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Risk Management

Risk Analysis of a DP Diving Vessel Up Weather Of Platform and Jack Up.

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INTRODUCTION

In July 2004 BHP Billiton (BHPB) were planning to install a number of pipeline spool pieces using a Class 3 DP vessel at facilities in the Angostura Field located offshore Trinidad. The vessel was to conduct diving operations on DP in proximity of the three fixed platforms. Jack up drilling rigs would be alongside two of these platforms.

At a HAZID meeting it was noted that the DP vessel would have to approach to within 30 meters of the above platforms and jack ups on a heading that would put the vessel beam to the prevailing current. Concern was expressed by BHP Billiton and the drilling contractors about the risk of a collision in the event of a DP problem. Global Maritime were therefore requested to quantify and mitigated the risks this DP operation.

The key objective of the work was to assess the potential risk associated with loss of position of the vessel such that she might collide with a platform or a jack up while operating in such close proximity. Then to identify suitable and appropriate risk mitigation measures to ensure the risks of the operation were as low as reasonably possible (ALARP).

INDUSTRY STUDIES AND VESSEL EXPERIENCE

A number of DP industry risk analysis studies have been conducted in the past. The most recent for platform collision was however published back in 1993 (Risk Analysis of collision of Dynamically Positioned Support Vessels – IMCA 115 DPVOA). This gave the risk of a DP vessel colliding with a platform at 1.6×10^{-5} per DP hour (7.13 DP years). It also gave the risk of a major loss of position put at 7.69 DP months, with 40% being due to drift off and 60% due to drive off.

Other studies performed by Global Maritime for other clients have attempted to use more up to date figures and used 6.286×10^{-5} per DP hour, and a ratio of drive off to drift off 60% and 40% respectively.

The 2001 IMCA DP incidents report included eight vessels that had good incident reporting records. Between them they reported two major losses of position out of thirty-five incidents. Assuming that they were on DP 50% of the time this gives a frequency of major loss of position around 2 DP years.

There are also more recent studies that have looked at the risk of what could be considered a comparable top event on DP for other DP applications. An IMCA Study – Quantified Frequency of Shuttle Tanker Collision during off take operations – IMCA M150 - gave the risk of DP Shuttle Tanker Collision as 3.9 x 10-6 per DP hour (29 years). A DeepStar Reliability Study GM-44387-0503-47539 gave a figure for an Emergency Disconnect for a DP drill ship at 1.01×10^{-5} DP hour (11.3 years).

The vessel to be used had recorded all its DP incidents since 1999 (see details later). During this time the vessel had four major losses of position and totaled 16,920 hours on DP. This was equivalent to two years on DP, about 40% of the available time. These incidents were all drift offs and none involved a collision with a platform. This gave an average time between incidents of 4,230 hours (5.79 months). This was more in agreement with the IMCA 93 figure than the improved trend inferred by the data from data from more recent years by GM and by IMCA 2001's eight vessels that reported well.

BHP Risk Criteria

BHP has established risk categories as follows:

Frequency	Likely hood
One or more times a year	Almost certain
Once every 1 to 10 years	Likely
Once every 10 to 100 years	Possible
Once every 100 to 1000 years	Unlikely
Once every 1000 to 10000 years	Rare

The IMCA figure of a 7.13 DP year chance of collision falls into BHP's category of **'Likely'**. However as the exposure time was relatively small and a loss of position need not necessarily result in a platform collision the risk category could be better than this.

As the exposure time was expected to total about 10 days (see later) this meant that the risk of a major loss of position was improved from about 7.69 months (234 days) by a factor of twenty-three. Additionally, assuming that there was a 50:50 chance that the loss of position would be in the direction of the platform and it was again a 50:50 chance that the crew will not recover the situation and avoid the platform. The risk improves by a further factor of four. This takes the 7.69 month figure of a major position loss to a 58.9 year (707.48 month) chance of collision, which moved the top event into BHP's risk category of **'Possible'**.

If the 2 year figure for a major loss of position was used the risk improves by another factor of about 4 to a 184 year chance of collision – a category of **'Unlikely'**. For the worse heading situation if an exposure time of 12 hours was assumed (see next section), then the figures derived above for 10 days exposure will increase by a factor of 20 and go from **'Possible'** to **'Rare'**.

EXPOSURE TIME

The exposure time figure used above where based on the following approximate timing for activities at the platform locations - as follows:

K1 Platform tie-ins, 7 days, 1 day of which would be for the riser flanges close up to jacket. This platform has the Nabors 657 jack up alongside.

C1 Platform tie-ins 7 days, riser flanges 1 day as K1 as above. This platform also has the Monitor jack up alongside.

CPP tie-ins 18 days, riser flanges 4 days. This platform has no jack up alongside.

Hydro testing of the pipelines will take 16 days and will involve vessel being on location at CPP with hoses to jacket but orientation could be adjusted to mitigate the risk of impact.

Umbilical pull-ins will involve 1 day at each platform location and will require diver access to base of each jacket.

The total critical exposure time was estimated at 1 day at K1, 1 day at C1, 4 days at CPP and a further day at each. This totaled 9 days where the vessel will be in a position of greatest risk. Allowing some contingency a figure of 10 days was assumed.

At a BHP meeting the exposure time for the worse heading situation was discussed. This was expected to be when the vessel was approximately 30m of and have its heading at its most restricted and beam to current. At this time stage there will be divers bolting up the flanges. Some 50 bolts will need to be connected and the time to perform this task was given as 6 to 8 hours. The time that this work can be performed can be carefully chosen to avoid high current and environmental conditions and an exposure time of 10 hours was assumed and allowing for delays a 12-hour figure was used for the risk calculation.

DP INCIDENT CAUSES

The IMCA report for 2001 DP Incidents gave the split of the primary causes for DP incidents are as follows:

Position References	20 to 23%
Computers	20 to 23%
Thrusters	17%
Operator	17% (downward trend from 25%)
Environment	8%
Remainder	attributed to generators, electrical, ‘other’

Class 3 DP Vessel

The DP system was classed to ABS class 3. The power generation was two sets of three diesel generators with each set in a separate engine room. These produce power at 660V and connect to split bus bars that are separated by two bus ties.

The vessel had three bow tunnel thrusters 1100kW and two stern azimuth thrusters. These are arranged so that one bow thruster and one stern azimuth were connected to the each side of the 660V switchboards. The frwd bow thruster could be assigned to either side of the 660V switchboard. The change over of this was automatic on loss of the switchboard but required a manual restart of the thruster.

The DP Control system was a ‘triple voting’ system with back up DP control system in a separate room per Class 3 requirements.

The position reference suite included:

- Two taut wires
- Two acoustic systems (different manufacturers)
- Two DGPS with multiple differential update systems
- Provision for Fan Beam (to be used for this job)

The sensor suite includes:

- Three gyrocompasses

- Three Vertical Reference units
- Three wind sensors

Four UPSs powered the DP systems, position reference systems and sensors, with the distribution sensibly split across them for redundancy.

Four experienced DP operators were onboard to man the DP control position, plus the Captains who were also qualified DP Operators. Their daily shift pattern was 12 hours on 12 hours off. Two work back-to-back 6 a.m to 6 p.m.; and two work back-to-back 12 a.m. to 12 p.m. They overlap operators as each gets to come on shift with an operator who has already done 6 hours. Their hitch pattern was a six-week rotation with a crew change every three weeks.

The vessel owners were members of IMCA and as such operated the vessel in accordance with IMCA guidelines, which could be considered to be the best industry practice. This involves having a DP operations' manual, a full FMEA of the DP system, annual trials, mobilization trails, watch keeping checklists, DP logbooks etc.

Worse Case Failures

The worse case failure of the DP system leaves the vessel with one bow thruster and one stern azimuth thruster and the possibility of restarting another bow thruster on the remaining healthy switchboard. The operations of the vessel therefore have to be limited to being within the capability of this worse case failure condition. This represents 42 tonnes of environmental force from wind, wave drift and current. A consequence analysis feature would warn the operator if this was being exceeded.

The redundancy provided by the two engine rooms and switchboards was not totally 'fool proof', because they were effectively interconnected by the DP control system. So if one side fails then up to three thrusters are lost and the DP control system doubles the load on the remaining thrusters to compensate. This could result in a black out if the remaining side cannot take the sudden increase in load.

If a UPS was lost the vessel could lose the stbd taut wire, both acoustics and DGPS 1. The DP needs to be set up with this in mind; plus where the Fan Beam was powered would require careful consideration.

The main known weakness of the DP control system was that it weighted the position references automatically according to their variance (noisiness), the lower the variance the higher the weighting. Thus if a position was seemingly 'perfect' then the DP would follow that reference even if the others all disagree with it. A seemingly perfect reference could be achieved by a frozen DGPS signal, dragging an acoustic transponder, a broken taut wire etc. In fact two of the four DP incidents where caused by a supposedly perfect position reference. A vigilant operator, who ought to be well aware of this limitation of the system, ought to be aware of this potential problem and so avoid this or get out of the problem quickly.

FMEA and Annual Trials

The FMEA for the total DP System had been updated in 2002. The vessel has performed Annual Trials every year recently and was due to perform them for 2004 after dry- docking and before commencing work for BHP. This would be an opportunity to conduct other tests deemed necessary as a result of the risk analysis.

Review of FMEA and Annual Trials

The FMEA and the Annual Trials Report for 2003 were reviewed and there were no outstanding recommendations. They were used as a direct input for the risk mitigation suggested later and defining the worse case failure scenarios.

DP Incident History

Since 1999 when the vessel started to fully record incidents there had been four major DP incidents. In two of the incidents a taut wire failed in such a way that it appeared as a ‘perfect’ position reference to the DP control system. Another was a blackout caused by an engineer stopping one diesel to perform an oil check before starting up a replacement. In the fourth the weather got up and the operator had failed to take the thrusters out of bias mode so there was insufficient thrust available.

The blackout would not have occurred had the vessel been diving, as checking oil was not allowed during diving and in addition it was no longer necessary to stop an engine to check the oil as there was now a spyglass fitted.

The perfect position reference problem was well known to the operators and they monitor the weighting more carefully.

The bias mode problem was over come by a written operational procedure that the crew was familiar with.

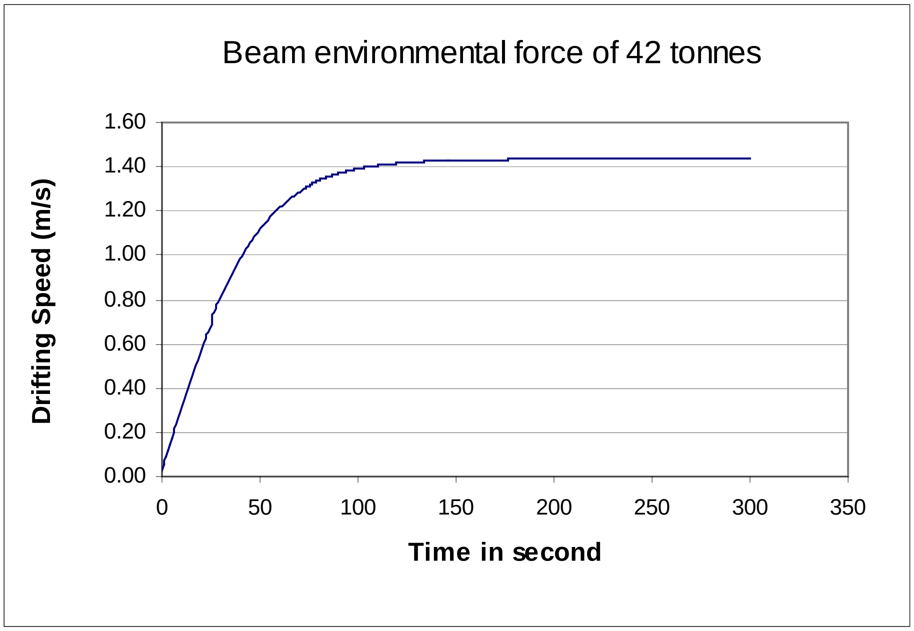
None of the incidents resulted in a collision and all were drift offs. The two perfect reference system failures could be designated as a primary cause of a computer or a position reference fault. The black out appears clearly to be an operator error. Not taking the system out of bias mode could be attributed to operator error, but could also be blamed on the computer as this could have been done automatically on rising demand. This split of reasons for incidents was reasonably in line with the IMCA incident reports, depending somewhat on how the cause was apportioned.

Over the five plus years since the vessel had logged 16,920 hours on DP. This was equivalent to nearly two years i.e. 40% of the available time. If all four incidents are included then this was a failure rate of one incident per 4230 hours or 5.79 months.

IMPACT ENERGIES

The maximum environment that the vessel can work in was dictated by the worse case failure, which was where this vessel was left with one bow thruster and one stern azimuth thruster. This represented a max environmental force on the vessel of 42 tonnes regardless of whether it was caused by wind, waves or current or any combination.

The drift curve for the 42 tonnes of environment using a 200 kN drag factor was as shown.



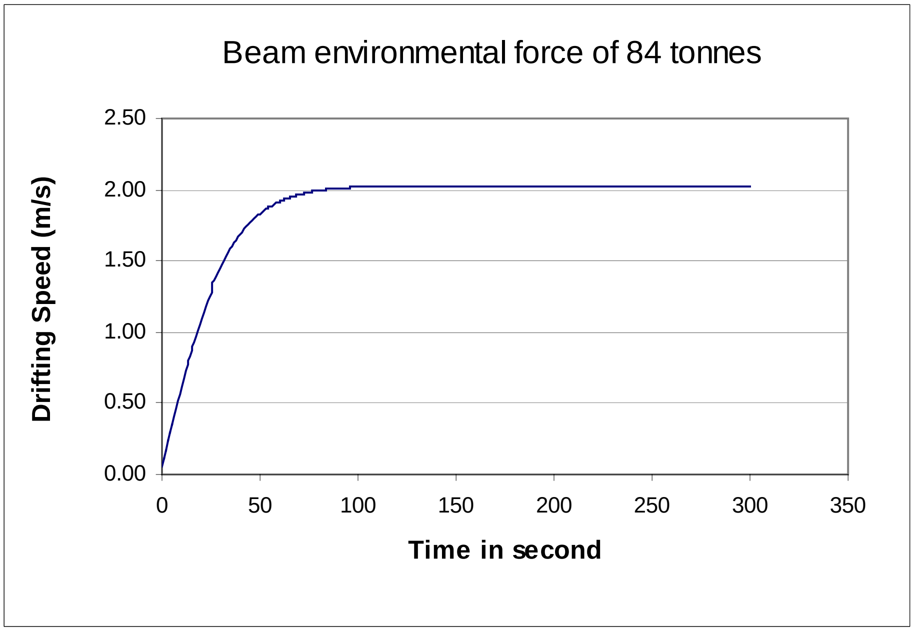
The vessel will be operating at up to 30 m from the platforms and as close as 10m, taking three points off the curve the impact velocities are

Distance from platform	Impact Velocity
10 m	0.73 m/s
20 m	0.96 m/s
30 m	1.1 m/s

Using the vessel's mass of 10,112 tonnes and an added mass in sway of 40%, the impact energies in joules were calculated using the formulae $E = 0.5mV^2$.

Distance from platform	Impact Energy
10 m	3.77 MJ
20 m	6.52 MJ
30 m	8.56 MJ

For the drive off situation it was be assumed that the vessel might drive off with twice the environmental force. The principle being that the vessel was approaching the limit of the environment and has a failure such that the vessel was driven of by the same amount of thrust towards the platform, i.e. another 42 tonnes and a total of 84 tonnes.



Again assuming the vessel operates between 10 to 30 m from the platforms, taking three points off the curve gave the following impact velocities.

Distance from platform	**Impact Velocity**
10 m	1.03 m/s
20 m	1.36 m/s
30 m	1.57 m/s

Using the vessel's mass as 10,112 tonnes and an added mass in sway of 40% the impact energies in joules can be calculated using the formulae $E = 0.5mV^2$.

Distance from platform	Impact Energy
10 m	7.51 MJ
20 m	13.09 MJ
30 m	17.45 MJ

The greater the distance from the platform, the greater the impact energy, but the longer there was for the operator to recover the situation. The time before impact for both drift off and drive off can be read off to be as follows:

Distance from platform	**Time before impact Drift Off**
10 m	26 sec
20 m	38 sec
30 m	48 sec

Distance from platform	Time before impact Drive Off
10 m	18.5 sec
20 m	27 sec
30 m	34 sec

Industry Standards and Considerations

API RP 2A and the HSE Guidance Notes have the same basic requirement for supply boat collisions:

0.5*a*m*v^2.

- 'a' is the coefficient of added mass which was 1.4 for sideways collision (according to both API and HSE)
- 'v' is the impact speed which depends on the maximum operating sea state for supply boat offloading (v=0.5*Hs). The North Sea has a harsh environment and HSE takes that as Hs=4m (and therefore v=2m/s). API gives v=0.5 m/s but states that this was for mild environments.
- 'm' is the supply boat mass. HSE recommends 5,000 tonnes as typical of North Sea boats. API recommends 1,000 tonnes as representative of 180-200 ft long boats used in the Gulf of Mexico.

API has the caveat that for deeper and more remote locations, the vessel mass and speed should be increased so there is a level of consistency between the two standards.

The resulting impact energy using HSE recommendation for side way collision was 0.5*1.4*5000*4=14MJ.

The resulting impact energy using API recommendations was for side way collision was 0.5*1.4*1000*0.25=0.175MJ

There are large difference between the recommended impact energy values and those calculated for the DP vessel earlier, but that was the nature of the problem as it is based on supply boats that operate in limited sea states.

The energy values above and those calculated for the DP vessel only represent the kinetic energy at the moment of impact and not the design impact criteria for the platform structure. This is because the motions of the drifting/rogue vessel and the platform will dissipate part of the kinetic energy. Another source of energy dissipation is the plastic strain of the vessel structure. It is only the remaining share that will have to be absorbed by the structure. According to the HSE Guidance Notes, a 14MJ kinetic energy would translate in no less than 4MJ of energy to be absorbed by the structure. If 4MJ was good for the platforms it should also be good for the jack-ups, which are more compliant and will have more significant motions. It is assumed that the structure can absorb the 4MJ with localized damage provided the remaining structural elements remain elastic and can resist environmental loads consistent with a repair period (usually a 1-year return period).

BHP offered the rule of thumb they had obtained from DNV that the absorbed impact energy would be 66% by the ship and 33% by the rig or platform. This was in line with the 14 to 4 ratio from HSE guidelines, which was 65% to 35%).

BHP also offered leg capacities of the two jack ups were given as 5 MJ and 14 MJ respectively. The following tables where provided by BHP to assess the potential for damage for the drift off and drive off situations:-

Impact Results for Drift Off

Distance from platform (M)	Reaction Time (S)	Energy (MJ)	Absorbed by jack up – 33% (MJ)	657 leg capacity (MJ)	Consequence Result	Monitor leg capacity (MJ)	Result
10	26	3.77	1.25	5	Minor	14	Minor
20	38	6.52	2.14	5	Moderate	14	Minor
30	48	8.56	2.85	5	Moderate	14	Minor

Impact Results for Drive Off

Distance from platform (M)	Reaction Time (S)	Energy (MJ)	Absorbed by jack up – 33% (MJ)	657 leg capacity (MJ)	Consequence Result	Monitor leg capacity (MJ)	Result
10	18.5	7.51	2.5	5	Moderate	14	Minor
20	27	13.09	4.29	5	Major	14	Moderate
30	34	17.45	5.81	5	Extreme	14	Moderate

The BHHP risk profile provided was as follows:

BHP Risk Profile

			Consequences				
		Factor	1	3	10	30	100
	Likelihood	Factor	Low	Minor	Moderate	Major	Extreme
< 1yr	Almost Certain	100	High 100	High 300	Extreme 1000	Extreme 3000	Extreme 10000
1 to 10 yrs	Likely	30	Moderate 30	High 90	High 300	Extreme 900	Extreme 3000
10 to 100 yrs	Possible	10	Low 10	Moderate 30	High 100	Extreme 300	Extreme 1000
100 to 1000	Unlikely	3	Low 3	Low 9	Moderate 30	High 90	Extreme 300
1000 to 10000	Rare	1	Low 1	Low 3	Moderate 10	High 30	High 100

The following risk profile table was the result of incident likely hoods, derived in section before in conjunction with BHP impact and risk profile tables. Based upon the limited exposure time (12 hrs) the risks associated with the operation are considered ALARP provided all the mitigation factors identified were implemented.

Likelihood	Jack Up 1	Jack Up 2
Possible (IMCA 93/ 10 days exposure – 58.9 years)	30 to 100	30 to 1000
Unlikely (IMCA 2001)	9 to 30	9 to 300
Rare (IMCA 93/ 12 hour exposure at worse heading)	3 to 10	3 to 100

VESSEL CAPABILITY

Beam Current The vessel had original capability plots produced by the DP control system supplier. These were the IMCA standard set for coincident wind, waves and 1.5 knot current. In Trinidad the wind situation was more likely to be fore aft on the vessel and the current on the beam. Additional plots for the beam current were therefore required to decide the maximum beam current capability of the vessel for the worse case failure. For expediency these new plots were produced by Global Maritime London, for all thrusters operational as well as for the worse case failure.

The plots show the vessel capability for various current speeds on the beam of the vessel (i.e. .at 90 degrees). The polar plots then shows the maximum wind speed the vessel can withstand for wind and waves at that incident angle for each current speed. For a worse case failure of a bow and stern azimuth thruster the vessel could withstand 2 to 2.5 knots of current on the beam with a wind of 20 knots on the bow or stern.

Current in the Area - A log of current profiles recorded from offshore Trinidad for 2003 was provided and reviewed. It was found that at only one time did the surface current reach 2 knots

(July 2nd) and on a few occasions it approached 2 knots around this date. It also reached 1.75 knots in November. Neither of these occasions could be correlated to high tides, and were therefore assumed to be either loop currents or the Orinoco River.

Capability Validation - In an attempt to validate the Global Maritime results a comparison was made with the original plots provided by the supplier. Comparing the vessels full beam capability with coincident wind waves and 1.5 knot current the original plots show a 40 knot wind capability whereas the GM shows a 20 knot capability. This was a wide discrepancy as the wind speed was a square law relationship the two sets are different by more like a factor of four. To resolve the differences a trial was conducted during the vessel's 2004 annual trials to attempt to give a practical measure of the beam current capability. The vessel was driven sideways with the DP control system's joystick using the aft bow thruster (thruster 3) and the starboard azimuth thruster. The joystick control was operated in high gain with and without the hold heading feature being selected. The vessel's speed was recorded every 15 seconds.

Using the maximum speed achieved for the port and stbd movements of 0.55 and 1.47 respectively. Taking the average to eliminate the effect of the weather gave 1.01 m/s.

1m/s = 1.93438 knots
Therefore 1.01m/s = 1.94 knots

As the thruster are around 70% - if they were at 100% this would represent an increase in 42.86%, which would represent on a square law an increase in speed of 19.52 % giving an estimated max speed for the worse case failure to 2.32 knots. This was in line with the predictions of the Global Maritime capability plots rather than the original DP supplier's plots.

The troubling result of the tests was that the thrusters did not achieve 100% in joystick. This was subsequently investigated and corrected so full power was available to the operator for the job.

THREATS AND RISK MITIGATION

As the vessel was class 3 there should be no known single failures that should cause the vessel to loss position. However there can still be a the possibility of a position loss due to:

- Unknown failure modes
- Operator error
- Systematic failures (all DP computers run the same software)
- Unexpected change in the weather
- Fast change in current

From the review of the FMEA, the analysis, attending the vessel, meeting in Trinidad and considering the threats above; the following were considered to be essential to mitigating the risk of this operation :

1. The DP was to be operated as class 3 with 660V and 480V switchboards, fuel and cooling systems separated, and the operational auxiliary pumps powered from the appropriate side of the switchboards.
2. Following a crew change personnel coming on 'hitch' would be given time to adjust to the shift pattern and the time zone shift before the job. Critical operations would be avoided, or additional assistance would be provided, in the interim.

3. The vessel should be operated such that if the 42 tonne limit was approached diving activities would be abandoned. This would be made part of the vessel's existing operating procedures and standing orders.
4. The worse heading situation of bolting the flanges at a restricted heading would be performed in the best possible weather conditions.
5. The Consequence Analysis function would be selected though out the operation and its validity tested during the Annual Trials.
6. The Fast Current Update feature would be selected though out the operation and its correct operation tested during the Annual Trials.
7. Accurate multiple weather forecast and loop current information would be provided on board.
8. Weather fronts would be diligently watched for on the radar.
9. Current measurements would be made regularly on board the vessel.
10. An independent direct measurement of the distance to the platform would be used as an input to the DP (e.g. Artemis or Fanbeam).
11. The survey system would be set up to show the platform and jack up outlines on the survey screen that the DP operator uses. This would be checked for accuracy using the Fanbeam system.
12. A 'toolbox' talk would be conducted with all the DP Operators regarding the limitations of the DP control system. In particular the 'perfect' position reference and thruster bias problems. This was a mature product and it would be expected that the potential for systematic failure could be considered rare. This and any other known problems could be discussed at the 'toolbox' talk.
13. The back up pumps, power supplies, UPSs batteries and DC supply batteries would be checked during the Annual Trials.
14. The design of the DP control system was dependent on a number of diodes that cut in back up supplies. These would be tested during trials.
15. All diesel generators would be tested to full load during annual trials.
16. All thrusters would be tested to full load during annual trials.
17. The beam current capability of the vessel with the worse case failure would be checked on trials by measuring the speed the vessel could achieve port/starboard. This required light weather condition and no current during the test.
18. Loss of a switchboard or engine room would be tested to ensure that the remaining diesels could take the sudden increase in load during annual trials.

CONCLUSIONS

The likely hood of a major loss of position was initially assessed as being 'likely' at every 6 months on DP. The likelihood of a platform impact for any vessel was initially assessed as being 'possible' at 7 DP years. However given the exposure time of around 10 days, the likelihood of a platform impact was reassessed as 'unlikely' at once every 58.9 years. For the worse situation where the vessel was totally restricted in heading, while the divers bolt the flanges together, the exposure time was low so the risk for this operation has been assessed as 'rare'. In addition, for this particular operation, the vessel would be able wait for the best weather and current conditions before attempting the work.

The analysis assessed the likelihood of an impact and the possible impact energy for vessel colliding with the BHP platforms offshore Trinidad C1, K1, and CPP, or the jack ups 657 and Monitor. This has been performed for both drift off and drive off conditions.

The analysis assessed, in broad terms, the consequences of such an impact or the design criteria to which the platforms, jack ups and vessel have been built. The weaker of the two jack up was the 657. The risk profiles were been derived and are given in this paper can be summarized in the following table.

Likelihood	Monitor	657
Possible (IMCA 93/ 10 days exposure – 58.9 years)	30 to 100	30 to 1000
Unlikely (IMCA 2001)	9 to 30	9to 300
Rare (IMCA 93/ 12 hour exposure at worse heading)	3 to 10	3 to 100

The thrust capability of the vessel was investigated for beam current conditions for the worse case DP failure and was expected to be able to maintain position with a beam current of 2 to 2.5 knots and a head or stern wind of 20 knots. A review of last year's logged current data for the work site indicated currents around 2 knots were only reached once in the year for a period of a few days.

The vessel was an older generation DP vessel but was well run and well maintained. The DP control system has some limitations and problems, but they were known and could be worked around.

The overall conclusion was that the risks associated with the Spool Piece installation were ALARP provided all the risk reduction measures identified were implemented prior to the start of the operation.