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DESIGN

“FMEA STUDIES – HOW DEEP SHOULD WE GO?”

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Abstract

Over the past dozen years the authors have found a wide variation in the standards used to achieve the mandatory standards for analysing failure modes and fault tolerance on DP vessels. While many companies and consultants claim to carry out failure mode and effect analyses, and the international standards make them mandatory for Class 2 and 3 DP operations, these standards do not set out how an FMEA should be carried out.

We believe any assurance that a vessel is immune to single point failure during DP operations can only be given after experienced surveyors have carried out a thorough and rigorous FMEA. Vessel owners and operators should satisfy themselves that an FMEA is structured with a robust methodology, uses worksheets to analyse all systems, sub-systems and their components, and reports on all potential failures and their consequences.

Any other form of survey or audit, whether carried out by independent surveyors or DP system manufacturers, cannot give the owner a guarantee that his vessel does not harbour hidden faults. Experience shows that such surveys can be valuable for testing or auditing a vessel in service, but only a full in-depth FMEA can ensure that all design and construction deficiencies are identified before they can lead to failures.

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1. Introduction

As described in another paper being presented here, the principal classification societies require either a Failure Modes and Effects Analysis or a detailed DP trials programme to be carried out before they will grant a dynamic positioning (DP) notation for a Class 2 or Class 3 DP vessel. Our experience has shown that the extent of any DP trials program, as part of the sea trials of a new vessel, is often very "grey" or, in some cases even, non-existent. Such a program may consist of a somewhat superficial review of the vessel systems to ensure redundancy and an implementation of the DP manufacturer's customer acceptance tests (CAT). It is rarely the detailed analysis and proof of fitness for purpose that should satisfy a concerned and prudent owner or ship operator.

Both the IMO and classification societies make it incumbent upon the owner to ensure the correct documentation and procedures are in place to obtain the required notation, while the level of documentation and the extent of trials procedures is very much left to the discretion of the responsible surveyor. Therefore it seems logical to us that the classification societies should work to common guidelines, similar to those which the IMO has issued for DP vessel systems and operations.

2. What is a Failure Modes and Effects Analysis (FMEA)?

The fundamental purpose of an FMEA is to give a description of the different failure modes of all the items of DP equipment in respect of their functional objectives. In this way, all catastrophic or critical failure possibilities can be identified, and either eliminated or minimised at an early stage in the project through design correction or the introduction of clear operational procedures.

A Failure Modes and Effects Analysis is a rather grand title and immediately tends to give the impression of an investigation of great detail and depth. However, this may not necessarily be so. System overviews can be performed in a matter of days or weeks, compared to a detailed analysis that may take many months, but at the end of the day both methods may be described as FMEAs and are assumed to have used equal diligence in reaching their respective conclusions. Anything other than a detailed FMEA should only be described and treated as a DP system overview or a DP audit.

To be effective an FMEA should follow national legislation and an industry standard such as MIL-STD 1629A of the United States Department of Defence. It should also make use of all current DP related guidelines that can assist in improving the redundancy and operability of a DP vessel. These include the IMO "Guidelines for Vessels with Dynamic Positioning Systems" (issued as MSC Circular 645) and the IMCA (previously the DPVOA) "Guidelines for the Design and Operation of Dynamically Positioned Vessels" (issued January 1995 and currently in revision).

3. What is the alternative to an FMEA?

By comparison with an FMEA, a DP system overview will typically be based upon the vessel's electrical and mechanical single line diagrams, using these higher level drawings to define redundancy and hence DP Class notation. No formal worksheets are used to confirm the systems and depth covered.

A common method used by shipyards to establish and define DP class notation will review the vessel's single line system diagrams, carry out the DP manufacturer's control system CAT and then issue a notation based on the combined results of the redundancy findings and the operational practices.

This degree of analysis is similar to that which would be carried out as a DP audit on a vessel prior to its short-term charter to a client, where there is insufficient time to conduct a full FMEA. It would involve a brief review of the ship's mechanical, electrical and control systems drawings (the latter including the DP system). This should highlight any obvious and basic weaknesses in the vessel's systems, such as a common electrical supply to DP systems or a lack of redundancy in the ship's auxiliary systems. It is likely to suit the shipyards, reduce the time spent on expensive sea trials and at the end of the day may give an owner the class notation he requires. But it certainly does not prove the redundancy of the vessel systems, and their interfaces at the deeper level, and does him no favours in the long term.

4. What Does an FMEA Consist Of?

Normally, the DP manufacturer will carry out an FMEA of his own control equipment and the signals to and from the thrusters, sensors and operator consoles. However, this is only one part of the DP control system and failure effects on all aspects and components of the DP computer equipment, component interfaces and power supplies are necessary. In our extensive experience, stretching back over nearly 20 years, it is the least expected items of equipment or system components which inevitably compromise the overall system reliability.

An FMEA does not address Mean Time Between Failures (MBTF). The assumption for any vessel equipment item is that if it can fail it will fail, and what are the implications of that? Where redundancy is not an integral part of the design it will be necessary to perform a Failure Modes and Criticality Analysis (FMCA) on the system, so that worst case scenarios can be developed and the consequences assessed.

The only correct way to analyse a DP vessel is to review all the mechanical, electrical and control system drawings for a vessel and to record the operation and failure modes on "FMEA Worksheets". The dynamic positioning system and all the vessel systems relevant to DP operations are essentially broken down into functional blocks and the main systems and their subsystems are investigated individually. The breakdown is performed to such a level of detail that all the system modules and their interfaces can be determined.

By carrying out a detailed and formal FMEA, the resulting document (as described in the paper by Tom Stockton and Roger Cornes) can be used as the basis for producing a worthy DP proving trials document. The alternatives cannot give the same end result as a thorough FMEA and its accompanying proving trials checklist.

5. Which Vessel Systems Should an FMEA Address?

The term "DP system" can be used to describe the vessel systems as a whole but, more correctly, it normally means the DP computers, consoles and sensors. In between these two extreme definitions there are a range of others, which often include the thrusters and may include the power generation system. As a consequence, the demand for a DP system FMEA does not by itself specify the scope and detail of the study.

In our view, the FMEA should be carried out for the vessel as a whole, allowing the study and analysis to take account of all potential services, interfaces and cross-connections which might affect the integrity of DP operations. For a drilling vessel, a brief assessment of the layout and major ship systems will show which areas and components are likely to have an impact on the DP system. Pipe handling, mud pumping and other systems have only the most tenuous connection to the machinery systems, although there may be electrical power aspects that need to be addressed and, at best, eliminated from the inquiry.

Those systems that form part of the conventional ship, such as cooling water, fuel, compressed air, electrical distribution and instrumentation, should be studied in-depth to ensure that all potential failure modes are identified, analysed and assessed. In the following examples, we will look at some machinery and electrical systems that help to illustrate the reasons why we believe an in-depth study is required.

6. Which Machinery Systems Are Likely to Cause Critical Failures?

The design and layout of a DP vessel's machinery systems are critical to both Class 2 and Class 3 operations. It is essential that, in Class 2 and Class 3 DP vessels, the loss of any mechanical system cannot give rise to a situation which exceeds the worst case failure scenario. This is normally accepted as being the loss of one switchboard section, the loss of all the generators associated with a switchboard section, or the loss of one engine room. If a vessel is operating on DP within its worst case failure capability, then any failure will not cause that vessel to lose position.

The mechanical systems, their functions and the consequences of some of their various failure modes are discussed below.

Compressed Air

Compressed air is used not only to start the generator engines, but also, at a reduced pressure to provide the control air for operating various associated engine room equipment and control systems. These might include control valve actuators, fuel trip valves, HVAC dampers, engine governor controls and overspeed trip protection devices.

Depending on the equipment and control system design the consequences of losing the vessel's compressed air or control air systems can be non-existent, negligible or catastrophic. Loss of starting air will not affect the on-line generator engines unless there are controls or safety systems that derive their air supply from the starting air supply via a reducer. If this is the case, and if there is only one starting air main distribution pipe, all the engines could stop. A number of alternative system changes can be made in order to provide some redundancy in the engine control air system. For example, it is possible to supply control air from an instrument air system, using the engine starting air via reducer as a backup. Alternatively, a crossover can be provided from the general service air system, fitted with suitable filters and air dryers.

Fuel valve trips and HVAC dampers normally require air pressure to close them, so that a loss of control air will not give rise to inadvertent shutdowns: accumulators are provided to store air for use in an emergency should the main supply be lost. However, certain systems can require air pressure to hold them open and it is necessary to ensure that loss of air supply does not result in a propulsion system failure.

Where control valves have pneumatic actuators, loss of control air will result in one of three failure modes – fail in its present position, fail to close or fail to open. The consequences and criticality of that failure will depend on the system design and parameters. For example, a cooling water system temperature control valve that fails fixed or full open (maximum cooling effect) is unlikely to cause any immediate problems. Similarly, a temperature control valve that fails closed (i.e. full recirculation) may not have any immediate effect on a system that has sufficient capacity. However, if the engines have only small cooling water header tanks, overheating may occur rapidly and result in engine shutdowns.

Therefore, when reviewing the design of control air systems, backup systems should be considered wherever possible. The failure modes of temperature control valve actuators should be assessed and alarms provided to give early warning of potential faults. Robust system design can minimise the consequences, and hence the criticality, of any failures.

Fuel Oil

Maintaining a constant fuel supply to the generator engines (and to the main propulsion engines where these are an integral part of the DP system) is critical. Any loss of fuel supply (including contamination) should be limited to the equivalent of the worst case failure mode, i.e. to the loss of a switchboard section.

To meet the engine room segregation requirements, Class 3 vessels require two fuel service tanks; however, this is not the case for Class 2 vessels. The implications of the loss of fuel supply on a vessel fitted with only one fuel service tank are serious, as it will shut all the engines down. The loss of fuel could be caused by contamination (including water), by spurious operation of the fuel service tank trip or system valves, or by human error.

To ensure maximum redundancy in the fuel supply system, the engine sets should be divided equally into two groups and each group supplied from its own tank. A normally closed crossover line should be installed to allow both groups of engines to be supplied from one tank, in the event of the other fuel tank becoming contaminated.

Although the loss of a group of engines due to contaminated fuel can be accepted, as long as the vessel is working within the capability of worst case failure, the situation should be avoided if possible. On a drilling vessel the consequences may include a reduction in power to drilling services whilst other generators come on-line. There could be insufficient electrical power for drilling if there is one engine down for service and all the remaining electrical power is required by the thrusters to maintain position. Therefore, consideration should be given to installing water detectors and coalescing filters in the fuel lines to each group of engines, as prevention against failure.

Some diesel engines require the fuel pressure to be boosted at the rail and this may be done by an engine driven pump plus an electrically driven standby pump; or even by two electrically driven fuel pumps. Some types of engine will continue to operate even in the event of a fuel pump failure, although the engines may not be able to deliver full power under these conditions. It is therefore imperative that the engine characteristics are tested during the FMEA proving trials to assess the consequences of such a fault. It is also important that electric fuel booster pumps are either supplied from the same side of the switchboard as that which the generators supply or, if two electrically driven booster pumps supply one main engine, that they are supplied from separate switchboards.

Where a DP vessel has twin main engines and uses high lift rudders to provide the aft transverse thrust, it is important to have both engines operational at all times. Should one fail, the other engine will be asked by the DP computers to increase its output to maintain the transverse thrust, and this can often cause the vessel to drive ahead and thereby lose its longitudinal position.

Lubricating Oil

The main lube oil systems associated with a vessel's DP system are those for the diesel generator engines, diesel driven thruster or main propulsion engines and thruster units.

Because centralised lube oil systems are rare, the consequences of failure of a lube oil system are normally restricted to a single item of equipment. This should have no impact on the DP capability of vessel if it is working within its worst case failure limits, unless the vessel happens to be a shuttle tanker with a single main engine.

Thrusters may have a single lube oil pump and lube oil filter which, if the pump fails or the filter becomes blocked in service, will result in a thruster shut down. This should not compromise the vessel's position, but will reduce its DP capability. The installation of two lube oil pumps and a duplex filter will increase the thruster's availability and decrease the likelihood of downtime.

Electrical supplies for lube oil pumps should be separated and connected such that a single fault on the electrical distribution system will not trip all the lube oil pumps. In addition, the pumps should be connected directly to the switchboard sections of the equipment they support. They should not be cross-connected so that loss of a switchboard section would shutdown the pumps on the opposite side, as this could cause all thrusters to be shut down.

The lube oil purification system should be reviewed to ensure that any problems or failures have a minimum effect on the engines or thrusters. There are vessels with engines that share a common lube oil sump and, in such cases, care must be taken to ensure that any loss of sump oil is quickly identified, with low level and purifier seal failure alarms to give warning before engine shutdowns occur.

Hydraulic Oil

From the point of view of DP, hydraulic control systems are used principally for pitch and azimuth control of thrusters: but they are also used for ballast valve actuator systems, watertight door operation and, in some cases, seawater valve actuators in the engine room or pontoons.

It is essential that any electrical failure in thruster hydraulic systems is limited to the worst case failure situation, so that at least 50% of the thrusters remain on-line to maintain the vessel's position. As with the lube oil systems associated with thruster units, correct segregation of electrical supplies to hydraulic pumps must be applied. Although a Class 2 vessel will still maintain position on the loss of a single thruster unit caused by a hydraulic system failure, the availability of each thruster will be increased by installing two hydraulic pumps and a duplex filter unit.

HVAC

A review of the heating, ventilation and air conditioning system is important, not only from the ventilation viewpoint but also from the aspect of fire protection. Electrical and electronic control components require good ventilation and, in the case of electronic equipment, need adequate climate control. It is therefore essential that any equipment that is temperature sensitive be sited in an air-conditioned space. The implications of the failure of air conditioning for spaces that contain sensitive control equipment, such as SCR rooms, switchboard rooms, DP computer rooms, etc., should be reviewed and, where necessary, backup air conditioning units should be fitted.

Fire integrity of machinery, electrical and control spaces is a requirement for Class 3 vessels, but should also be reviewed in a Class 2 vessel. SOLAS requirements must be applied to to ensure the correct fire rating is applied for division bulkheads and to minimise the risk of fire spreading through and into compartments that contain essential DP equipment. Consideration should be given to the routing of ventilation trunking and to the installation of fire dampers in order to reduce the length of the fire path.

Sea Water Cooling

Seawater is the principal cooling medium used on board ships, either directly or indirectly via a fresh water cooling system. Class 3 requires duplication and segregation of the sea water cooling systems, while Class 2 only requires duplication of the active parts of the system i.e. generators and thrusters. A ring main type system will meet the Class 2 requirements, but a pipe section or isolating valve failure may well require a shutdown of the complete cooling water system.

Therefore, if practical operating and normal maintenance criteria are taken into account, a more flexible system should be considered. This could include installing isolating valves in a ring main system, to divide it in half, and installing the sea water cooling pumps so that either side of the system can be supplied to retain 50% of the power generation, thrusters and auxiliary services. Electrical supplies to the sea water cooling pumps should be taken from separate sides of the switchboard sections, to ensure that at least pump is operational in the event of a switchboard section failure.

Ideally, two independent cooling water systems should be installed to backup the redundancy requirements with regard to generators and thrusters. There should be a crossover between the two systems and, although two cooling water pumps should be installed in each system, it is possible to “economise” and install a single standby pump with crossover to either system. In the latter case, sufficient capacity should be designed into the fresh water cooling system to maintain system cooling whilst a changeover is being effected.

Although the cooling systems may have a stand-alone standby pump or pumps, it is also worth considering other backup options, such as a ballast pump or a fire and GS pump. One of these could be used as a duty pump in the event that one of the normal pumps is out of service for maintenance reasons.

Fresh Water Cooling

As with sea water cooling systems, separate fresh water cooling systems are only necessary for Class 3 DP vessels. Fresh water systems are sometimes centralised, so that all main and auxiliary equipment is cooled by one or two systems. Power supplies to the pump motors should be segregated and connected so that a switchboard section failure will not compromise the worst case failure capability.

Diesel engines, in particular, frequently have entirely self contained cooling systems, and any failure should be limited to a single machine and not compromise the station keeping of the vessel. Availability of each engine can be improved by installing an electric standby pump as back up to the engine driven fresh water circulating pump.

There is no legislative requirement for redundancy in static systems if they are adequately protected and of proven reliability. However, even with two cooling water pumps, consideration should be given to carrying out maintenance on piping and valves, which might require shutting down the system if only a single piping system were installed. Designing a fresh water cooling system in a similar way to the sea water cooling system, with dual systems, isolating valves and additional pumping arrangements, will enhance the overall flexibility and availability of the system.

FMEA proving trials should be carried out to establish the plant response to a loss of cooling water pressure, so that the period of time is known before overheating of engines or thrusters occurs.

Flooding

Flooding of a compartment containing DP system equipment has to be considered for a Class 3 DP vessel, but not Class 2. Review of the vessel's watertight compartments layout should ensure that positioning will not be effected should any space become flooded and DP related equipment put out of service, e.g. electrical distribution boxes, power, or control cabling.

Fire Fighting

Fire protection to SOLAS and Class 3 requirements will be applied as necessary to the compartments. However, consideration should be given to the installation of fixed fire fighting systems outside SOLAS requirements (in spaces containing engines over 750KW and those with boiler plant) so as to protect the high value assets of DP related equipment. This could be extended to switchboard rooms, SCR rooms, etc.

7. Which Electrical Systems Are Likely to Cause Critical Failures?

When analysing all the high, medium and low voltage electrical systems, including the uninterruptible power supplies (UPS), it is essential for Class 2 and Class 3 DP vessels that a failure of any of the electrical distribution systems will be limited to a worst case failure situation. In such an eventuality this will allow the vessel to remain on station, provided it is working within the worst case failure DP capability.

Thorough analysis of both LV and UPS systems is critical as they normally provide power and backup power supplies to main control systems, power management, governor controls, ICS, etc. It is essential that these systems are fully redundant to meet DP class requirements and, where necessary, additional backup supplies should be provided. Electronic governors may require individual internal battery backup to maintain their operation in the event of a failure of the main power supply.

Distribution

For both Class 2 and Class 3 DP vessels, redundancy is required in the electrical switchboards and distribution boards at all voltage levels. High voltage for propulsion motors, medium voltage for auxiliary machinery and switchboard controls, low voltage for control systems and equipment, engine and governor controls. UPS systems are usually provided for the DP control system, the integrated control system, the power management systems and the engine and governor controls.

Separation of cable routes is mandatory for Class 3 vessels. We believe this requirement should also be considered for Class 2 vessels, at least in critical areas such as the engine room, as an alternative to providing protection for cable runs. Separation between power and control cables, although not a requirement in itself for Class 2 vessels, should be reviewed as a possible prevention of induced interference in adjacent control signal cabling. Where protection of cable runs is required, special attention should be paid where cables have to run close to potential direct hazards, e.g. diesel engines, purifier rooms, boiler rooms, HV and MV switchboards, or where cables could run directly over the top of the top of this equipment.

Particular attention should be paid to MV distribution systems to deck equipment which is not normally part of the ships fixed electrical installation, e.g. ROV spreads, sub-sea trenching equipment, sub-sea pipe spooling equipment, etc. Isolating transformers should be installed and breaker capacities rated correctly to prevent the possibility of a short circuit in any of the temporary deck equipment being transferred back to the vessels MV system, as this could cause loss of power to the essential DP systems and equipment.

Switchboards

As stated in the mechanical section, it is essential that electrical supplies in systems are connected in such a way that, should a fault occur on a single switchboard section or distribution system, the fault is contained and not transferred to another section.

An electrical discrimination exercise must be carried out as part of the FMEA study to ensure that any short circuit faults are confined to that level and not allowed to transfer to other circuits within the system, as this could lead to a DP system failure.

On some vessels the emergency switchboard feedback (to the main switchboard) is essential for continued DP operation of the vessel in the event of a main switchboard section failure. The correct connections must be made between the main and emergency switchboards to ensure that all the equipment and systems can be supported in the worst case failure scenario.

Protection of the main switchboards and generators against electrical faults is most important. Protection devices should be installed to protect against under-voltage, under-frequency, phase-to-phase short circuits, earth faults, and both under- and over-excitation.

Where MV power is required for operation of HV circuit breakers, separate supplies must be provided for each switchboard section. For backup purposes, cross connection of either of the supplies to both sections of the switchboard could be facilitated by means of a transfer switch: however, the switching arrangement must be analysed to ensure a possible failure does not cause a loss of power to both sides of the switchboard.

The separation requirements for switchboards in Class 3 vessels is clearly defined, but the implications on a Class 2 vessel should be reviewed with respect to the possible outcome of a short circuit and resultant electrical fire in a switchboard section. Although the tiebreaker will protect the healthy section electrically, the physical construction may allow the fire to migrate and lead to a total switchboard failure.

Physical separation of switchboards and transformers should be considered for HV and MV systems but, where this is not possible, construction of the equipment and layout of the spaces should be such as to minimise the effects of a fire. In addition, consideration should be given to the installation of a fixed fire fighting system, over and above the SOLAS requirements.

Loss of power to an UPS system or a transformer/rectifier system supporting a battery backup system will result in that system failing when the battery becomes exhausted. It is essential that a fuse failure alarm is installed in the supply circuit to warn the operator of such a system fault.

8. Which Instrumentation and Control Systems Are Likely to Cause Critical Failures?

In many respects the control systems on a DP vessel are less likely to produce unexpected failure mode surprises than either the machinery or electrical systems. This is mainly because the major sub-systems (the DP system, the integrated control system and the alarm and monitoring system) are normally designed and manufactured specifically for the purpose. However, as with any system, nothing should be taken for granted by the surveyors. Control systems, by their nature, act as the interfaces between all the other vessel systems and this means that they require a great deal of analysis, particularly of the interfaces between them and with the mechanical and electrical systems.

Some of the instrumentation and control system failure modes are described in the sections above, as they are often an integral part of the machinery systems. The following comments relate to the more specialised instrumentation systems.

DP Control

The DP system is normally subject to its own FMEA but, because of commercial confidentiality and the inherent complexity of design, the manufacturer almost always carries this out. However, because this system is also a standard and many similar or identical systems are installed on other vessels, the DP vessel owner can be fairly confident in the robustness of both the hardware and software designs.

Potential weaknesses leading to failure modes are likely to be found in the power supply arrangements or in the specific configuration of sensor inputs or feedback connections. Particular areas that can hide faults are the gyro and environmental sensors, and the thruster command and response connections. It is also worth remembering that most DP system designers are specialists who have no detailed knowledge of the actual vessel in which their system will be installed, nor of the specific operations it will undertake. What may seem a sensible assumption to them, perhaps relating to the location for a DP computer cabinet or to the sequence of operations carried out by the crew, may not actually be carried out in that way on the ship. The FMEA must look at these aspects in order to identify failure consequences.

Vessel Integrated Control Systems

Both ICS and centralised alarm and monitoring systems have interfaces with many vessel systems and components. In themselves they are unlikely to give rise to single point failures of dynamic positioning, but a failure of part of such a system could result in hidden faults; so that, when another fault occurs either warning signals or backup systems are not available.

Such systems are normally designed into a vessel at the outset, in which case they should be robust and provided with self-monitoring alarms. However, there are occasions where they are added on as an apparent afterthought, or “bolted on” during the conversion of an existing vessel. In these cases the design and installation needs to be analysed carefully to identify failure modes and effects.

Fire Detection

The vessel’s fire detection system should be reviewed to ensure that the correct detectors are installed in the appropriate compartments and spaces. Smoke detectors should be fitted in switchboard rooms, as these are more likely to detect the onset of a fire than a flame or a rate of rise detector. The position of detector heads should be checked, to ensure that air movements from the ventilation system do not adversely affect them.

9. What Does a Formal FMEA Cost the DP Vessel Owner?

International legislation requires DP systems to meet its class requirements, and the DP vessel's owner is consequently obliged by the classification society to provide an FMEA of his vessel in order to obtain Class 2 and 3 notation (as an alternative to the shipyard trials document). However, the Owner should look upon this, not as an imposition and extra cost which he could well do without, but as an opportunity to confirm his vessel's redundancy characteristics, thereby increasing the vessel's performance and its availability to work. In other words, a relatively minor investment at the early design and construction (or conversion) stages of a project will bring considerable benefits in increased workability and reduced downtime.

We have carried out many FMEAs in which we have identified potential failure modes that could have caused significant downtime or, worse, loss of critical position if the FMEA had not been carried out. As a result of carrying out an FMEA on a cable ship, fitted with a simplex (single) DP computer, we identified a problem with the power supply changeover relay that would have prevented a changeover from the computer to the joystick in the event of a computer failure.

Sometimes we have been asked to conduct the FMEA as a result of a failure in service. In one case a single high voltage switchboard, which should ideally have been split by means of bus-tie breaker, suffered from a short circuit that blacked out the vessel and caused a loss of station.

In another DP incident investigation we found that a diving support vessel had struck a gas platform when one of the stern azimuth thrusters suddenly went to maximum pitch. It subsequently transpired that a soldered joint on the thruster feedback potentiometer had broken, sending a false signal to the computer, which ordered maximum pitch. This incident occurred before the IMO guidelines came into force; however, at that time, we would have requested that such a potential single point failure be addressed by the vessel's owner in consultation with the thruster manufacturer. If this approach did not solve the problem then appropriate procedures would have been developed to cover the eventuality.

During the current year we have carried out trials on a DP vessel which turned out to have failure modes in the main propeller feedback that would cause vessel drive-off and in the bow thruster feedback that would cause the vessel's heading to become unstable. In addition, and as a result of carrying out a DP proving trial directed at uncovering switchboard failures, it materialised that all the bow thrusters could be lost together (with consequent loss of vessel position) because the emergency switchboard connection was on the wrong side of the main switchboard.

The above failures are dangerous for any untethered vessels and safety of personnel is always of the utmost importance, but for drilling vessels and shuttle tankers the economic consequences could also be dire.

These incidents demonstrate that a detailed FMEA and subsequent DP proving trials would have eliminated the above failures. The additional cost of carrying out a detailed FMEA is small, particularly when compared with the loss of a single day's hire, and for DP drilling the loss of mud alone could come to half a million dollars.

10. Conclusion

The best and most structured way, and we believe the only way, to meet these requirements is to carry out a formal and in depth FMEA. This paper started off with the title asking how deep this study should be? We hope that the arguments presented above, and the selected examples of the varied nature of failure modes on DP vessels, have been able to show that the question can only be answered by allowing the FMEA study to pursue its investigations as far as the analysis requires. Putting artificial limits on the extent of the study, either in availability of detailed drawings or in preventing specific FMEA trials, will meet neither the spirit nor the intent of the guidelines.

Of course, this should not and cannot justify a blank cheque for the FMEA auditor and it would be in nobody's long-term interest if it did. We contend that the use of a clearly defined methodology for carrying out the FMEA will allow the required in-depth study to be attained without the uncertainty and indiscipline that a less structured approach would bring. One of the major limitations imposed, particularly with vessel conversions, is time: and conversions, by their very nature, often involve continuous design changes and delays in producing final drawings. When everyone is up against a tight delivery deadline (in terms of both schedule and cost) there can often be major resistance from both project team members and contractors to the challenges and questions resulting from an FMEA study.

Obviously, the earlier in the project schedule that the FMEA requirements are known, the easier it is to ensure that they are met. If the high level design issues can be known and analysed during the early stages, then the more detailed and in-depth analysis can be programmed and achieved before time constraints intervene. Commissioning and delivery pressures are not the right environment under which to argue the scope of work of the FMEA. After all, at the end of each day the vessel's owner, operator and charterer all want to be able to sleep peacefully in the assurance that all exposure to risk of DP failure has been minimised as far as is reasonably practicable.