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Case Study of DP Vessels Performing SIMOPS

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CASE STUDY OF DP VESSELS PERFORMING SIMOPS

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ABSTRACT

A case study for vessels performing simultaneous operations (SIMOPS) of an example deep water oil field have been performed. This included calculating the probability of collision between DP & DP vessels, DP vessel & a permanently moored semi-submersible, and DP vessel & subsea structures. Quantifying the consequences if such collisions were to occur was also performed as part of this study. Collision risk was classified using probability and consequence criteria determined by practical engineering experience and literature review.

There are two critical failures that potentially cause a DP vessel to lose station so that an emergency disconnect from the well is required: a drift-off and a drive-off. A drift-off, is a total loss of power, i.e. blackout, that causes the vessel to move off location in the direction of the prevailing environment. A drive-off, is a near instantaneous position adjustment by the DP system generally caused by an errant position reference input which makes the DP system think the vessel is off station.

The methodology for assessing DP units is to apply scenario information i.e. critical weather direction, vessel drifting speed, and distance to collision in order to derive the probabilities of particular consequences. Risk for collision is classified by the probability of occurrence and the resulting consequence, hereby represented by impact energy.

In general, the analysis has indicated that the probability of collision and resulting impact energy respectively, decrease and increase with distance. Usually SIMOPS activities occur at large distances, which greatly reduces the likelihood of collision, but when the DP vessels are massive such as drill ships, the resulting impact energies become very large with severe consequences that shouldn’t be disregarded.

1 INTRODUCTION

Projects driven by fast track schedules are using multiple DP vessels (usually of different class) simultaneously during the field development phase, which present a multitude of collision scenarios. In order to gain a good understanding of the DP system’s limitations, an analysis method to quantify the collision risk for DP vessels performing SIMOPS is presented herein.

The intention is to provide DP operators and their clients with an analytical methodology to identify and mitigate the risk associated with performing SIMOPS, especially for prolonged durations. The risk of each SIMOP scenario is quantitatively assessed in order to assist in the planning and evaluating of those SIMOPS in question. This quantitative risk will be based on probability of station keeping failure combined with the resulting consequences, i.e. impart energy.

2 CASE STUDY SCENARIOS

The objective of this case study is to represent the current trend of utilizing DP vessels in the deepwater field development process. For simplicity, a single permanently moored semi-submersible and only three DP vessels are considered for this case study. The DP vessels are performing typical installation operations, such as installing suction piles, hooking up mooring lines, and installing umbilicals and risers. In addition, one of the DP vessels is continuously performing drilling operations in the field. When a DP vessel is operating in close proximity to another DP vessel or a floating unit, the possibility of a collision is easily identified and the risk can be mitigated appropriately. However, the risk of a collision for DP vessels operating for prolonged periods at evidently long distances may be underestimated.

The DP vessels used for this case study are:

- Vessel A: A Class 3 DP installation vessel with over 100,000 tons of displacement
- Vessel B: A Class 2 DP drill ship with over 100,000 tons of displacement
- Vessel C: A Class 3 DP installation vessel with over 10,000 tons of displacement

When a DP system failures occurs, the drifting (rogue) vessel could not only collide with the production semi-submersible but also collide with the other DP vessels. Deepwater fields include numerous subsea structures, such as manifolds, risers, flowlines, and mooring lines. Due to the high density of subsea structures there is also the possibility of collisions between risers or lines hanging of DP vessels with such subsea structures. While mooring lines, risers and umbilicals are small in size in comparison to vessels they can occupy large areas and restrict DP operations. Although these potential collisions may not be readily apparent during the planning process or from the surface, the financial consequences may be severe.

2.1 COLLISION SCENARIOS BETWEEN VESSELS

To identify the potential vessel-to-vessel collision scenarios, information regarding the installation locations and the proposed installation scheduled is required. A field layout map is used to determine the critical distances between vessels operating in the field. The operation schedule is used to determine the durations of all the simultaneous installation operations. This information is put into a comprehensive collision scenario matrix with the vessels, installation activities, failure modes, distances, environmental heading, and durations listed.

Figure 1 illustrates the field layout chosen for this case study. There are three drill centers in the field, with the semi-submersible installed on drill center 1. DP operations occur at all three drill centers.

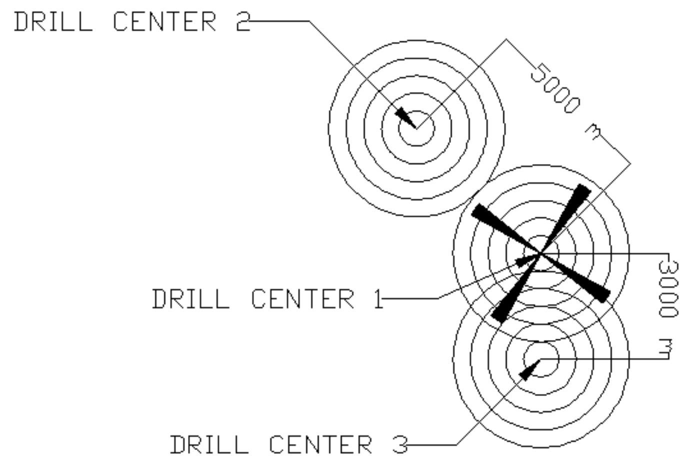


Figure 1: Case Study Field Layout

The following collision scenarios were established for our case study, with the details shown in Table 1:

- Vessel A is in close proximity to the semi-submersible for hooking up the mooring lines and installing flow lines. While vessel A is installing flowlines, vessel B is 3000 m away.
- Vessel B is drilling 3000 m away from the semi-submersible, but would operate at the same drill center XX with vessel C which is installing flowlines and umbilicals.
- Vessel C operates in close proximity to the semi-submersible installing umbilical and flowlines.
- Vessel C installs an umbilical at a drill center 5000 m away from the semi-submersible.

Most of the collision scenarios have actual durations on the order of a few days, however to be conservative the durations are rounded up to the next 30 days. When a DP vessel is operating at the same drill center as another vessel, a distance of 30 m is assumed.

It should be noted that not all possible scenarios are included in Table 1. Most of the presented failure modes are caused by drift off, while only two drive-off scenarios for vessel C are considered in our case study. It will be shown later in section 4.2 that vessel C has the fastest drifting speed among all vessels, so the probability of collision caused by vessel C drive-off is higher than vessels A & B.

Table 1: Scenarios for Vessel Collisions

Vessels	Activity	Failure	Distance	Env.	Dura-tion

Rogue	Static	Rogue	Static	Type	(m)	Direction	(d)
A	Semi	Connect Mooring	Connect Mooring	Drift Off	30	Omni	30
A	B	Install flowlines	Drill	Drift Off	3000	S	60
A	Semi	Install flowlines	NA	Drift Off	3000	N	60
B	C	Drill	Install Flowlines	Drift Off	30	Omni	30
B	Semi	Drill /Completion	NA	Drift Off	3000	S	90
B	C	Drill	Install Umbilical	Drift Off	1000	N	30
B	A	Drill	Install Flowlines	Drift Off	3000	N	60
C	Semi	Install Umbilical	NA	Drive Off	30	Omni	30
C	B	Install Umbilical	Drill	Drive Off	30	Omni	30
C	Semi	Install Umbilical	NA	Drift Off	5000	SE	30
C	Semi	Install flowlines	NA	Drift Off	30	Omni	30
C	Vessel B	Install flowlines	Drill	Drift off	30	Omni	30

2.2 COLLISION SCENARIOS BETWEEN DP VESSELS AND SUBSEA STRUCTURES

The following collision scenarios between hang-off risers on DP vessels and subsea structure are considered for this case study:

- Drilling risers on rogue vs. semi-submersible's mooring lines.
- Drilling riser on rogue vessel vs. flowlines.
- Drilling riser on rogue vessel vs. umbilicals.
- Drilling riser on rogue vessel vs. production and export pipelines.
- Drilling risers on rogue vessel vs. seabed.

For collisions between the seabed and hung off drilling risers, a recoil height of 30 ft was assumed to calculate the horizontal distance to collision using the slope of the seabed. Table 2 contains the subsea collision matrix.

Table 2: Scenarios for Subsea Collisions

Vessel	Subsea Structure	Failure Mode	Distance (m)	Direction	Duration (d)
A	Test Flowline	Drift Off	150	E	60
A	Umbilicals	Drift Off	150	S	60
A	Sea Bed	Drift Off	500	N	60
A	Mooring Line	Drift Off	4000	SE	60
A	Mooring Line Center	Drift Off	5000	SE	60
A	Export pipeline	Drift off	2500	E	60

3. ENVIRONMENT

Omni-directional and directional wind, current and seastate parameter, applicable to one-year return period are used directly in the risk analysis. For the case study one-year return period criteria for the Gulf of Mexico are used.

From a purely operation perspective performing SIMOPS under 1-yr condition is conservative because vessel motions exceed operation tolerances. But in the area of fast moving storm or eddies, this metocean criteria is appropriate.

4 ANALYSIS METHOD

4.1 RISK ASSESSMENT INPUT

The DP position loss data has been derived from the International Marine Contractors Association (IMCA) 2000 database [1], which includes a record of the incidents of DP position loss due to large excursion, drift off and drive off.

The IMCA database enables derivation of frequencies and probabilities of position loss due to drift off. The distance that the vessel travels before the drift is stopped depends on the weather conditions and the ability of the key DP personnel to react quickly and correctly. There are three situations that can cause the vessel to drift off position as given below:

- Total blackout
- Partial blackout resulting in insufficient thrust
- Incorrect thrust commands

Drive off is a move under power away from a desired position. Drive off may occur at full power, as the DP system is in effect trying to attain or regain a position, either because of false position information or wrong position inputs. The details within the IMCA database describe a multitude of different faults and errors, for the purpose of this report they are simply categorized as follows [2]:

- The primary cause of drive off is operator error.

- The secondary cause is DP control failure. Either the DP computer or peripheral fail alone or fail due to operator error.
- Position reference "freeze" or poor information is accepted.

The frequency of drive off events that have actually caused contact with another installation is very low, largely because the majority of DP working hours are spent away from other installations. Similarly, very few of these events can be attributed historically to class 3 vessels, since the classification does not include the majority of DP diving vessels.

The following frequencies and probabilities are derived from the IMCA database.

Table 3: DP Failure Probabilities

Incident	Frequency per DP hour	Probability of Annual Occurrence
Drift Off	2.092E-5	0.1283
Drive Off	1.476E-5	0.0905
Large Excursion	1.700E-5	0.1042
No Position Loss*	3.232E-5	0.1982

* Incident occurs but there is no position loss

It is important to note that this data covers a range of various vessels and is not divided according to DP class. As a result, the data must be regarded as being conservative when applied to class 3 vessels and non-conservative when applied to smaller supply/AHTS vessels.

In the event of a drift off, estimates for the probability of recovery are extracted from [3] and shown in Table 4. A residual probability that it is not possible to recover in 10 minutes or more has been derived as P=0.005.

Table 4: Probability of Drift Off Recovery

Recovery Time (minutes)	Probability
0.0-1	0.2
1-2	0.16
2-3	0.13
3-4	0.12
4-5	0.11
5-6	0.10
6-7	0.07
7-8	0.05
8-9	0.04
9-10	0.02

In the event of a drive off, estimates based upon practical experience, for the probability of recovery are given in Table 5.

Table 5: Probability of Drive Off Recovery

Recovery Time (minutes)	Probability
0.0 – 0.5	0.5
0.5 – 1.0	0.9
1.0 – 2.0	1.0

4.2 DRIFT AND DRIVE OFF RATES

Wind, wave drift and current forces for the vessels under the desired metocean condition was used to determine the drift and drive off rates between any two locations for the metocean criteria discussed earlier. These results are given by solving the differential equation below in Matlab.

$$\frac{d^2\mathbf{S}}{dt^2}\mathbf{M} = \mathbf{F}_{wave} + \mathbf{F}_{wind} + \mathbf{F}_{drag} + \mathbf{F}_{Thrust}$$

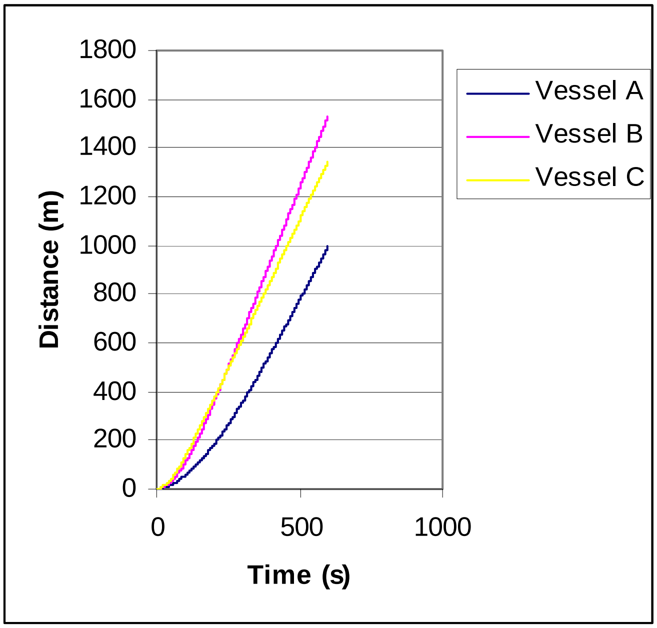
Equation 1: Calculation of drift –off and drive-off distance

Here ***S*** represents the drift distance. ***M*** is the mass matrix. $\mathbf{F}_{drag} = \mathbf{F}_{current} \cdot \left|\mathbf{V}_d - \mathbf{V}_c\right|(\mathbf{V}_d - \mathbf{V}_c)/\mathbf{V}_c^2$. V_c and V_d are the current and drift velocity respectively, F_{wave}, F_{wind} and $F_{current}$ are the environmental loads, F_{Thrust} is the thrust force.

For categories involving two DP vessels, drift and drive off are considered for both vessels since either one may lose position at any time, i.e. the rogue vessel. In other words, each scenario was evaluated twice with each vessel acting as either static or rogue. For categories involving a DP vessel and the semi-submersible, the DP vessel was always the rogue vessel. It was assumed the semi-submersible would never be the rogue vessel since the environmental criteria for the installation phase is too mild to damage the semi's mooring system. In other words, semi-submersible installation operations would cease long before environmental conditions approached the semi's mooring system limits.

The drifting rates for all vessels can be seen in Figure 2 below.

Figure 2: DP vessel Drifting Rates



From Figure 2, it can be seen that Vessel A drifts slowest, while Vessel B drifts the fastest among three DP vessels.

Collision due to drive off is only considered for vessels operating at the same drill center i.e. 30 meters apart, since the recovery time is less than two minutes. The drill centers are located far enough apart that recovery times would be in excess of two minutes therefore a collision is not possible due to drive off.

4.3 COLLISION PROBABILITY ANALYSIS

The methodology for assessing DP units is to apply scenario information and event probabilities in order to derive a cumulative probability of a particular collision. The methodology can be described as follows:

- Apply incident probability as required on the risk of DP failure, e.g. drift off, to derive the incident probability, P(Drift off).
- Combine this probability with the appropriate weather conditions acting in a sector such that the drifting vessel can collide with another unit. Derive probability of the appropriate weather conditions acting in appropriate section, P (Weather Direction).
- Utilizing derived drift distance vs. time data for the drifting vessel, together with probability of recovery, derive the probability of recovery/non-recovery within the time it takes for the vessel to drift the required distance to collision, P (non-recovery).
- Combine the derived probabilities to give an estimate of the collision risk for a particular scenario, i.e.

$$P(collision) = P(DriftOff) \times \sum_{j=1}^{J} \sum_{i=1}^{I} P_{ij}(non-recovery) \times P_{ij}(WeatherDirection)$$

Where index i is wind speed sector number, j is direction index from 1 to 8, representing 8 different wind directions-N, NE, E, SE, S, SW, W & NW. P_{ij}(Weather Direction) represent for weather in critical direction, P_{ij}(non-recovery) is the associated non-recovery probability.

- The process is repeated for other scenarios.

4.4 IMPACT ENERGY

The Kinetic Energy (KE) of the rogue vessel at the computed distance to collision is used to calculate the total impact energy. The kinetic energy for each vessel is heading dependent. For example, a vessel may drift faster under quartering seas than beam seas, resulting in greater kinetic energy. The maximum kinetic energy for each vessel is considered for impact energy. Equation 2 calculates the kinetic energy for a vessel drifting head on, where M and M_A are the mass and surge added mass of the rogue vessel, and V_S is the calculated surge velocity. This same type of calculation was performed for beam and quartering drift modes.

$$KE = 0.5(M + M_A)V_s^2$$

Equation 2: Kinetic Energy

Using the principle of the conservation of energy, vessel mass determines energy distribution after the collision, given by Equation 3, where M_1 is the mass of the static vessel and M_2 and V_2 are the mass and impact velocity of the rogue vessel. Note that added mass is included in M_1 and M_2.

$$KE_a = 0.5 \frac{M_1 M_2}{M_1 + M_2} V_2^2$$

Equation 3: Absorbed Kinetic Energy

The following conservative assumptions have been made:

- 100% of the kinetic energy is conserved in the impact.
- All motion is assumed to be in the horizontal plane, without rotation.
- The rogue vessel directly strikes the static vessel and are thus joined.

- Friction and wave radiation damping is not considered in these equations.

4.5 RISK DEFINITION

The definition of risk adopted for this study is classified by the probability of occurrence and the resulting consequence i.e. impact energy as shown in Table 6 and Table 7.

To help distinguish between collision scenarios the resulting risk categories have been color coded, red, yellow, and green to represent high, medium and low risks respectively.

10,000 and 1,000 yr return periods are the probability criteria used to define low and high occurrence. Impact energies of 15 and 100 MJ are the low and high values used to define the consequence criteria. The basis of these risk criteria is discussed further below.

Table 6: Risk Criteria

Probability / Frequency	Consequence
Low = Return period greater than 10,000 yr	Low = Less than $100,000 Energy is less than 15 MJ
Medium = Return period greater than 1,000 yr.	Medium = Less than $2 million Energy is less than 100 MJ.
High = Return period less than 1,000 yr	High = More than $2 million Energy is greater than 100 MJ

Table 7: Risk Definition Matrix

Probability / Frequency	x Consequence	= Risk
L	L	L
L	M	L
L	H	M
M	L	L
M	M	M
M	H	H
H	L	M
H	M	H
H	H	H

1,000 and 10,000 yr return periods were chosen as probability criteria from previous engineering experience.

Many impact design standards (DnV, LR, NORSOK, UKOOA) for offshore structures are based upon collisions involving a typical supply vessel of 5,000 tons drifting at 2 m/s. API-RP2A [10] uses a 1,000 ton vessel with a velocity of .5m/s. These standards were developed for traditional fixed platforms and supply vessel interactions. However, the industry's trend of moving to deeper water and using floating production systems such as semi-submersibles, TLPs, and FPSOs has warranted further investigation into collisions involving larger vessels and impact energies.

The Health & Safety Executive has organized various studies on collisions. These include historical and numerical investigations into collisions involving offshore structures located in the North Sea. A selection of these is used as guidelines to determine collision consequences ([4], [5] and [6]).

Historically, collisions between floating production systems and other vessels are infrequent. A few incidents in the North Sea involving FPSOs and shuttle tankers have been reported [7]. Incidents involving drilling semi-submersibles have also been reported in literature [8]. In general, these collisions involved relatively low impact energy, however the potential of higher energy collisions exist [9].

Recognizing the potential of high-energy impacts involving floating systems several FE analyses have been performed [7]. An FE analysis involving typical FPSOs and shuttle tankers for bow and stern collisions for empty and fully loaded conditions and KE ranging from 10 to 100 MJ has been performed This study indicated hull penetrations ranging from .73 to 5.56 meters. An FE analysis of collisions involving 5,000 and 9,000 ton supply vessels impacting the columns of drilling semi-submersibles was performed [8] resulting in impact energies ranging from 5 to 22 MJ. Maximum penetrations on the order of 1.5 meters are reported.

It is important to note, that all three vessels in this proximity study are considerably more massive than those presented in the literature review. The impact energy for the case study vessels at even moderate speeds may result in significant hull damage and financial consequence to both vessels involved. In other words, the consequences for any collision will most likely be high.

Although the collision scenarios for this proximity study do not match those given in literature, they serve as guidelines to the amount of hull damage expected if a collision were to occur. It is assumed that hull damage to the semi and DP vessels would be comparable to those predicted in literature. However, it is outside the scope of work for this case study to determine the actual hull damage to any of the SIMOPS vessels. The consequence criteria selected with the aide of literature are as follows:

- Low consequences are expected for impact energies below 15 MJ. This magnitude of energy is near that required by design. Minor damage is expected to both vessels.

- Medium consequences are expected for impact energies between 15 and 100 MJ. Literature has shown that hulls may be penetrated at this range of impact energy. Water tightness will be broken.
- High consequences are expected for impact energies greater that 100 MJ. Hull penetrations greater than 1 meter are expected. One or more compartments may be flooded. Stability of either vessel may be compromised.

For collisions between vessels and their respective equipment and subsea structure the impact energy is classified by the probability criteria alone. The resulting damage between vessel equipment and subsea structure is difficult to quantify.

5. RESULTS

The collision risks between vessels are shown in Table 8. The ranked results show that only one scenario is categorized as high risk, while there are 7 and 4 medium and low-risk scenarios respectively. The top 4 risks involve vessels operating within 30 meters of each other, i.e. operating at the same drill center. The result trend follows pre-analysis expectations that the highest risk installation operations are those occurring at closest proximity to other vessels. However, it should be noted that SIMOPS at different drill centers may have higher risk than those at the same drill center. The risk at different drill centers is higher because the durations are longer than those at the same drill centers. The two drive-off scenarios are categorized as low risk, although the two vessels are operating at the same drill center.

Table 8: Vessel collision risk ranking

Rank	Vessels		Activity		Failure	Dis-tance	Env.	Dura-tion	Proba-bility	Impact Energy	Risk
	Rogue	Static	Rogue	Static	Type	(m)	Direc-tion	(d)		(MJ)	
1	A	Semi	C.M.	C.M	Drift Off	30	Omni	30	6.61E-03	20.47	H
2	C	Semi	I.F.	NA	Drift Off	30	Omni	30	8.14E-03	12.83	M
3	C	B	I.F.	Drill	Drift Off	30	Omni	30	8.14E-03	12.54	M
4	B	C	Drill	I.F.	Drift Off	30	Omni	30	6.72E-03	9.96	M
5	B	Semi	D&C	NA	Drift Off	3200	S	90	2.01E-05	353.12	M
6	A	B	I.F.	Drill	Drift Off	3200	S	60	1.34E-05	159.62	M
7	B	A	Drill	I.F.	Drift Off	3200	N	60	1.32E-05	314.07	M
8	A	Semi	I.F.	NA	Drift Off	3200	N	60	1.32E-05	177.4	M
9	C	Semi	I.F.	NA	Drive Off	30	Omni	30	7.29E-04	13.87	L
10	C	B	I.U	Drill	Drive Off	30	Omni	30	7.29E-04	13.55	L
11	B	C	Drill	I.U.	Drift Off	1100	N	30	1.33E-05	71.49	L
12	C	Semi	I.U.	NA	Drift Off	5000	SE	30	1.10E-05	49.78	L

*C.M.=Connect mooring, I.U.=Install umbilicals, I.F.=Install Flowlines, D&C=Drilling/completion

Table 9 contains the results for subsea structure scenarios. Unlike the vessel-to-vessel scenarios, these ranks are based on the probability of occurrence only. 10,000 and 1000 yr return periods are the probability criteria used to define low and high risks.

It can be seen that only one scenario was categorized as high risk. This is due to the possible collision with a test flowline; the collision with umbilical scenario was categorized as medium risk; while the collisions with mooring lines, export pipeline and sea bed are all at low risk.

Table 9: Collision with subsea structure risk ranking (Vessel A)

Vessel	Structure	Failure Type	Distance (m)	Direc-tion	Dura-tion (d)	Probability Of Collision (P)	Return period in years (1/P)
A	Test Flowline	Drift Off	150	E	60	1.2E-03	8E+02

A	Umbilicals	Drift Off	150	S	60	9.1E-04	1E+03
A	Sea Bed	Drift Off	500	N	60	6.1E-05	2E+04
A	Mooring Line	Drift Off	4000	SE	60	2.2E-05	5E+04
A	Mooring Line Center	Drift Off	5000	SE	60	2.2E-05	5E+04
A	Export pipeline	Drift off	2500	E	60	1.8E-05	6E+04

6. CONCLUSION

Collision frequency and resulting impact energy for three DP vessels operating simultaneously during the installation phase of a permanently moored semi-submersible have been evaluated and categorized into high, medium and low risk.

The environmental conditions used for this case study were a one-year return period conditions commonly used for the Gulf of Mexico. In general, the analysis has indicated that the probability of collision and result impact energy decrease and increase with distance, respectively. It was found that the close proximity SIMOPS, accounted for the highest risk. However, collision risks between vessels at different drilling centers are not necessarily less than those at the same drill center, since the collision probability increase linearly with the durations of the SIMOPS. This is especially important for DP vessels such as drill ships, operating on DP for durations approaching a year.

Generally, risk level caused by DP vessel drive off is low, since the drive-off vessel can be recovered within two minutes.

The collision risk between hang-off riser on DP vessel with subsea structures are categorized by collision occurrence only. In our case study, only one collision scenario with test flowline is ranked as high risk.

For those scenarios categorized as high risk, the following risk and contingency plans can be performed to reduce the collision risk:

Mitigation	Notes
Safety Anchor	May make DP unstable and may present a hazard in itself. Could have one let go to reduce drift & stop, or have anchor on risers.
Safety Boat	MODU and Safety Boat have a quick connect system. Problem is Boat is another collision hazard and connecting in an emergency can be fraught.
Weather Forecast	Pull off before weather gets too bad
Real time drift off analysis feature of the DP control system	Can be used in real time to predict the trajectory of the DP vessel in drift off for existing or forecast environmental conditions.
Consequence analysis feature of the DP control system	Warns the operator whether if in the event of the worse case failure the vessel can hold position or not. Can be done for existing and future weather conditions and equipment availability.
Drill certain wells before the production unit is installed	This minimizes the duration of SIMOPS, which can be lengthy for drilling operations.
Use of well specific operational guidelines for pre planning	Specific for each location with contingency plans laid out and requirements.
Riser height	Develop means of raising the riser higher when it disconnects to give more clearance above subsea obstacles.
Collision avoidance Radar	Used with Ecdis and possibly over lay of field and obstructions – should be on a UPS.
Inter Vessel Communication	Set up independent unique command channel between vessels. Test regularly.
Minimize exposure time	Run riser in safe position then move over location, use of dual derricks, etc

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