



TECHNICAL AND OPERATIONAL GUIDANCE (TECHOP)

TECHOP (D-02 - Rev1 - Jan21)

FMEA TESTING

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1 INTRODUCTION

1.1 PREAMBLE

1.1.1 The guidance documents on DP (Design and Operations and People) were published by the MTS DP Technical Committee in 2011, 2010 and 2012, respectively. Subsequent engagement has occurred with:

- Classification Societies (DNV, ABS)
- United States Coast Guard (USCG)
- Marine Safety Forum (MSF)
- Oil Companies International Marine Forum (OCIMF)

1.1.2 Feedback has also been received through the comments section provided in the MTS DP Technical Committee Web Site.

1.1.3 It became apparent that a mechanism needed to be developed and implemented to address the following in a pragmatic manner.

- Feedback provided by the various stakeholders.
- Additional information and guidance that the MTS DP Technical Committee wished to provide and a means to facilitate revisions to the documents and communication of the same to the various stakeholders.

1.1.4 The use of Technical and Operations Guidance Notes (TECHOP) was deemed to be a suitable vehicle to address the above. These TECHOP Notes will be in the following categories:

- General TECHOP (G)
- Design TECHOP (D)
- Operations TECHOP (O)
- People TECHOP (P)

1.2 TECHOP NAMING CONVENTION

1.2.1 The naming convention, TECHOP (CATEGORY (G / D / O / P) – Seq. No. – Rev.No. – MonthYear) TITLE will be used to identify TECHOPs as shown in the examples below:

Examples:

- TECHOP (D-01 - Rev1 - Jan21) Addressing C³EI² to Eliminate Single Point Failures
- TECHOP (G-02 - Rev1 - Jan21) Power Plant Common Cause Failures
- TECHOP (O-01 - Rev1 - Jan21) DP Operations Manual

Note: Each Category will have its own sequential number series.

1.3 MTS DP GUIDANCE REVISION METHODOLOGY

1.3.1 TECHOPs as described above will be published as relevant and appropriate. These TECHOP will be written in a manner that will facilitate them to be used as standalone documents.

1.3.2 Subsequent revisions of the MTS Guidance documents will review the published TECHOPs and incorporate as appropriate .

1.3.3 Communications with stakeholders will be established as appropriate to ensure that they are notified of intended revisions. Stakeholders will be provided with the opportunity to participate in the review process and invited to be part of the review team as appropriate.

2 SCOPE AND IMPACT OF THIS TECHOP

2.1 SCOPE

2.1.1 This TECHOP addresses DP FMEA proving trials and important tests which should be carried out to validate certain types of DP Class 2 and DP Class 3 redundancy concept.

2.1.2 This revision includes a DP FMEA proving trials gap analysis template that can be used to gauge the scope of a DP FMEA proving trials program in relation to the class of vessel (DP Class 2 or 3) and the power plant configuration (busties open or busties closed).

2.2 IMPACT ON PUBLISHED GUIDANCE

2.2.1 This TECHOP impacts MTS DP Vessel Design Philosophy Guidelines, Part I Section 22 & Part II Sections 22.5 & 22.6.

3 CASE FOR ACTION

3.1 HISTORY OF DP INCIDENTS RELATED TO POWER PLANT FAILURES

- 3.1.1 There is a long history of blackouts and other DP incidents associated with a small group of failure modes which are capable of defeating the redundancy concept of a diesel electric power plant operated as a common power system (closed busties). Traditional protection schemes for diesel electric power plant do not address these failure modes effectively but solutions are now widely available and should be incorporated in the power plant design.
- 3.1.2 Some of these failure modes can also lead to failure effects exceeding worst case failure design intent in DP class 3 vessels operating with two or more independent power systems (busties open). This problem can occur because non DP related consumers located in a common space are powered from switchboards intended to be redundant. The act of collocating consumers makes all power systems feeding that space vulnerable to severe voltage dips associated with the effect of clearing faults in the fire or flood damaged compartment. Such voltage dips can cause thruster and auxiliary system malfunction.
- 3.1.3 This TECHOP addresses the need for DP FMEA proving trials to include certain important tests to prove the fault tolerance of diesel electrical power plants and their control systems. Some tests apply to any DP Class 2 or DP Class 3 designs and others apply only when the power plant is operated as a common power system (closed busties).

3.2 RECOMMENDED ACTION

- 3.2.1 Those preparing DP FMEA proving trials for DP Class 2 and DP Class 3 vessels should review the guidance in this TECHOP and ensure that these tests are included in the DP FMEA proving trials where required.
- 3.2.2 Those reviewing DP FMEA proving trials may wish to use the DP FMEA proving trials gap analysis tool to identify any deficiencies in the trials program in Appendix B. It may be used in combination with the DP FMEA gap analysis tool to identify whether additional analysis and tests are required.

4 SUGGESTED IMPLEMENTATION METHODOLOGY

4.1 INTRODUCTION

4.1.1 The purpose of this TECHOP is to help ensure:

- The competent execution of FMEA proving trials for newbuild DP Class 2 and DP Class 3 vessels and major conversions – (Not retrospective).
- The best possible outcome in terms of verification of DP redundancy.
- Classification society approval is achieved with the minimum of delay or need for further testing to close out concerns.
- The FMEA and proving trials results meet all current industry expectations to reduce the need for additional verification activities before the vessel enters service.
- In the case of vessels already in service, the need for effective barriers to mitigate risk arising from analysis and testing that has been omitted is identified.

4.1.2 **Application:** This TECHOP is applicable to the DP notations of any Classification Society. Some parts are only applicable to vessels intending to operate their diesel electric power plant as a 'closed bus' power system. The guidance is not intended to be exhaustive rather it is focused on a few areas which routinely cause problems in the competent execution of DP FMEA proving trials.

4.1.3 **Distribution:** Stakeholders are encouraged to distribute this TECHOP to any and all parties who may benefit from the information. In particular, management and technical representatives for shipyards and DP equipment vendors for power systems, control system, engines and thrusters. This guidance should be included in contracts and specifications for the vessels and brought to the attention of designers and equipment manufactures as soon as it is practical to do so following project initiation.

4.1.4 **Background:** DP FMEA proving trials are intended to establish the level of redundancy and fault tolerance provided by the DP system and confirm the analysis in the FMEA. The DP system (all systems required to maintain position and heading) of DP class 2 and DP class 3 vessels must be single fault tolerant in respect of defined failure criteria which varies slightly from one classification society to another. A large number of tests and failure simulations are carried out at trials to prove that equipment and systems intended to provide redundancy have the necessary performance, protective functions and monitoring systems to ensure the integrity of the DP redundancy concept.

4.1.5 There are a small number of tests which require more preparation than others and shipyards and equipment manufacturers are encouraged to participate in the preparation of the methods for these tests to ensure they are carried out safely, efficiently and effectively.

4.1.6 The reasons that some tests can be problematic are as follows:

- The shipyard or equipment manufacturer is not able to carry out the test due to lack of knowledge, preparation or specialist test equipment.
- The equipment manufacturer refuses to carry out the tests on the grounds of concerns related to potential equipment damage.

4.2 THE NEED FOR TESTING

4.2.1 Testing is a vital part of any process intended to ensure the integrity of a fault tolerant system based on redundancy. There are three key elements in any fault tolerant system based on redundancies which are Performance, Protection and Detection. For a system to be considered fault tolerant in respect of its defined failure criteria, all DP related equipment must be capable of its nominal performance which includes dynamic attributes such as response time and accuracy not just steady state capacity. All protective functions designed to isolate faults and prevent them propagating from one redundant system to the other, must work effectively on demand. Protection may include automatic functions and procedural barriers, particularly in relation to internal and external common cause failures. Detection provides the means to identify when the system is no longer fully fault tolerant and that operations should be terminated. Detection may include alarms and monitoring but also periodic maintenance and testing such as annual trials. Establishing the need to test DP systems raised the following issues:

- What to test?
- When to test it?
- Where to test it?
- Why should it be tested?
- How should it be tested?

4.2.2 These questions are answered in the sections that follow.

4.3 WHAT TO TEST?

4.3.1 This is superficially the easiest question to answer. From a goal setting perspective, the intention is to test every system upon which station keeping integrity depends such that the requirement to prove performance, protection and detection is satisfied. In practice, it takes a very detailed examination of every system to identify where these attributes are important. This function is part of the DP FMEA process and requires the cooperation of the system manufacturers.

4.4 WHEN TO TEST IT?

4.4.1 This is potentially the most difficult question to answer. Lack of performance, hidden failure of protective functions and hidden failure of alarms and monitoring functions can all defeat a DP redundancy concept. It is not possible to predict when failures can occur but the probability that equipment or components of a particular type will have failed in service by a defined time can be established from historical data or accelerated ageing tests. Unfortunately, so many other factors can influence the reliability of these predictions that the DP community elected to establish a test regime based on fixed annual and five yearly surveys. Confidence in the performance of equipment or functions should be highest immediately after it has been tested and degrades towards zero over time to the point where historical evidence suggests that all such components are likely to have failed.

4.4.2 There are two phases of testing:

1. Proving trials on a new build.
2. Periodic testing on a vessel in service.

- 4.4.3 **Phase 1 – Proving trials:** Proving trials are so called because they are intended to confirm that the DP FMEA correctly predicts the way the DP system operates and fail and that the system has all the attributes upon which fault tolerance depends. The ideal situation is that the DP FMEA identifies all those performance, protection and detection attributes in hardware and software upon which the redundancy concept depends and tests are performed to verify these attributes. At this stage, the intention is to prove the efficacy of the redundancy concept. That is to say to prove that a particular system or function is capable of doing what is required of it even if it is operating correctly. Once it has been established that all the necessary attributes are present and they provide the DP systems with fault tolerance then this aspect of testing need not be repeated for another five years according to existing guidance. That is to say that unless there is evidence to the contrary or the DP system is modified, it is now accepted that the redundancy concept provides the expected degree of fault tolerance. The testing regime now moves to Phase 2.
- 4.4.4 **Phase 2 - Periodic testing:** Phase 1 has established the efficacy of the redundancy concept. The purpose of Phase 2 is proving that the required attributes are still present and effective after time in service. In the absence of any better scheme the DP community elected to adopt a test period of one year with a three month window either side of the anniversary of the original proving trials for this purpose. Within this time all attributes upon which redundancy depends should have been demonstrated to be operational and effective in respect of the performance, protection and detection attributes they provide. For MODUs, a rolling program of continuous testing has been established in IMCA M190. All other vessel types historically perform this function as batch trials where all tests are carried out on Annual DP trials. A number of important functions may also be tested more frequently at field arrival trials to provide confidence that the DP system is fully functional before starting work.

4.5 WHERE TO TEST IT?

- 4.5.1 It is in the process of answering this question that some of the practical difficulties encountered in achieving the ideal situation described above come to the fore. The answer to the last question painted a picture of a ‘testing utopia’ in which all test requirements were fully understood and achievable at DP FMEA proving trials. Reality is considerably different and there is significant opportunity for improvements which would benefit all stakeholders in the DP community.
- 4.5.2 The development of DNV RP-D102, ‘FMEA of Redundant Systems’ has done much to improve the link between the Failure Modes and Effects Analysis and the DP FMEA proving trials that are intended to prove the FMEA is correct.
- 4.5.3 The best place to test a DP redundancy concept is with the vessel operating on full auto DP in its defined power plant configurations. There is a limit to the extent that environmental conditions can be selected for trials but some confidence can be gained using performance tests that simulate limiting environmental conditions. Further confidence can be built up during the vessel’s service life by taking opportunities to confirm the DP vessel is a capable of its predicted station keeping capability when limiting conditions present themselves, such as while waiting on weather.
- 4.5.4 DP FMEA proving trials attempt to test all attributes of the redundancy concept upon which fault tolerance depends including hardware and software but practical limits imposed by the lack of suitable testing tools and commercial pressure to limit sea trials time which is expensive means that DP FMEA proving trails are not a comprehensive test of all attributes nor is a DP FMEA a complete record of all the protective functions because the visibility of these is limited to what is provided by automation and control systems vendors in their Functional Design Specifications.

4.5.5 There are other practical reasons why DP FMEA proving trials do not represent a comprehensive test of the DP systems.

4.5.6 Practical reasons include:

- Concerns over equipment damage close to vessel delivery.
- Lack of adequate test tools.
- Limited visibility into software.
- Inadequate test time established by commercial pressure based on custom and practice and not on an understanding of the test imperatives.

4.5.7 Other reasons include:

- Incompetent analysis and trials program.
- Incomplete analysis and trials program.

4.5.8 The gap between current practice and expectations is discussed later but for the purposes of concluding this section it is clear that other test opportunities should be used such as at Factory Acceptance Testing and during commissioning which can be achieved with little impact on delivery schedules but significant benefits in terms of preventing faults and design flaws progress further throughout the build state.

4.6 WHY TO TEST?

4.6.1 This question has been partially addressed by the answer to the question of 'What to Test' but it is legitimate and understandable that those who have to pay for testing would want to understand why tests are necessary and what benefit this brings them. Too little thought goes into justifying tests and much is based on tradition, custom and practice. Three works of industry guidance provide a basis to improve this situation.

- IMCA M190 Guidance for Developing and Conducting Annual DP Trials Programmes for DP Vessels.
- MTS DP FMEA Gap Analysis tools for FMEAs, Proving Trials and Annual trials
- DNV RP-D102 'FMEA of Redundant System'

4.6.2 IMCA M190 provides guidance on how to optimise testing for periodic trials making use of planned maintenance in a manner that can be used to satisfy the requirements for an annual test where it makes good sense to do so.

4.6.3 DNV RP-D102 requires a link from the failure modes and effects analysis that allows each failure effect to be proven and thus prove the conclusions of the analysis.

4.6.4 One of the most significant problems in optimising the testing of the DP systems is because there are many stakeholders in the verification process who all need to have their own requirements satisfied including:

- Classification society surveyors.
- Owner's site team and inspectors for commissioning.
- Charterers.
- DP FMEA provider.
- Flag state inspectors.

4.6.5 Because the requirements for systems testing of some of these stakeholders can be satisfied by testing while the vessel is in an incomplete state it is common for the shipyard to conclude that such a test should satisfy all parties with an interest in that particular system. Unfortunately, this is not always the case and there can be understandable frustration when other parties wish to included testing of system at sea trials when these systems have already past commissioning tests to satisfy the owner and classification society.

4.6.6 Tests which typically fall into this category include tests of:

- Machinery performance.
- Power management automation.
- Alarms.
- Emergency stops.
- Safety systems.
- Battery endurance.
- Pump change overs.

4.6.7 This is one of the reasons why it is important to document the reasons for carrying out each test. The reasons why commissioning tests are not always acceptable include:

- The system was tested in isolation without noting the effects on connected systems.
- The system was not stressed in the way in which it would be following a failure.
- The test was carried out alongside i.e. not on DP.
- The test was carried out using load banks and not the thrusters thus the levels of harmonic distortion and reactive power are different.
- The power management and DP control system were inactive during the test.
- The tests did not examine the effects of systems failure or note any alarms to initiate operator intervention.

4.6.8 Unfortunately, this issue is not easily resolved. Delaying commissioning tests until the vessel is ready for DP FMEA proving trials denies the shipyard valuable time to remedy faults and installation errors. Carrying out DP FMEA proving trials with the DP system only partially completed does not provide the necessary level of confidence. Therefore, there will always be some testing that appears to be duplication because it is performed on the same system but in actual fact each test has a different purpose and a different focus and requires to be witnessed by parties with different skill sets and responsibilities. This is not to say that there can be no overlap. Every effort should be made to carry out those tests which can satisfy FMEA objectives with the vessel alongside or in a partially complete state but this requires forward planning and the cooperation of the stakeholders for each phase of testing.

4.7 HOW SHOULD IT BE TESTED?

4.7.1 The answer to this question is, 'as realistically as possible', with due regard to personnel safety and risk of equipment damage. That is not to say that tests that are absolutely necessary to prove the efficacy of a redundancy concept should be omitted if there is risk rather that this concern may guide the development of the test strategy and also the design of the target system so that it is 'designed to be tested'. In short, do not build something that cannot be tested.

4.7.2 Ultimately, the risks associated with failing to properly test a DP system lie largely with the vessel owner and those who engage the vessel to conduct DP operations on their behalf. Unfortunately, the consequences may also be borne by those who have no control over the test regime and who put their trust in the designers, developers and regulators to reduce the risk to a reasonable level.

4.7.3 There is little point in testing systems in an unrealistic manner for example, simply opening the bustie between two switchboards and tripping the generators on one of them in no way recreates the conditions a power plant experiences during a short circuit. Such tests may be useful to confirm the assignment of consumers but no-one should be under any illusion that this in any way proves the power system is fault tolerant in respect of a short circuit fault.

4.8 TRIALS PROGRAMME ACCEPTANCE CRITERIA AND SCOPE

4.8.1 Test outcomes will be judged against:

- The requirement to maintain position and heading.
- The rules for the DP notation being sought.
- Any additional requirements in the scope of work for the FMEA.
- The vessel's Worst Case Failure Design Intent (WCFDI) which specifies the minimum number of generators and thrusters remaining fully operational after the worst case failure. Note that loss of ability to generate power or thrust after transient load limiting functions have ceased will be considered as a failure even if the equipment remains online.

4.8.2 **Note:** Those tests in a trials program are designed to prove that the vessel's DP redundancy concept has all the necessary attributes. It should be noted that tests which appear to be function tests rather than failure simulations are in fact necessary to prove the integrity of the redundancy concept which depends on **Performance, Protection, Detection and Fail-safe.**

4.8.3 **Performance:** Redundant equipment must be present in both number and capacity.

4.8.4 **Protection:** All necessary protective functions are in place to prevent faults in one redundant system being transferred to another or to prevent internal or external common cause failure modes affecting more than one redundant group.

4.8.5 **Detection:** The vessel has the necessary monitoring and alarm function to detect critical hidden failures. It is accepted that formally documented periodic testing may be used as mitigation of hidden failures in some cases.

4.8.6 **Fail-safe:** Tests will be included to prove the fail-safe' condition of redundant elements – In this context the term 'fail safe' implies the equipment does not fail in a manner that could lead to a drive off such as a thruster failing to full thrust or uncontrolled change in thrust direction. The same concept is applied to position reference system and vessel sensors or other elements that may affect the operation of the DP control system.

4.9 TESTING REQUIREMENTS

4.9.1 The following tests should form part of the DP FMEA proving trials where they are considered necessary to prove the redundancy of the DP system. Content may vary depending on the equipment class and operational configuration of the power plant e.g. Class 2, Class 3, open bus or closed bus. All tests listed below must be carried on full auto DP with all DP related systems in their normal configuration for carrying out DP operations in the intended equipment class (unless the test method specifies an alternative configuration). Note that the test outcome will be regarded as unacceptable if the severity of the failure effect exceeds the WCFDI even if the vessel maintains position in the environmental conditions prevailing during the test. Maximum use of data loggers should be made to recorded test results for ease of verification and future use. The period with which such tests should be repeated should be established by vessel operators and based on the need to ensure protective functions do not become hidden failures but it is not envisaged that short circuit testing would form part of an Annual DP trials program for example.

4.10 CLOSED BUS DP CLASS 2 & DP CLASS 3

4.10.1 **Voltage dip ride through capability:** It will be necessary to demonstrate by testing that the severity of the failure effect does not exceeded the Worst Case Failure Design Intent (WCFDI) following a short circuit and earth fault anywhere on the power distribution system (worst case to be demonstrated). This test is also required on DP Class 3 vessels operating with independent power systems (open busties) where colocation of consumers (DP or Non DP) introduces the potential for voltage transients to occur on power supplies intended to be separate and redundant.

4.10.2 **Critical active power imbalance:** It will be necessary to demonstrate by testing that the severity of the failure effect does not exceed the WCFDI following a critical active power sharing imbalance as may be caused by a fuel control system fault causing one generator to fail to full power. Failure to zero fuel should also be tested.

4.10.3 **Critical reactive power imbalance:** It will be necessary to demonstrate by testing that the severity of the failure effect does not exceed the WCFDI following a critical reactive power sharing imbalance as may be caused by an excitation control system fault causing one generator to fail to full excitation. Failure to zero excitation should also be tested.

4.10.4 **Critical line current imbalance:** It will be necessary to demonstrate by testing that the severity of the failure effect does not exceed the WCFDI following a critical line current imbalance as may be caused by a broken conductor or the single phasing of a large load.

4.10.5 **Overload - load acceptance and rejection:** It will be necessary to demonstrate by testing that the power plant is capable of accepting (without malfunction) the largest step load that may occur as the result of a single failure. It is accepted that load shedding systems may be used to augment the load acceptance of the engines providing tests demonstrate the load shedding system is effective and robust. Acceptable load rejection must also be demonstrated in response to the worst case loss of load.

4.11 ALL DP CLASS 2 AND DP CLASS 3 DESIGNS

4.11.1 **Control network redundancy and performance:** It will be necessary to demonstrate by testing that redundant control system networks for thruster and power system control are single fault tolerant and that each redundant element is capable of the necessary performance. To this end, it will be necessary to carry out data throughput tests and network storm tests on each channel (Net A & B). The trials program should include tests to confirm the independent joystick remains operational with both networks in a failed state.

- 4.11.2 **Automatic blackout recovery:** Where automatic blackout recovery is required by the DP notation or by the owner's FMEA specification it will be necessary to carry out tests to demonstrate fully automatic blackout recovery. The blackout will be initiated by simulating suitable power system failure conditions and not only by stopping engines (generator 'protection trip' and 'engine stop' should both be used as means of initiating blackout).

4.12 INDEPENDENCE OF PROTECTIVE FUNCTIONS

- 4.12.1 Where protective functions are used to moderate failure effects their use for this purpose will only be accepted as contributing to redundancy if it can be demonstrated that they are independent of the control system to a degree which ensures that a single failure cannot create a fault condition requiring the protective function to act and disable the protective functioning intended to detect and isolate that fault (to prevent it affecting the operation of other redundant equipment groups).

- 4.12.2 Note that the DP systems of vessels intending to operate their power plants as a common power systems (closed bus) are unlikely to be considered as complying with applicable rules and guidelines unless they have independent protection against all failures that create active and reactive power sharing imbalance. Such vessels will also have to demonstrate the efficacy of their electrical protection schemes and demonstrate the voltage dip ride through capability of the entire plant by live short circuit and earth fault testing on full auto DP.

4.13 MITIGATION OF FAILURE EFFECTS BY OPERATOR INTERVENTION

- 4.13.1 It is unlikely that operator intervention to moderate the effects of failures will be accepted as contributing to redundancy unless there are clear and unambiguous alarms to indicate the condition and there is adequate time for the operator to carry out the intervention and it is clear from the information provided by the alarm and monitoring systems what intervention is required. Note DP rules and guidelines often require that redundant equipment be made available automatically and with a minimum of operator intervention so reliance on operator may not be accepted by class.

4.14 VENDOR PARTICIPATION

- 4.14.1 It is acknowledged that these tests may be challenging to execute and support from equipment manufacturer's representatives is likely to be required. The technical expertise of DP system manufactures and vendors is recognised and their technical input to FMEA proving trials may be essential in some cases. This TECHOP actively encourages equipment manufacturers and vendors to participate in the preparation of test methods and procedures to prove the DP system attributes discussed above. If the equipment provider wishes to do this, they should submit their proposed test method to the FMEA team with adequate time for review to determine whether test methods satisfy the objectives of the test. If they do then the test may be carried out as described. If not, the FMEA team should advise the authors as to the reasons the test objectives are not met so that the test can be modified accordingly.

- 4.14.2 Contributions to test methods and procedures can be made at any time in the FMEA process however it may be logical to do so when the preliminary FMEA proving trials document is submitted to the shipyard for review. Shipyard technical representatives and all DP equipment vendors are encouraged to read the preliminary FMEA and proving trials to understand the reasons for testing and the test objectives.

4.15 UNACCEPTABLE TEST RESULTS OR FAILURE TO PROVE TEST OBJECTIVES

4.15.1 Failure to achieve the test objectives because of an unsatisfactory outcome or by failing to carry out the required testing in a manner which satisfies the test objectives will result in a Category 'A' finding or concern being raised at FMEA proving trials. The existence of findings or concerns in this category is likely to be a barrier to acceptance by regulators such as class and US Coastguard and prevents the vessel from achieving the desired class notation. It is likely to delay or prevent acceptance by charterers.

4.16 DP FMEA PROVING TRIALS GAP ANALYSIS

4.16.1 The preceding sections have discussed some of the essential tests that should be included in DP FMEA proving trials. There are however many more tests that should be included to have an acceptable level of confidence in the DP System. Appendix A contains a checklist that can be used to gauge the scope of a DP FMEA proving trials program.

4.16.2 The purpose of this gap analysis is to help ensure that DP FMEA Proving trials for DP Vessels:

- Are competently executed.
- Test all DP related systems.
- Consider the influence of the industrial mission on the DP redundancy concept.
- Prove the conclusions of the DP FMEA.

4.17 GUIDANCE FOR USE IN THE PREPARATION OF A GAP ANALYSIS

4.17.1 There are several sources of information on the scope and details of failure modes and effects analysis:

- MTS DP Vessel Design Philosophy Guidelines Part II.
- DNV Recommended Practice for FMEA of Redundant Systems, RP-D102.
- IMCA Guidance M166 – ‘Guidance on Failure Modes and Effects Analysis’, April 2002.
- IMCA M206 A Guide to DP Electrical Power and Control Systems.
- IMCA M190 Guidance for Developing and Conducting Annual DP Trials Programmes for DP Vessels.
- MCA M191 Guidelines for Annual DP Trials for DP Mobile Offshore Drilling Units.

4.17.2 New sources of guidance are published periodically and further revision of the MTS DP Vessel Design Philosophy Guidelines will reference these sources as they become available. The sources of guidance listed above have been used to prepare the gap analysis table in Appendix B.

4.18 CARRYING OUT A GAP ANALYSIS

4.18.1 The purpose of the gap analysis is to check the scope and methodology used in the DP FMEA Proving Trials against published industry guidance and not to repeat or correct the analysis. The gap analysis is typically carried out using only the FMEA and Proving Trials program as source material.

4.18.2 A FMEA Proving Trials gap analysis can be performed using the table in Appendix A. The number of tests to be carried out is indicative of the complexity of modern DP vessels and the number of systems, subsystems and equipment items that influence the redundancy concept.

- 4.18.3 A simple colour coding scheme can be used to identify whether a particular issue in the table had been satisfactorily addressed, partially addressed, omitted completely or contains significant errors. Grey can be used to indicate issues that do not apply to the design of the subject DP vessel.
- Green – Test procedure satisfactory.
 - Yellow – Test procedure incomplete.
 - Red – Test procedure unsatisfactory (Test omitted or contains significant errors).
 - Grey – Not applicable.
- 4.18.4 An example of a significant error would be omitting to test or simulate a failure mode with potential effects exceeding the worst case failure design intent. Such errors and omissions may also be reflected in the FMEA.
- 4.18.5 A DP FMEA and its associated proving trials program should have sufficient information to allow a complete understanding of the redundancy concept. However, in some cases, when considering items that should be tested in a DP FMEA it may not be obvious from the FMEA report whether the equipment is not fitted to this particular vessel or it is fitted but the test procedure been omitted. The following rules may be applied to determine the category to assign in the gap analysis table:
- If the omission could conceal failure effects of severity greater than the worst case failure design intent it would be categorised as RED.
 - If the target vessel is a new-build awaiting trials then the trials program and DP FMEA can be revised to remedy the deficiencies.
 - If the omission would have no significant impact on the severity of failure effects then the issue may be categorised as GREY.
- 4.18.6 For example, the absence of a test to simulate failure of a remote valve control systems may mean that a single point failure associated with all cooling valves failing to the closed position has been overlooked.
- 4.18.7 However, the absence of tests to simulate failure of the fouling of a fuel oil cooler is unlikely to be significant if inspection confirm there is no connection between redundant fuel or cooling water systems.
- 4.18.8 Once the grey entries have been discounted, the ratio of yellows and reds to the overall number of issues can be used to provide an indication of the level of deficiency in percentage terms.
- 4.18.9 A summary report discussing the problems and major deficiencies can also be provided along with suggestions on how to remedy the test program and complete it to the required level.
- 4.18.10 Four columns in the table indicate the DP system arrangements to which each issue applies: There are typically entries in several columns for each issue.
1. **Closed busties:** A tick in this column indicates that issues should be discussed in FMEAs for all Classes of vessel (2 & 3) that operate their power plant as a single common power system.
 2. **Open busties:** A tick in this column indicates that the issue should be considered for all Classes of vessels that operate their power plant as two or more isolated systems.
 3. **DP Class 3** An entry in this column indicates the issue should be considered for DP Class 3 designs. If this is the only entry against a particular issue then it is typically an issue associated with the effects of fire and flooding.

4. **Fail Safe:** An entry in this column indicates the issue is related to systems which can fail in such a way as to cause a drive off, typically thruster controls systems or DP control system, references and sensors.

Note: The most useful time to carry out a DP FMEA proving gap analysis is on the draft revision of the trials program when it is submitted to the vessel owner for review prior to submission to Class for approval. It may be difficult to influence further development after Class has approved it with comments. If the vessel has already entered service and the analysis is performed on the completed trials program then the process in the following section should be followed to mitigate the risks.

4.19 PROCESS FOR MITIGATING OUTPUT OF DP FMEA PROVING TRIALS GAP ANALYSIS

4.19.1 Appendix A provides a flowchart which describes the process for mitigating the output of the DP system FMEA gap analysis. There are essentially six steps to be completed if the gap analysis indicates that action is required:

1. Carry out the gap analysis.
2. Confirm any yellow and red findings by reference to the original vessel design documentation.
3. Perform additional Failure Modes and Effects Analysis to address the gaps.
4. If unacceptable failure effects are identified then two possible courses of action are possible depending on whether the vessel is still awaiting trials or whether it has already entered service.
5. If the vessel is already in operation at the time of the gap analysis, develop effective means to mitigate the risks based on the key elements of Design, Operations and People (or combinations of these)
6. Document the mitigations and evaluate the potential for updating the vessels DP system FMEA as part of the FMEA management process.
7. Manage the mitigating measures.
8. If the vessel is a new build awaiting trials then update the trials program to remove the deficiencies.

5 CONCLUSIONS

5.1 THIS TECHOP PROVIDES GUIDANCE ON THREE MAIN ISSUES

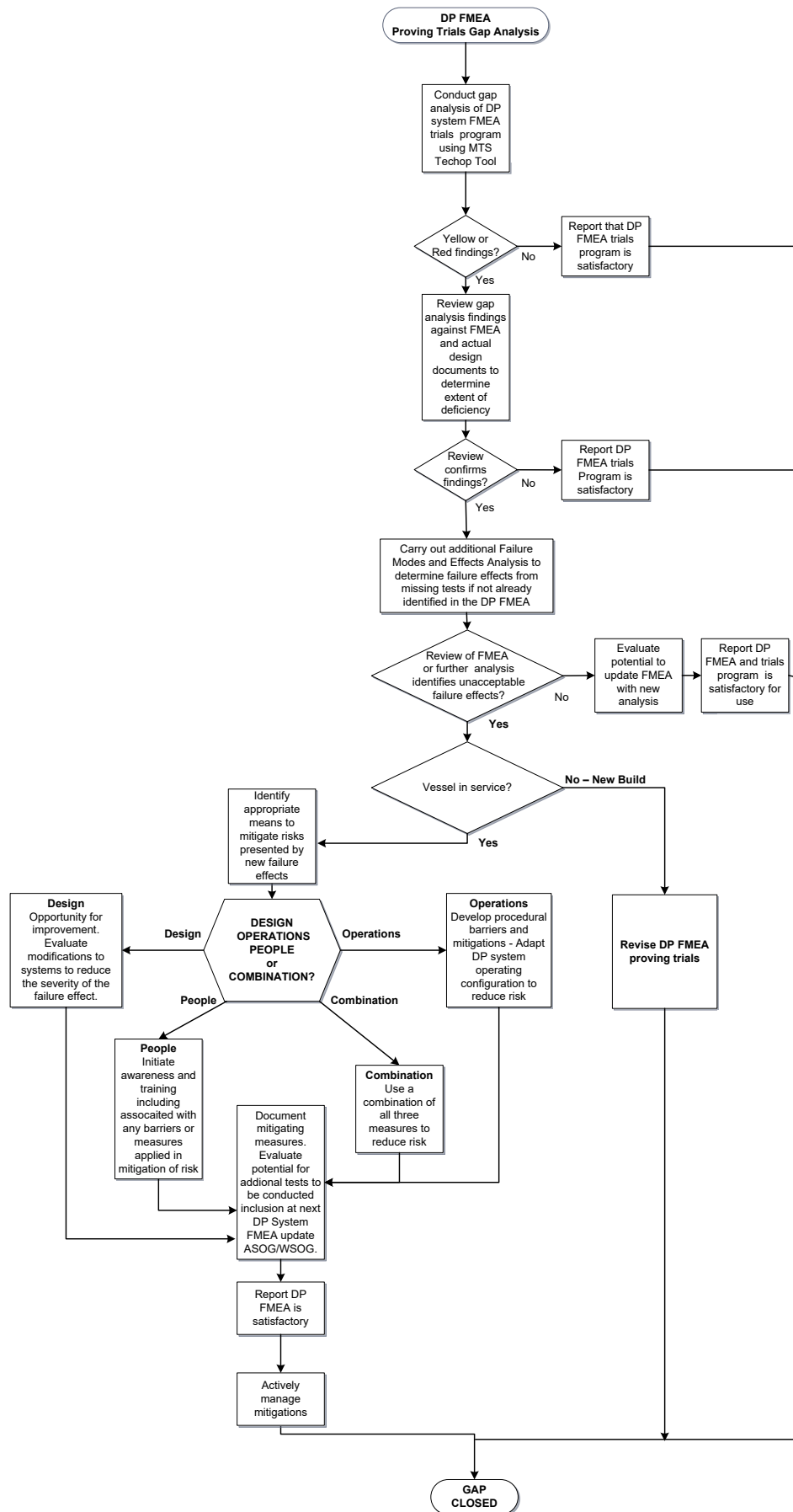
- 5.1.1 General guidance on the role of testing as part of the DP system verification process.
- 5.1.2 Tests which are essential to validate the redundancy concept of certain types of DP power plant. These tests should be carried out as part of the DP FMEA proving trials. The period with which such tests should be repeated should be established by vessel operators and based on the need to ensure protective functions do not become hidden failures but it is not envisaged that short circuit testing would form part of an Annual DP trials program for example. There is a long history of DP incidents related to these failure modes, these tests are intended to reproduce but effective solutions are now available and vessel designers are encouraged to ensure all necessary protective functions are in place to ensure a successful DP FMEA proving trial's outcome and timely acceptance of the vessel.
- 5.1.3 A gap analysis tool that can be used to determine whether the scope of a DP FMEA proving trials program is adequate.

6 MISCELLANEOUS

Stakeholders	Impacted	Remarks
MTS DP Committee	✓	To track and incorporate in next rev of MTS DP Operations Guidance Document Part 2 Appendix 1. Communicate to DNV, USCG, Upload in MTS website part
USCG	✓	MTS to communicate- FR notice impacted when Rev is available
DNV	X	MTS to Communicate- DNV RP E 307 impacted
Equipment vendor community	✓	MTS to engage with protection suppliers
Consultant community	✓	MTS members to cascade/ promulgate
Training institutions	X	MTS members to cascade/ promulgate
Vessel Owners/Operators	✓	Establish effective means to disseminate information to Vessel Management and Vessel Operational Teams
Vessel Management/Operational teams	✓	Establish effective means to disseminate information to Vessel Operational Teams

APPENDICES

APPENDIX A FLOWCHART



APPENDIX B GAP ANALYSIS CHECKLIST

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
DP Control System	Software Audit	Record software and firmware versions of all relevant DP equipment	1	✓	✓	✓				
DP Sensors	Gyrocompass XX	Failure modes for the Gyrocompasses	2	✓	✓	✓				
DP Control System	Heading Control and Heading Out of Limits Alarms	Check heading control and alarm limits	3	✓	✓	✓				
DP Sensors	Wind Sensor XX	Failure modes for all Wind Sensors (Record location data)	4	✓	✓	✓				
DP Sensors	MRU (Type XX)	Failure modes for all Motion Reference Units	5	✓	✓	✓				
DP Sensors	Draught Gauges	Failure modes for Draught gauges	6	✓	✓	✓				
Position References	DGPS Failures	Failure modes for the Differential Global Navigation Satellite Systems	7	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
Position References	HPR Failures - Type XX	Failure modes for acoustics	8	✓	✓	✓				
Position References	CyScan / Laser based Reference Failures - Type XX	Failure modes of Laser based position reference systems	9	✓	✓	✓				
Position References	RadaScan / Radio based Reference Failure - Type XX	Failure modes for microwave and other radio based position reference systems	10	✓	✓	✓				
Power Distribution	DP/IAS UPS Numbers XXX, XXX, XXX - Redundancy Tests	Capacity and failure tests for DP/IAS UPS's	11	✓	✓	✓				
Power Distribution	UPS Distribution Panel (XXX)	Failure testing of UPS distribution	12	✓	✓	✓				
Power Generation	Emergency Generator Starting and Control Supplies	Failures of Emergency generator starting and control power	13	✓	✓	✓				
DP Network	Network Throughput Test	Capacity testing of network throughput	14	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
DP Network	Network Storm Tests	Failure and response testing of protection from broadcast storms	15	✓	✓	✓				
DP Alert	Manual DP Alert System	Functional and failure testing of manual DP Alert System	16	✓	✓	✓				
DP Alert	DP Alert Tests (Automatic)	Functional and failure testing of automatic DP Alert System	17	✓	✓	✓				
Communications	Voice Communications (Auto Telephone, Sound Power Telephone & UHF)	Functional testing of communications systems	18	✓	✓	✓				
Independent Joystick System	Independent Joystick	Functional failure and testing of independence from the DP control system	19	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
Power Management	Propulsion Demand Tests	Testing ability of power system to stabilise and maintain position through various propulsion demand	20	✓	✓	✓				
DP Control System	DP Performance (Cross and Circle)	Accuracy and performance testing of the position references	21	✓	✓	✓				
DP Control System	DP Capability Plot Confirmation - (Sideways Speed Test)	Test to confirm the accuracy of the DP Capability plots	22	✓	✓	✓				
DP Control System	Gain Margin Test	Functional testing of various gain settings of the DP control system	23			✓				
DP Control System	DP Consequence Alarm Tests	Alarm testing of the consequence alarm with relevant failures	24	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
DP Control System	Main DP Controller Failure Tests	Failure testing of DPC controllers to verify seamless switching	25	✓	✓	✓				
DP Control System	Main DP Component Failure Tests	Failure testing of RHUB/RSER and RBUS modules within the DPC 3 cabinet	26	✓	✓	✓				
DP Control System	DP Class 3 Backup DP System Failure Tests	Failure tests for the backup DP Control System	27			✓				
DP Control System	DP Class 3 Backup DP System Performance Tests	Performance and accuracy tests for the backup DP Control System and connected sensors and position references	28			✓				
Thrusters	Thruster Degraded Capability	Performance testing with degraded thruster capability	29	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
Power Distribution	24Vdc Distribution	Power distribution failures of the 24Vdc distribution	30	✓	✓	✓				
DP Control System	DP Console Changeover	Failure testing of the DP console changeover	31	✓	✓	✓				
Thrusters	Thruster Control System Tests	Failure modes of the thruster control system	32			✓				
DP Control System	Pos Dropout Alarm and Mathematical Model Tests	Dead reckoning test to observe effect of loss of all PRS	33	✓	✓	✓				
Emergency Stops	Thruster Emergency Stops - Operation, Line Monitoring & Failure	Functional and failure testing of the thruster emergency stops	34	✓	✓	✓				
DP Control System	Thruster Loss Tests	Test to observe effect of complete individual and group thruster losses	35	✓	✓	✓				
Power Management	Generator Running Order Selection	Functional tests of generator running order selection	36	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
Power Management	Load Dependent Start Tests - kW	Functional testing of Active Load dependent start capability	37	✓	✓	✓				
Power Management	Load Dependent Start Tests - kVAr	Functional testing of Reactive Load dependent start capability	38	✓	✓	✓				
Power Management	Alarm Start and Start All Generators Function	Functional testing of alarm start and start all generators on a failure condition	39	✓	✓	✓				
Power Management	Minimum Generators Test	Test to ensure last generator on bus cannot be stopped by the PMS (or minimum no. of gens)	40	✓	✓	✓				
Power Management	Non DP Related Load Phase Back	Functional testing of phase back of non DP related loads or preferential tripping	41	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
DP Control System	Thrust Bias Shedding	Functional testing of bias shedding by DP control system on increase over limit of power consumption	42	✓	✓	✓				
Power Management	Non DP Related Drives PMS - Vessel PMS Interface Tests, Alarms & Failure Effects	Functional and alarm testing: Interface of IM and non DP related drives with PMS	43	✓	✓	✓				
Power Distribution	Power Distribution Failure Tests - Main power generation level	Failures of the distribution at the power generation level	44	✓	✓	✓				
Power Distribution	Power Distribution Failure Tests - Auxiliary systems	Failures of the distribution of the vessel's auxiliary systems	45	✓	✓	✓				
Power Distribution	Power Distribution Failure Tests - Emergency power	Failures of the distribution of the emergency power system	46	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
Power Distribution	Power Distribution Failure Tests - Small power and lighting (Main)	Failures of the distribution of the small power and lighting for the Main power system	47	✓	✓	✓				
Power Distribution	Power Distribution Failure Tests - Small power and lighting (Emgy)	Failures of the distribution of the small power and lighting for the Emergency power system	48	✓	✓	✓				
Power Distribution	Power Distribution Failure Tests - IM power distribution effect on DP	Failures of the distribution of the IM power distribution system and its effect on DP	49	✓	✓	✓				
DP Control System	Field Station Failure Tests - Thrusters FS XX to FS XX	Field station failure tests for thrusters	50			✓				
Engine Control System	Field Station Tests - Engine Control and Safety FS XX to FS XX	Field station failure tests for engine control and safety system	51	✓	✓	✓				
Power Management	Field Station Tests - PMS Field Stations FS XX and FS XX	Field station failure tests for power management system	52	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
Auxiliary Systems	Field Station Tests - Auxiliary Field Stations FS XX to FS XX, FS XX	Field station failure tests for auxiliary services	53	✓	✓	✓				
DP Network	NDU Failure Tests	Network distribution unit failure tests	54	✓	✓	✓				
Safety Systems	Failures of the CO ₂ System Interface	Failures of the CO ₂ fire fighting system and effects on DP	55	✓	✓	✓				
Safety Systems	Engine room Fire Dampers and Quick Closing Valve Control System	Failure modes of engine room fire dampers, QCVs and effect on engines	56	✓	✓	✓				
Power Generation	VT & CT for Switchboard, Governor and AVR	Failures modes of various sensors providing inputs for the power generation controls	57	✓		✓				
Auxiliary Systems	Seawater Cooling System	Failure modes of the SW cooling system	58	✓	✓	✓				
Auxiliary Systems	Thruster Drive Cooling Skid	Failure modes of the thruster drive cooling system	59	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
Engine Cooling System	Engine High Temperature Freshwater Cooling	Failure modes of the Engine HT FW cooling system	60	✓	✓	✓				
Auxiliary Systems	Auxiliary Freshwater Cooling System	Failure modes of the auxiliary FW cooling system	61	✓	✓	✓				
Fuel System	Fuel Systems Tests	Failure modes of the engine fuel system	62	✓	✓	✓				
Compressed Air	Starting Air	Failure modes of the starting air system	63	✓	✓					
Compressed Air	General Service Air	Failure modes of the general service air system	64	✓	✓	✓				
Compressed Air	Instrument and Control Air	Failure modes and alarms of the instrument and control air systems	65	✓	✓	✓				
Valve Control System	Remote Control Valve Systems Tests	Functional and failure testing of the RCV system	66	✓	✓	✓				
HVAC	Ventilation Systems Tests	Failure modes of the ventilation system	67	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
Power Management	Control Power System Port & Starboard	Failure modes of the control power for the switchboard	68	✓	✓	✓				
Engine Control System	Engine & Generator Protection, Alarms and Trips	Functional testing of the Engine and generator protection	69	✓		✓				
Power Distribution	Pre-magnetizing System Failure Tests	Failure modes of the transformer pre-magnetizing system	70	✓		✓				
Power Management	PMS/Plant Interface Tests - Analogue Connections	Failure mode testing of the various analogue sensory connections between the power plant and the PMS	71	✓		✓				
Power Management	PMS/Plant Interface Tests - Digital Connections	Failure mode testing of the various digital sensory connections between the power plant and the PMS (e.g. breaker status)	72	✓		✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
Power Management	PMS Blackout Detection Failure Tests	Functional and failure testing of the PMS blackout detection feature	73	✓	✓	✓				
Power Generation	Governor and Load Sharing Failures	Failure modes of the governor and load sharing lines if present	74	✓		✓				
Power Generation	AVR Failures	Failure modes of the Automatic Voltage Regulators	75	✓		✓				
Power Management	Base Load - PMS Failure Tests	Functional testing of the base load function and testing of related failures	76	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
Power Management	Generator Protection (Blackout prevention) - Internal Failures & Power Failure	Functional and failure testing of the generator protection system with relation to preserving power plant stability and preventing partial and complete blackouts	77	✓		✓				
Thrusters	Thruster Drive Failure Tests	Failure modes of the thruster drive	78	✓	✓	✓				
Auxiliary Systems	Auxiliary Drive Failure Tests	Failure modes of auxiliary drives	79	✓	✓	✓				
Power Management	Drive to PMS Interface	Failures of the drive to PMS interfacing connections	80	✓	✓	✓				
Automation System	VMS/IAS to Thruster Control Unit Interface	Failure modes of the interface between the Integrated Automation System and the Thruster Control Unit	81	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
Thrusters / Generators	Thruster and Generator Full Power Tests	Performance testing of the thruster and generators to ensure rated capacity	82	✓	✓	✓				
Auxiliary Systems	Thruster Auxiliary Systems Tests	Failure modes of the thruster auxiliary systems	83	✓	✓	✓				
Thrusters	Speed / Torque Command, Feedback and Limitation	Failure modes of the thruster speed/torque control system	84	✓	✓	✓				
Thrusters	Thruster Azimuth Command and Feedback Tests - IAS or ACU	Failure modes of the thruster azimuth control system interface between the DP control system and the Azimuth Control Unit	85	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
Thrusters	Thruster Azimuth Command and Feedback Tests - ACU	Failure modes of the thruster azimuth control system interface between the Azimuth Control Unit and the azimuth angle encoder	86	✓	✓	✓				
Thrusters	Thruster Control Unit	Failure modes of the Thruster Control unit	87	✓	✓	✓				
Thrusters	Thruster Phase back - Power Plant Stability	Functional testing of thruster phase back for blackout prevention and to maintain power plant integrity	88	✓	✓	✓				
Power Management	Power Plant ESD Function & Failure Tests - FS XX to FSXX	Functional and failure testing of the power plant ESD system	89	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
Power Management	Blackout Recovery - Partial Blackout	Functional testing of the blackout recovery process based on partial blackout of the switchboard (may be equivalent to the WCFDI)	90	✓	✓	✓				
Power Management	Blackout Recovery Full Blackout - With Emergency Generator	Functional testing of the blackout recovery process based on complete blackout of the switchboard (will exceed the WCFDI) with the utilisation of the emergency generator	91	✓	✓	✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
Power Management	Blackout Recovery Full Blackout - Without Emergency Generator	Functional testing of the blackout recovery process based on complete blackout of the switchboard (will exceed the WCFDI) without the utilisation of the emergency generator	92	✓	✓	✓				
Engine Control System	Generator Protection Communications Network Faults	Failure modes of the generator protection communications network	93	✓	✓	✓				
DP3 Requirements	DP Class 3 Simulation of Compartment Loss - Bridge	Class 3 simulation of loss of all equipment in a compartment due to fire/flood	94			✓				
DP3 Requirements	DP Class 3 Simulation of Compartment Loss - Backup DP Control Station	Class 3 simulation of loss of all equipment in a compartment due to fire/flood	95			✓				

DP FMEA PROVING TRIALS GAP ANALYSIS - TRIALS DOCUMENT NUMBER XXXXX REVISION X – REVIEW OF CONTENT										
APPLICATION				GAP ANALYSIS						
SUB SYSTEM	TEST DESCRIPTION	CONTENT	ID NO.	CLOSED BUSTIE OPERATION	OPEN BUSTIE OPERATION	DP CLASS 3	FAIL SAFE	CROSS REFERENCE TO FMEA	YES / PARTIAL / NO / NOT APPLICABLE GREEN / YELLOW / RED / GREY	CONCERNS
DP3 Requirements	DP Class 3 Simulation of Compartment Loss - Engine Control Room	Class 3 simulation of loss of all equipment in a compartment due to fire/flood	96			✓				
DP3 Requirements	DP Class 3 Simulation of Compartment Loss - Electrical Equipment Room	Class 3 simulation of loss of all equipment in a compartment due to fire/flood	97			✓				
DP3 Requirements	DP Class 3 Thrust Command and Feedback Failures - BACKUP DP System	Class 3 simulation of loss of all equipment in a compartment due to fire/flood	98			✓				
DP3 Requirements	DP Class 3 Direction Command and Feedback Failures - BACKUP DP System	Class 3 simulation of loss of all equipment in a compartment due to fire/flood	99			✓				
DP3 Requirements	DP Class 3 Failure of Fire Backup Switch	Class 3 simulation of loss of all equipment in a compartment due to fire/flood	100			✓				