environmental condition of the vessel according to the thrust utilization and the relative positioning performance.
- Apply the percentage of occurrence for that maximum acceptable environmental following the wave scatter diagrams
- Sum up the percentage of occurrence for each environmental quadrant.
- Combine the percentages of the eight environmental quadrants to obtain the total percentage of operability.

The weather is calm and stays stable during the operational period at the site. It can be seen from Figure 5 that the chance of a wave height of 2.5 m is expected to be in the range of 0.3%, 0.2% and 0.1% for months from October to December, respectively. The probability of having a significant height of 3.25m is 2.3%, 2.1% and 2.2% for this period.

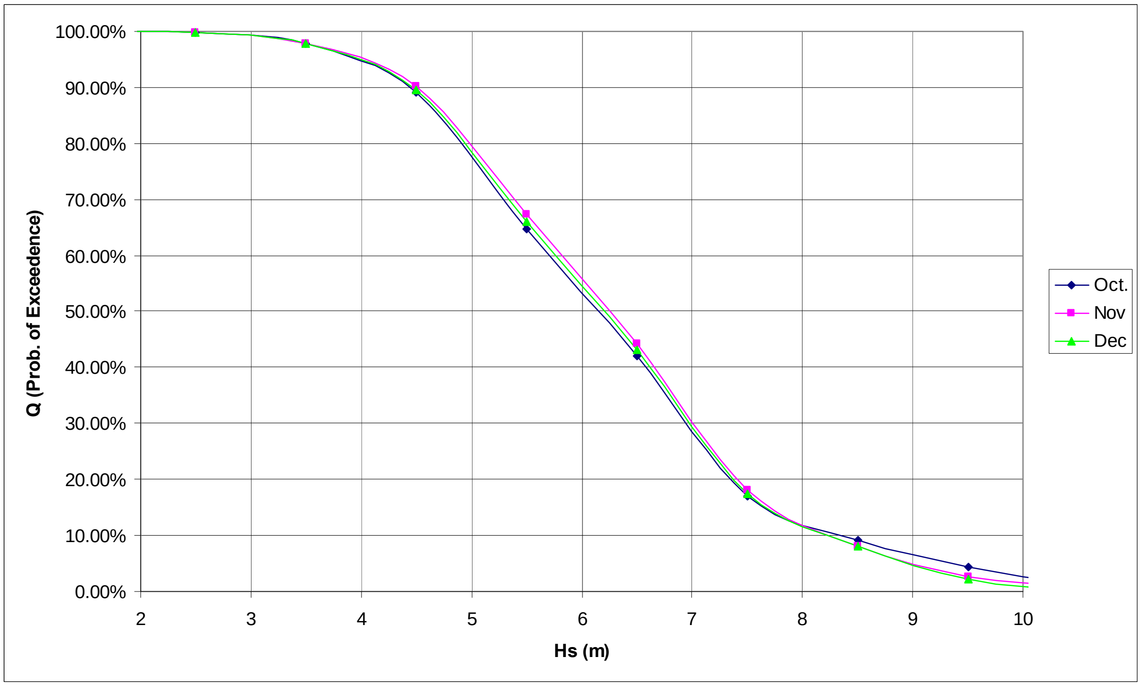

Figure 5: Probability of Exceedance of Wave Height for October, November, and December,

Based on the limiting allowable Hs in Table 5 and scatter diagram for field, the operabilities for gangway connected condition for this DP vessel at the GoM field are approximately 93.4%, 93.2% and 91.7% for the months of October, November and December respectively.

4-Conclusion

This study is to investigate the operational limits of a DP vessel alongside a deep-water Spar at Gulf of Mexico while gangway connected between the months of October and December. This operability study is a tool that was used in conjunction with the ASOG process to support the project team decision making process of when the DP vessel should be disconnected and safely moved away from the platform.

As part of the Shell DP DEP process the ASOG was the tool used to identify the worst case scenarios and other combinations of function failures that may leaves the vessel in a reduced station keeping capacity. This reduced capacity will have to deal with the study results and maintain station within the parameters expected, anything below this capacity will trigger a reduced status that may require immediate action from the DP Operator.

The simulations provided results on the thrust utilization and the relative positioning performance at predefined environmental conditions. The results presented provided detailed information about motion ranges and thruster demand to maintain station keeping, this values were used in the ASOG process to accurately determine operational status conditions and establish where the operational contingency and action plan.

The methodology used to this study is:

- Calculate the hydrodynamic and response parameters of the DP vessel and Spar
- Obtain time series of relative motions between the DP vessel and Spar
- Use DP Simulator to quality the DP control accuracy for various environmental Conditions

- Calculate operability

The initial DP simulation cases are based on 17 m/s wind speed (API Wind spectrum), 0.35 m/s current and 3.25m of significant wave height for head, quartering and beam seas. Wind and current direction is collinear with the wave direction. The results show that significant thruster forces must be used to compensate for wind and current. The wind load is the dominating force for the initial quartering and beam sea simulations. In some loadcases, the thruster load criterion is fulfilled by reducing wind speed to 13 m/s and wave height to 2.5 m.

The operability for gangway connected condition for the vessel at the deep water spar are approximately 93.4%, 93.2% and 91.7% for the months of October, November and December respectively.

The method used for the specific operability study can also be used for other studies where the DP performance is a vital part of the overall availability.

References

[1] "Kongsberg K-Pos Dynamic positioning, Optimizing complex vessel operations", www.km.kongsberg.com

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[3] "DP Operations Guidance. Part 2 Appendix 2 (DP project / construction vessels" *Marine Technology Society DP Committee, October 2010.* www.dynamic-positioning.com