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DYNAMIC POSITIONING CONFERENCE
October 7 - 8, 2008

Risk, FMEA and Reliability

Crossing the Salt Barrier by Using a Reliable DP Vessel

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Abstract

In 2007, Petrobras made one of the most important discoveries in its history: a mega oil bed in the Tupi area, off the Southeastern coast of Brazil. To get there, a salt barrier that is two kilometers thick needs to be crossed. The exploration equipment needs special care because the salt formation becomes pasty at high temperature. This huge challenge makes a Dynamically Positioned vessel the right tool to be used by Petrobras at that field although the risk of losing position, either through a blackout situation or due to a system failure that brings it the fame of "intrinsically unsafe". The purpose of this work is to describe the trials techniques that Petrobras DPPS carries out as part of its safety program to increase the *reliability* of DP vessel operations and, as a consequence, to reduce the number of *incidents* especially in *critical* locations. Also, the presentation will highlight the importance of carrying out acceptance and annual trials to get the expected results.

Pre-salt layer: the new challenge

In 2007, Petrobras made one of the most important announcements in its history: the Discovery of a mega oil bed in the Tupi area, off the Southeastern coast of Brazil. The discovery represented a technological leap: it was made seven thousand meters below the water surface, crossing a salt barrier that is two kilometers thick. The company is now diving into a series of major challenges to develop the means to explore what may be one of the world's largest oil fields.

The 300-kilometer distance between Tupi and the Santos coast is the first challenge. How will the natural gas be transported from the wells? Alternatives are being analyzed, such as installing a thermoelectric plant at high sea – it would use the gas to generate electricity which, in turn, would be transported to the coast via cables -, compressing the gas, or even liquefying it to be transported by vessels.

To reach the oil in the Tupi field, a distance about two kilometers to sea floor will have to be crossed. Then there will be another kilometer of the type of rock known as post-salt. The wells Petrobras currently explores in high sea are in this geological layer.

After the post-salt comes an unprecedented challenge: the salt layer, which is two kilometers thick. This formation started being created 150 million years ago. The salt accumulated in it is the same as used to season our food, but with a "small" difference: since it is on the bottom of the earth, at high temperatures, it is pasty, and this demands special care with exploration equipment. BR technicians have developed computerized models to foresee salt behavior under these conditions.

Finally, the layer that holds the oil, known as pre-salt, is at a depth of five to seven kilometers – although it is after the salt layer, geologically it was formed earlier.

While Petrobras is still analyzing the mega Tupi area production capacity, the research has proved it is the same type of oil, which, after refined, produces larger volumes of gasoline and other fuels. The density that was found, 28 degrees API, is a sign of its excellent quality. Before announcing the Tupi discovery, several wells were drilled in fields off the Southeastern and Southern Brazilian coast. The samples proved this is the same type of oil, a sign the region may hold an even bigger reserve. If the challenges increase at the same rate, Petrobras will be able to face them with its technology.

A 'reliable' DP vessel: definition

In principle a "*reliable* vessel" is one that has been received (acceptance trials) with all of the medium and high risk nonconformances (including those of FMEA) solved, and its "degraded status" defined and applied. During its operational life it remains "*reliable*" if it does not present any degradation that would compromise its capacity to maintain position. This definition is used in the construction of what we call a "restriction diagram", specific for each DP rig, and is used to define the operational risks of DP units in congested areas or near to any other obstacles either above or below the surface.

How to make a DP vessel reliable?

IMO Standards

The International Maritime Organization Guidelines for class 2 or 3 Dynamic Positioning Vessels (MSC 645, 1994) established in chapter 5:

- Complete initial survey of the DP-system to ensure full compliance with all the applicable parts of the guidelines including the ability to keep position after single failures.
- Annual survey to ensure that the DP-system has maintained its ability to keep position after a single failure.
- Complete tests, similar to the initial survey at intervals not exceeding five years.
- Tests should be made every time an accident occurs which affects the safety of the DP-vessel, or whenever any significant repairs or alterations are made to demonstrate full operational condition capacity.

Dynamic Position Systems are projected to comply, at a minimum, the IMO guidelines for each specific vessel class. By attending these guidelines a certificate will be issued by one of the international classification societies (ABS, BV, DNV, Lloyds). However, the choice of the class is a prerogative of the country's government where the vessel will operate or their agents (self-regulation). The IMO MSC-645 document is a broad standard as it should be but, at same time, it no longer reflects the present condition. As a consequence, new built or upgraded vessels should also meet more detailed technical specifications adopted by governments or operators.

IMCA Guidelines & Issues

IMCA publishes a variety of guidance documents, setting out industry good practice based on the cumulative experience of its members operating around the world to help them in ensuring safe and efficient operations. A key document in relation to DP is the *Guidelines for the design and operation of dynamically positioned vessels* (IMCA M 103), which is regularly reviewed and updated to reflect technological developments and operational achievements. IMCA also works closely with other organizations (notably holding observer status at IMO) where it can represent members, put forward their expertise and assist in ensuring national/international regulations and other industry documents appropriately reflect the industry, its technology and successful self-regulation where relevant.

A range of documents also address the trials program and audits for DP vessels, helping to set comprehensive formats out to be widely adopted and recognized by vessel operators and their clients in order to ensure that every relevant aspect is being addressed and then further enhancing efficiency.

Technical reports are also issued, aimed at helping vessel operators to review, specify, maintain and use a variety of system, such as DP control, propulsion, power, vessel management systems and other equipment.

MTS Guidelines & Issues

Marine Technology Society's main focus, especially at the DP conference, is to share important knowledge, as well as presenting state-of-the-art and evolving technology pertaining to all aspects of DP. This includes supply, offshore drilling, floating production, pipe laying, and multi-service vessels. Presentations and panel discussions by recognized experts in DP and DP-associated fields are focused on key issues, such as safety, *reliability*, training, vessel power, plant and thruster design and sensors. In

addition, a number of vessel owners discussed the design, configuration and experience of their new-builds.

MTS, with its sections and subsections, works as a "best practices community" with focus on developing, validating and disseminating lessons learned and best practices to improve *reliability* on DP vessels.

Classification Societies Rules

According to ABS, "classification societies are organizations that establish and apply technical standards in relation to the design, construction and survey of marine related facilities including ships and offshore structures. These standards are issued by the classification society as published rules. A vessel that has been designed and built to the appropriate rules of a society may apply for a Certificate of Classification from that society. The society issues this certificate upon completion of relevant classification surveys.
Such a certificate does not imply, and **should not be construed as an express warranty of safety** *(our emphasis)*, fitness for purpose or seaworthiness of the ship. It is an attestation only that the vessel is in compliance with the standards that have been developed and published by the society issuing the classification certificate."

The standard and rules adopted by the Classification Societies has contributed to the *reliability* of DP vessels. However, this *reliability* is obtained through a classification process which could present differences in its execution from region to region. As it is very complex, the DP system contains a lot of variables that can only be dealt with by specialists who are not always available in every location where Classification Societies maintain representatives.

FMEA (Failure Modes and Effect Analysis)

For class 2 and 3 vessels the Classification Societies have been recently demanding the carrying out of FMEA's procedures, even though they are not obligated to by the IMO. This technical *reliability* study should demonstrate that a *single failure* will not result in a loss of position. Furthermore, to be valid, it should eliminate all possible single failure points, guarantee redundancy and avoid uncontrolled drifting of the DP vessel. To accomplish this, it should at least contain the following:

- An operational description of the entire DP system to the component level to demonstrate that the DP system has adequate redundancy and that all measures to reduce vulnerability to *single point failures* have been applied to the project.
- A test worksheet for all types of potential failure modes observed in the system description, including field tests to confirm a project has the proper redundancy or not;
- A matrix of consequences for each potential failure mode identified and a specific risk classification;
- A list of recommendations classified according to the level of risk (i.e. frequency x consequences matrix) decrypted in the document and confirmed by testing;
- A living document to be permanently updated;
- A deep involvement of the whole DP team to always keeping in mind that there could a *single* point *failure* in the system;

Furthermore, FMEA shall be considered as a training resource for DP system operators as it has a unique description of the entire DP system, including all its main redundancies.
However, there are doubts about the *reliability* and/or redundancy of DP systems when submitted to this kind of analysis, as FMEA sometimes DOES NOT:

- Consider human error.

- Provide in-depth information on interrelation at component level, which creates obstacles in the effort to eliminate single failure points;
- Use enough qualified multi-disciplinary teams, which could result in low-quality *reliability* analysis;
- Sufficiently value the professional experience of the vessel operational / maintenance team, such as vessel particulars;
- Consider diverse operational system modes, such as bus bar configuration (open /close).

If these problems were corrected, FMEA would become an extremely efficient tool. There would still be a lack of motivation for the vessel teams to adopt FMEA as a day-to-day tool, making it a "live" document, being updated continuously. In Petrobras, the DPPS group uses the FMEA as an auxiliary tool during acceptance and periodic trials.

PETROBRAS / DPPS: the history

1978: - Up to 1984, DP vessels operated by foreign oil companies under risk contracts with poor DP technology transfer;
1984: - First DP vessel contracted by Petrobras;
1985: - A giant field called Marlin is discovered by a DP vessel;
1992: - A safety program called DPPS (Dynamic Positioning safety Program) was created to deal with a high level of incidents;
1995: - "DP incidents data bank" and "restriction diagram" created;
1996: - Another very large field discovered (Roncador);
- The DPPS program was expanded from strictly operational procedures to also include equipment testing to meet IMO-MSC-645 guidelines;
- First FMEA done on vessels with high incident levels.
- First DPPS seminar to deal with "Emergency Disconnections";
1997: - Second generation of "restriction diagram" developed;
1998: - A significant increase in number of DP vessels. Development of "nonconformances data-bank software";
- Second DPPS seminar to deal with DP procedures;
2000: - 24 DP vessels under contract. Second version of "nonconformances data-bank" installed;
2003: - BDIP improved, based on oracle software;
2004: - Third version of "nonconformances data bank", based on Oracle software;
2005: - Fourth DPPS seminar, DP human error incidents analysed;
2006: - First version of "DP professional qualifications data bank";
2008: - First version of "acceptance and annual trials data bank" software and third version of "restriction diagram".

PETROBRAS / DPPS: tools used to increase reliability

Technical Specifications

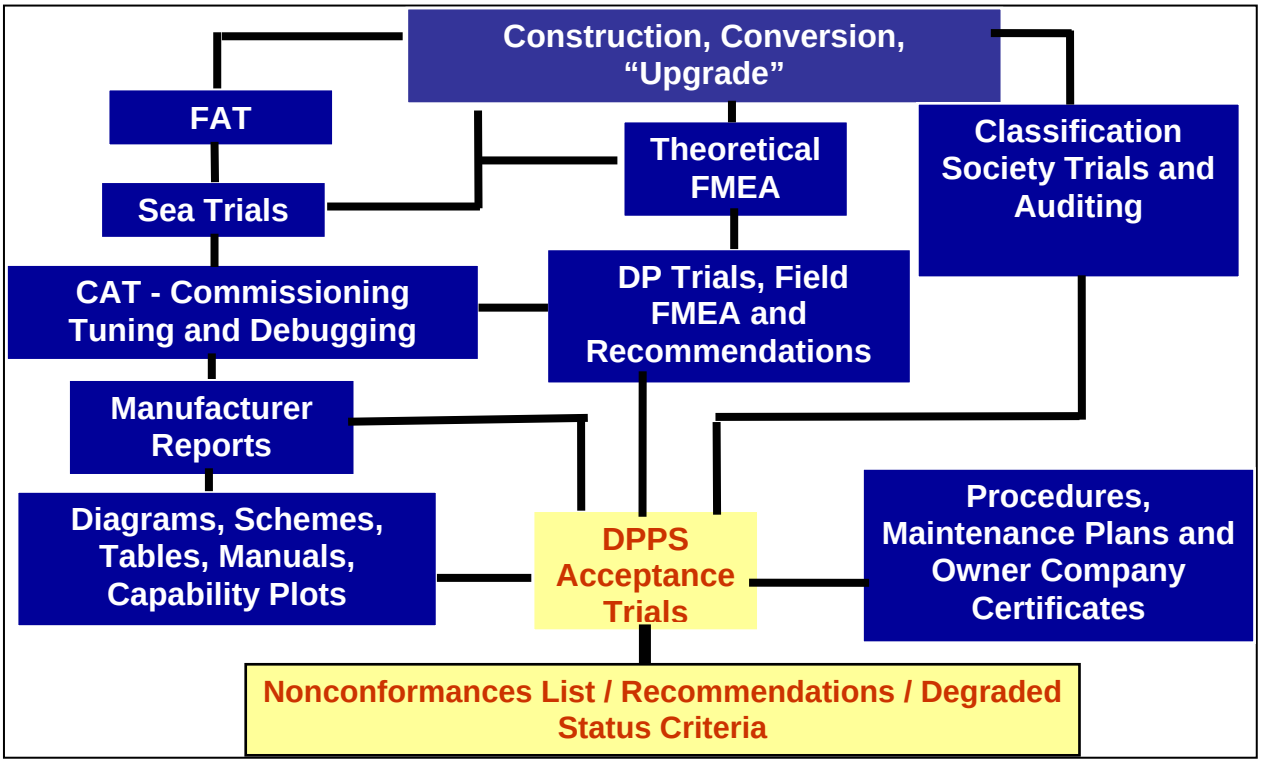
The specifications requested by Petrobras's E&P department reflect years of experience and lessons learned, taking also into account the nonconformances and/or incidents reported in a specific data banks, state-of-the-art technology, increase in deep water exploration, local environment changes (consequences of improvement in weather data monitoring) and oil field project design difficulties due to restriction diagram application. The minimum specification for DP rig vessel is IMO class 2, however a complete detailing up to component level is done to eliminate the possibilities of lack of redundancy that could cause a position loss. The trial process is essential to confirm the real need of these technical requirements to improve system performance and security of operations.

Trials

To further enhance DP vessel *reliability* only trials procedures contained in a corporative software program called SINPEP (Petrobras Electronic Standard Integrated System) are permitted to be used. The trials are performed upon request of a contract manager, who follows an approved timetable. In the acceptance trials a complete vessel study is performed (equipment characteristics, technical and performance data, commissioning, operational history, previous trials, FMEA, etc) before the functional tests. At annual trials only technical verifications and functional tests are done according to a checklist. These tests of the vessel's real operational condition also provide a unique opportunity for training DP system personnel. Among these, the blackout tests (with or without automatic recovery), the emergency tugboat connection tests and the drift-off tests are the most important ones. Brazilian offshore oil field operational parameters and limits are mainly based on the results of these tests.

Acceptance Trials

An initial trial is carried out to ensure that the vessel complies with all technical specifications stipulated in the contract. The professional qualifications of the vessel crew are also confirmed at this time. To make sure all interested parties are fully informed, any contractual non-conformity discovered are then registered in a data bank with is accessible to all interested parties so that the personnel responsible take appropriate action to eliminate them within a specified time. As a further guarantee of *reliability* Petrobras has a policy of demanding that Contractors follow recommendations stipulated by international organizations such as IMCA, DPVOA, as well as those of equipment manufacturers. The acceptance trials procedure can be seeing in the flowchart shows:



Annual Trials

As Petrobras considers annual trials to be one of the most important tools to ensure *reliability*, it not only follows IMO recommendations, but its own much more demanding regulations as well. However, Petrobras does not think that annual trials, no matter how through, are by themselves sufficient to ensure DP vessel *reliability*. Therefore, Petrobras conducts equipment functionality trials and verification of important accessories such as DP and PMS "dataloggers", specially their synchronization, which is extremely important to find the root cause of incidents.

In general, some additional benefits in conducting trials are that they create a culture of professional cooperation, accident prevention and knowledge sharing. *This attitude is very important!*

Major Incident Investigations

All major incidents are investigated by a qualified Petrobras DPPS technician. First, all vessel operations are suspended until the root cause of the incident is identified. Then, corrective / preventive measures are implemented to guarantee that the incident will not be repeated. Only after this will operations be restarted. Finally, all information related to the incidents is registered in the DP incident data bank and nonconformances in a separate data bank for reference to help solve / prevent similar problems on other vessels

CONPROS – DP Professional Qualification Databank

Human error has been one of the main root causes of incidents and this rate has increased over the last few years. This fact is well know in the world DP community and proved by our DP incident data bank. Lack of professional experience and qualification was one of the points identified as a basic cause of human error. In order to identify those employees who require additional training DPPS created a data bank for technicians who work on DP vessels to register and evaluate their professional qualification to make sure that they meet a minimum international standard.

BDIP – DP Incidents Databank

To improve *reliability* Petrobras decided to develop software in-house. The information in this data bank, which has more than 750 registered cases since 1984, is an excellent analysis tool used to prevent similar incidents occurring.
By definition, BDIP considers for analysis that DP Incidents are **any events that potentially can lead to an emergency disconnection**. So, every incident registered on BDIP is linked with an event described as one of the status as below:

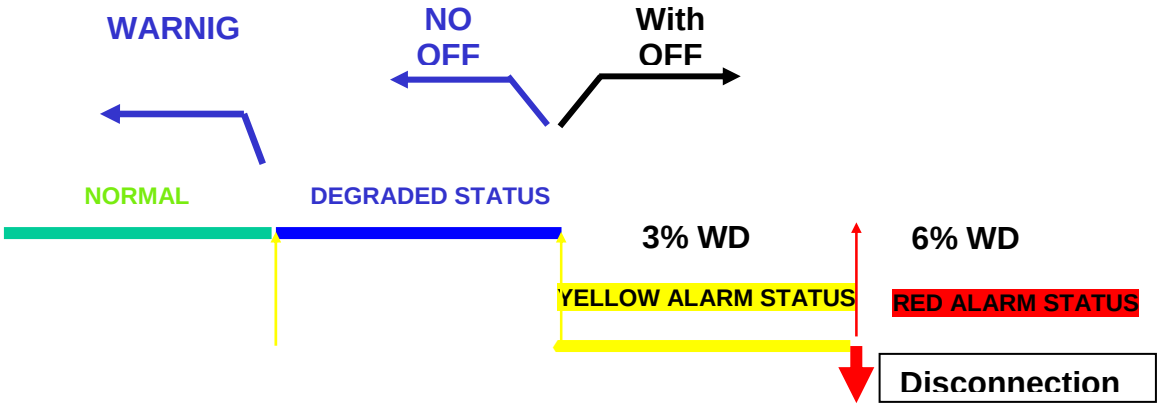
Degraded Operational Status - when the vessel, due to failures, malfunctions or high demand loses the minimum needed redundancy for DP System & Equipments to proceed safely with the operations and, consequently, loses the safe operational capacity of station keeping.

Yellow Alarm Status – when the vessel's safe operational capacity is compromised since there is an offset related to the well and/or an abnormal LFJ deflection.

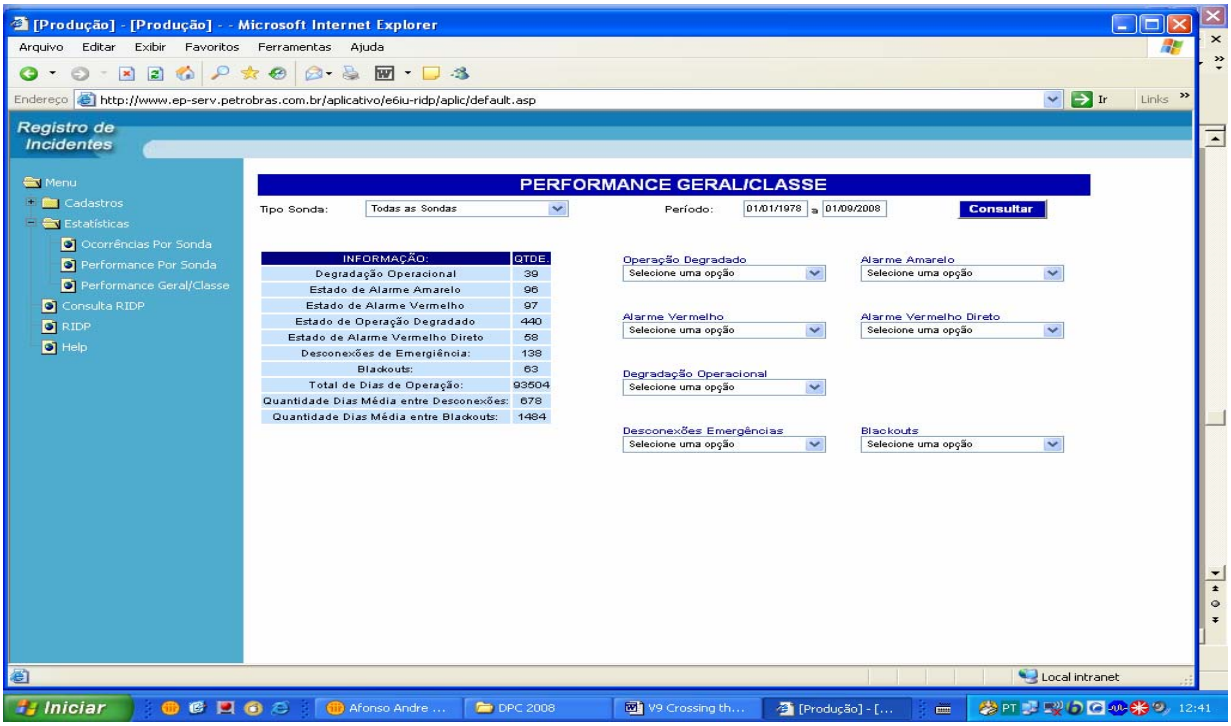
Red Alarm Status – when the vessel's station keeping capacity is irreversibly lost, resulting in a high offset and a high LFJ deflection. In that situation the vessel must proceed with an emergency disconnection.

Straight Red Alarm Status – when the vessel suddenly loses the capacity of station keeping even if there is no offset or LFJ deflection. DPO must proceed with the emergency disconnection.

The following table summarizes the status above described:



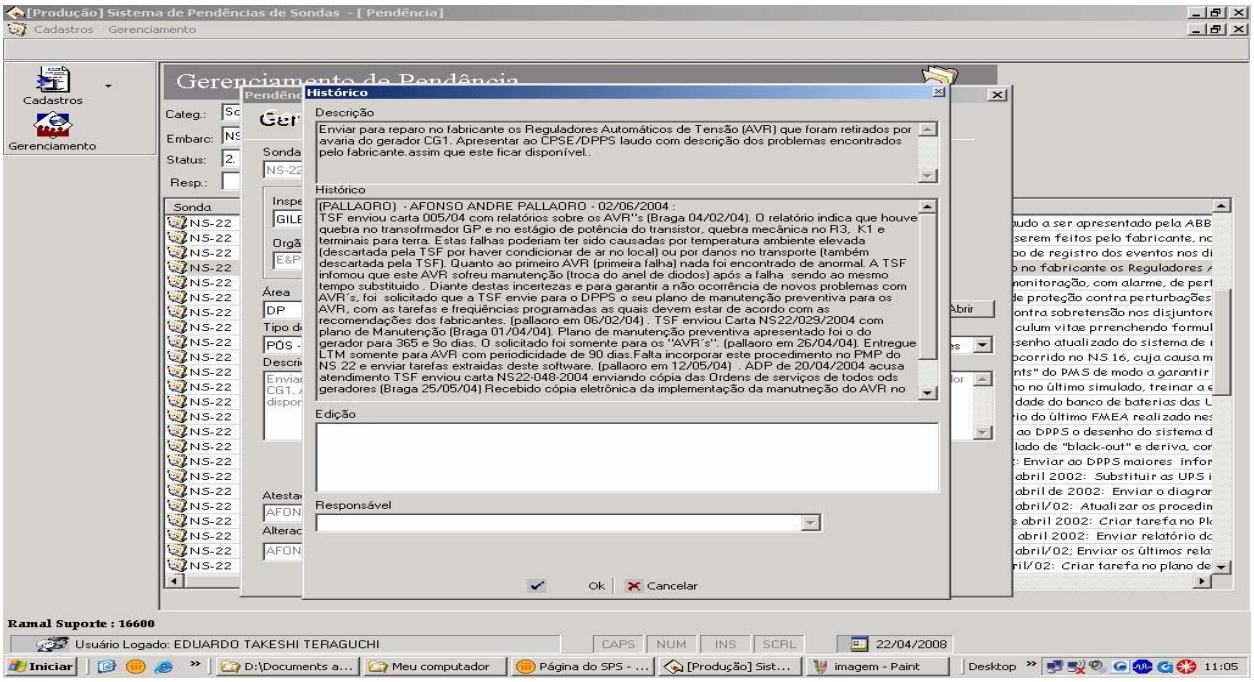
CAUSE	EFFECT	CONSEQUENCE
Loss of Redundancy	Degraded	Without loss of position - Possible cease of operations (Critical Operation)
Progressive loss of station keeping capability	Yellow Alarm / Red Alarm	Loss of position with control – preparation for disconnection => disconnection
Sudden loss of station keeping capability (ex: black-out)	Straight Red Alarm	Loss of position without control => Immediate disconnection



SPS – Nonconformances Control Databank

The Nonconformances Control Databank provides an easy handling of trial and incident pending problems. This software helps Contractors and Petrobras in the process of nonconformances solving by the use of software filter facilities and deadline alerts for each stage of solution. Vessels *reliability* depends on nonconformances resolution in time and can be decisive for the occurrence of incidents.

The following image shows one of the screens used in this software.



Screen shown a nonconformance historic of the data bank

SII – Computerized System for Acceptance and Annual Trials (a recently developed tool)

It was observed that, in some cases, different results were obtained on trial tests. To solve this problem, a standard test-execution was established. In order to get that, a positive answer for the three questions below was required:

1) Is the test critical for the positioning of the vessel?
2) Can it be carried out in a different way?
3) If so, are the results different?

Using this criterion, some procedures for testing were standardized, which resulted in more predictable answers and better orientation /training for executors giving them the necessary support to obtain more accurate results. By doing so, the hidden failures that might become a serious incident will be much easier to be found.

The results we got so far have encouraged us to standardize every test. Several benefits will arise from this standardization:

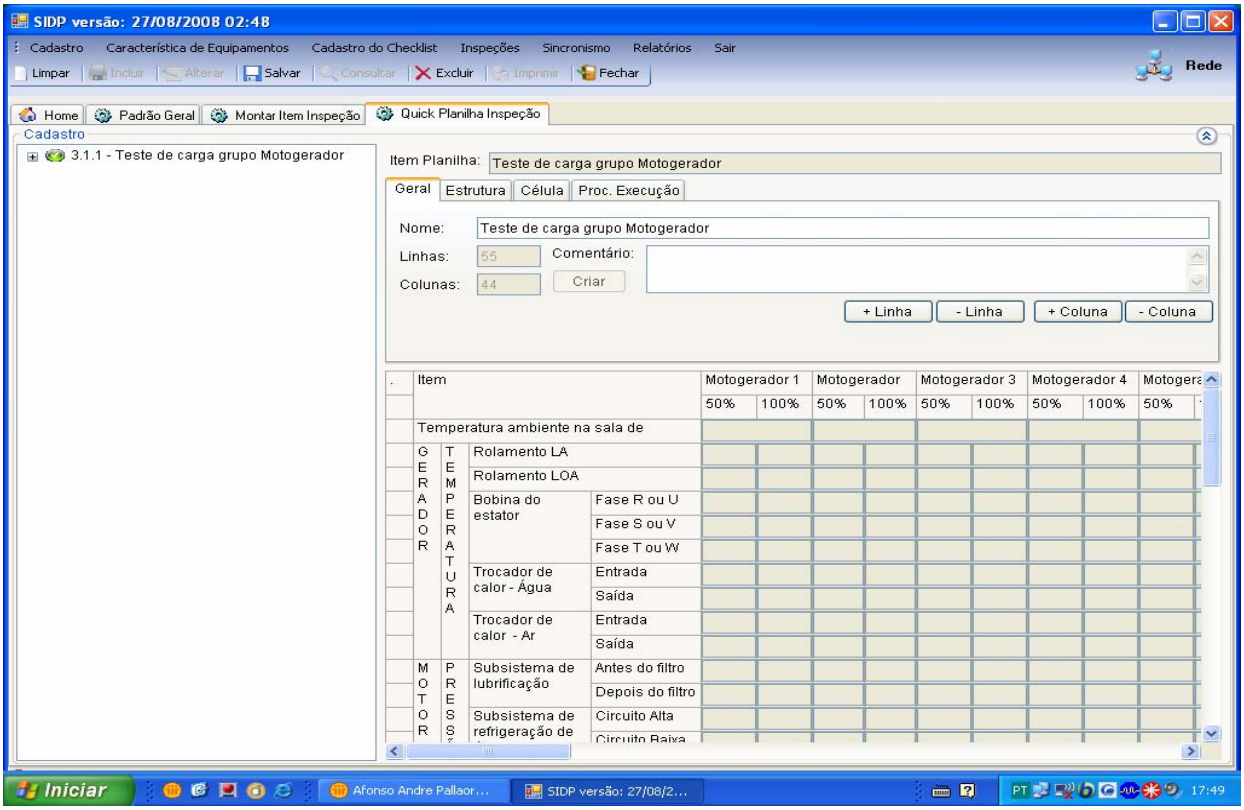
- Information about the equipment operational status;
- Statistical *failure* analysis;

- Automatic software alert for negative test results;
- Automatic nonconformances for negative results;

This software is expected to be very important in identifying and treating abnormalities as well as avoiding their repetition. Consequently, superficial treatment or lack of consistence in solutions will be eliminated. Because of every catastrophe has its origin in a sequence of small incidents their early detection and elimination is essential.

The aforementioned advantages demonstrate the importance of the Computerized Trials System, although the improvement of efficiency of high-skilled surveyors, our most important value, was the main reason for its development. Some tests of the annual trials, even though well planed and optimized, demand dedicated rig time, which is proportional to the experience of the involved technicians and the desired quality of them. The software's functionality saves the time spent for searching specific information such as settings, ranges, and filling reports, etc. This time is now focused on tests that will improve the vessels *reliability.*

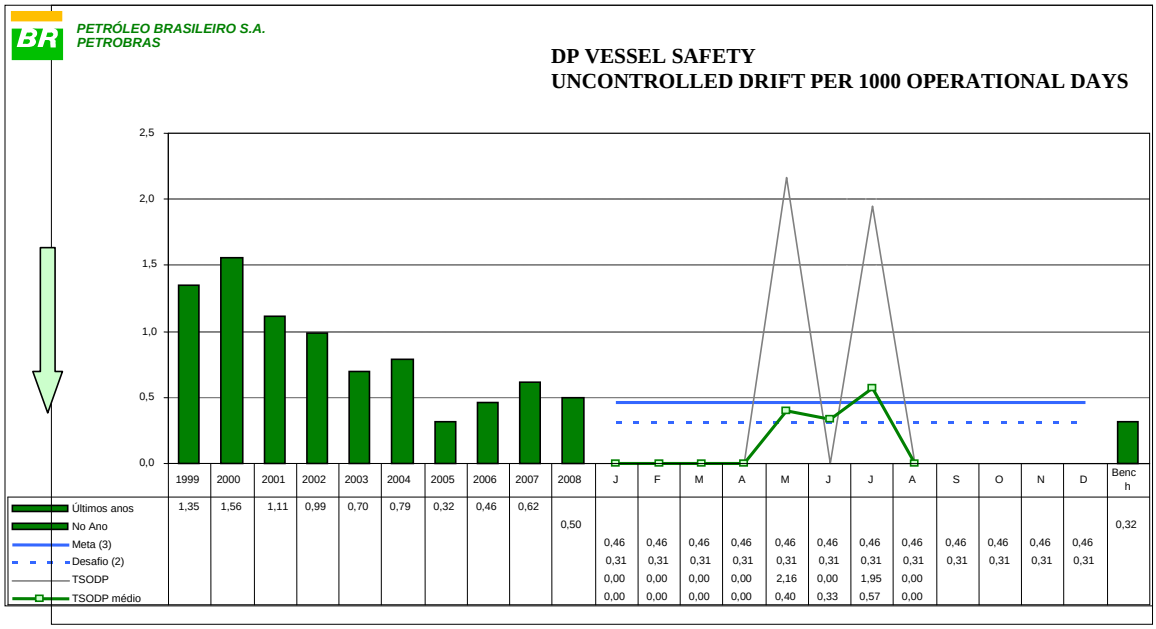
As the new system was designed for tablet (digital pen computer) utilization, the tests and their reports are done simultaneously. It results in a higher focuses on testing process and even on the search for a single point failure that can be consider a major improvement for vessels *reliability*. Another advantage of this dynamic and integrated system is the possibility to view the history of the equipment on previous tests. According to its behavior special attention will be given.



Page of computerized system shown an engine test

Conclusion

DPPS has shown very good results since its creation in 1992. The most important result has been the reduction in the number of disconnections caused by equipment failure. A dramatic fall in the rate of incidents on DP vessels attests to the quality of the tools used to increase reliability.



Taking into consideration everything we have learned since the beginning of DPPS, we are confident that we are on the right track. Although, to guarantee continuous success, the problem of insufficient qualified personnel, which will continue for the foreseeable future, can only be solved through improved user-friendly technology, especially predictive maintenance and on-line equipment monitoring.

We at Petrobras believe that DP vessels *reliability* is the future and we will continue to successfully pioneer new DPPS technology as needed, e.g., pre-salt exploration, ultra deep-water drilling, etc.

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