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DNV GL Enhanced Thruster Assisted Position Mooring assurance – A Digital Twin Approach

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DNV GL AS

Abstract

The ongoing increasing demand for energy is pushing oil and gas exploration further offshore and deeper. For medium and shallow water drilling in harsh environment and for oil production with Floating Production and Storage Offloading units (FPSO), thruster assisted position mooring systems are often employed. In these operations the vessel position and heading are maintained by a control system which automatically controls the thruster action based on the line tension and the vessel motion. For both FPSOs and mobile offshore drilling units, the DNV GL class notation POSMOOR-ATA(R) is traditionally issued after testing on the first drilling/production location. This is because proper testing of the thruster-assisted position mooring control system and mechanical equipment can be performed only with the actual mooring lines and in the class-approved water depth. This has always been an issue for the yards and owners of not having all the class notations in place at vessel delivery. Another drawback of the current practice is that testing at the first operating location is performed in present weather conditions only. Moreover, the test has limited focus on the failure handing capability of the position mooring control system.

To overcome the limitations of the current practice, DNV GL is introducing an enhanced POSMOOR-ATA notation scheme employing simulator-based testing with a Digital Twin of the vessel, mooring lines and environment to issue the class notation at the building phase. The aim of this paper is to describe the current approach with today's challenges and issues, present the new DNV GL class approach to show how a vessel digital twin can be used in a simulated environment for "digital assurance" of thruster-assisted position mooring control systems.

Contents

Introduction

The ongoing increasing demand for energy is pushing oil and gas exploration further offshore and deeper. According to the DNV GL energy transition outlook 2019, Figure 1, the fossil fuel share of energy mix will decline from 81% today to 56 % by 2050, still representing a large contribution in the total mix (see [1] for more details). In addition, increased requirements for fuel efficiency and cost-effective solutions, plus environmental limitations are introducing new challenges, both technologically and operationally.

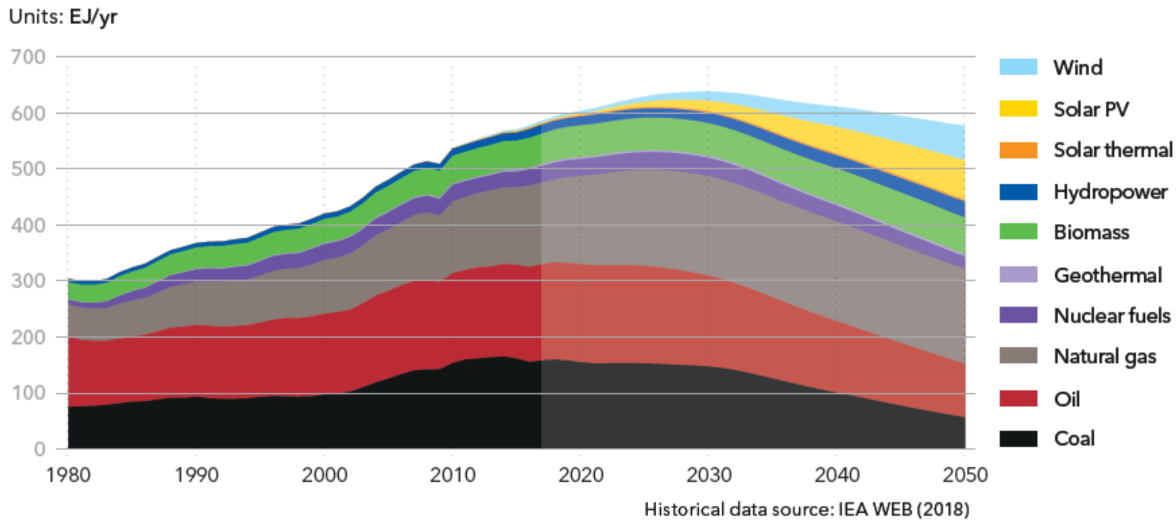

Figure 1: DNVGL Energy Transition Outlook 2019 - World primary energy supply by source

Typically, drilling operations in deep water (deeper than 1500 m) are performed in Dynamic Positioning (DP) mode. Thruster assisted position mooring configurations are often the preferred choice for harsh environments and water depth up to 1500 m (sometimes even deeper with synthetic lines) as the mooring lines in combination with the DP system provide a better positioning performance than in pure DP mode. At the same time, Floating Production Storage and Offloading (FPSO) units equipped with thruster-assisted position mooring systems have become more common. The typical FPSO mooring configuration is a turret mooring system that allows for weather-vaning in order to minimizes the environmental loads and the vessel motion. In these applications the vessel position and heading are maintained by a control system which automatically controls the thruster action based on the line tension and the vessel motion. For the certification of these systems, DNV GL provides a class notation called POSMOOR-ATA (including also an ATAR version) which covers material, components and control systems [19].

Figure 2: Stena Don - position mooring rig (courtesy of Stena)

For both FPSOs and mobile offshore drilling units, the DNV GL class notation POSMOOR-ATA (and POSMOOR-ATAR) is traditionally issued after testing on the first drilling/production location. This is because the proper testing of the thruster-assisted position mooring control system can be performed only with the mooring lines deployed in the class-approved water depth. It is not uncommon that drilling POSMOOR-ATA units perform many jobs in pure DP mode (without mooring lines) before the first assignment in POSMOOR-ATA mode. This results in having the class notation issued some months or even years after the unit is built. Due to this, yards cannot deliver the units according to contractual requirements and vessel owners are not able to market their rigs with a POSMOOR-ATA notation. For the customers that wanted the notation at the build phase, tests may be performed outside the yard. These tests are set-up to reproduce as best as possible operating conditions in terms of line tension and equipment stress but are typically very costly, time-consuming and inefficient. Other drawbacks of the current practice are that testing at the first operating location is performed in present weather conditions only and the test has limited focus on the failure handing capability of the position mooring control system.

Another aspect of the current practice, which is mainly relevant to mobile units, is that for each rig mooring location a mooring analysis shall be submitted for class approval. This analysis is mainly performed to ensure that the mooring system can withstand the environmental loads and the rig will be able to maintain its position by the help of thrusters and mooring lines (also considering equipment failures). Today's challenge is that the mooring analysis does not always reflect the way that the mooring system will be operated together with the thruster system in real operations. This often makes the mooring analysis as an exercise with limited value.

The third and last challenge in the current regime is that a tuning of the control system for positioning mooring that is effective for one water depth may not be effective for another one. If a mobile unit moves from one location to another, a new mooring analysis needs to be performed to ensure that the new location mooring pattern satisfies a certain standard. Different oil fields may present different water depths and sea bottom configuration (different production riser configurations for example). This can result in a mooring system with different static and dynamic characteristics (drag, damping, restoring forces, etc.). The control system tuning that resulted in accurate positioning performance in one field may results in poor, not robust and unstable positioning performance in another fields. This may not be discovered immediately at the new location but only when the environmental conditions became more severe for example. Not adequate tuning may lead to a loss of position with consequent damage to people, the asset and environment.

To overcome the limitation of the current practice, DNV GL class will introduce an enhanced POSMOOR-ATA scheme. The aim of this paper is to describe the new DNV GL class approach to show how a vessel digital twin can be used for "digital assurance" of thruster-assisted position mooring control systems and to present an example of a recent pilot project.

Digital Twin

A digital twin is a virtual model of an asset, maintained throughout the lifecycle and easily accessible at any time; see for example [2], [3]. It is a central part of the digital asset ecosystem and will enable a new generation of advanced predictive analytics.

A digital twin can integrate data from different products and sensors. Data smart asset solutions are a key to reducing operational costs. A digital twin is a concept that will enhance information management and collaboration, where the experts can work together, preventing costly mistakes and rework.

The digital twin developed for digital assurance for thruster assisted position mooring systems includes time-domain models for running simulations for predicting the vessel motion behavior and to provide all the necessary signals to a position mooring control system to test its software and the overall performance in depth (see the green boxes in Figure 4). A digital twin simulator environment is shown in Figure 3.

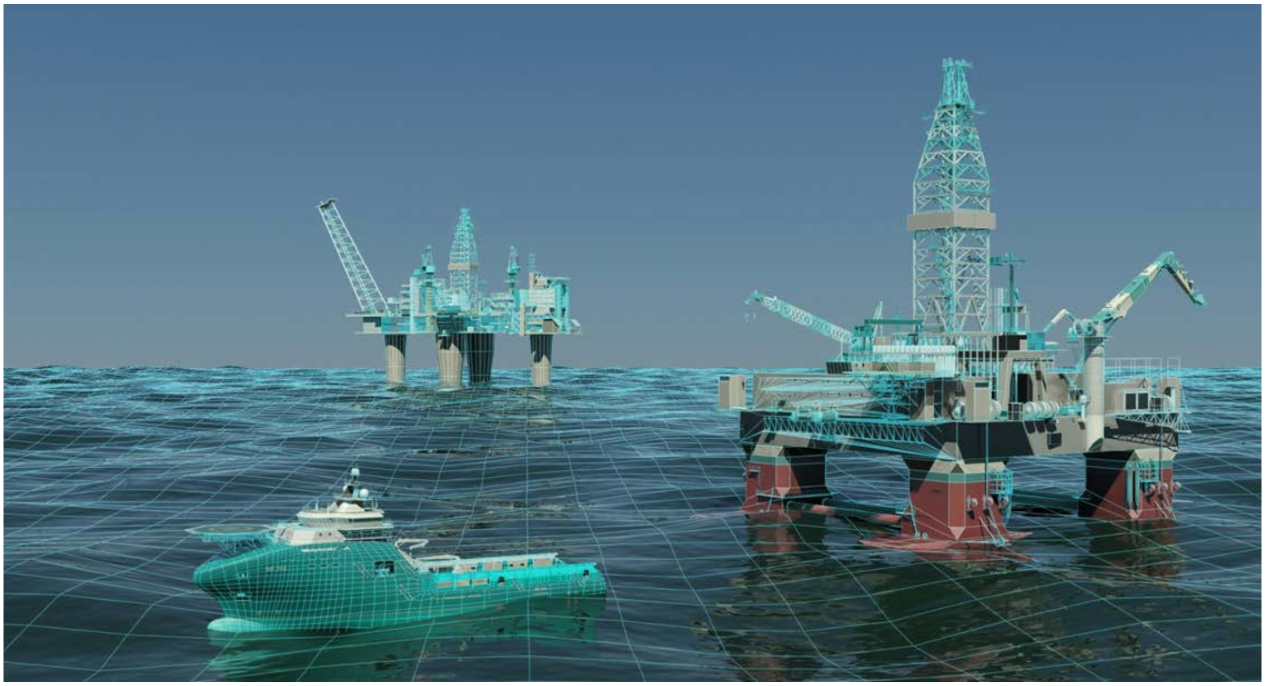

Figure 3: A digital twin simulation environment

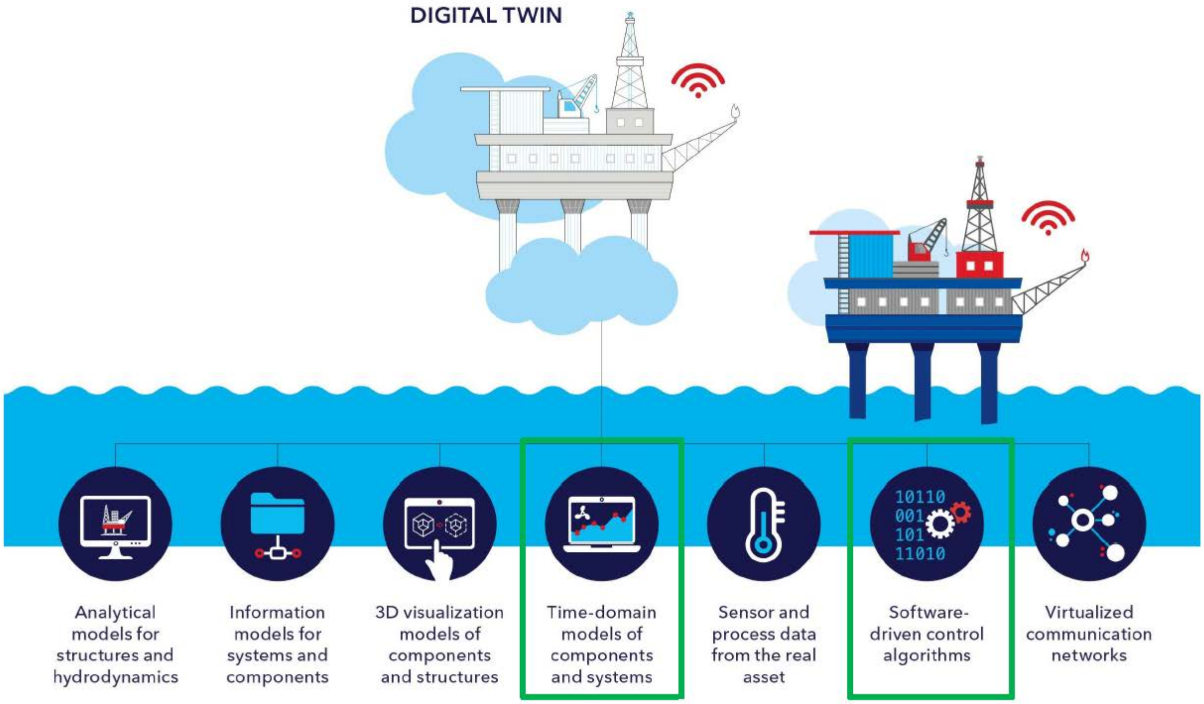

Figure 4: Digital Twin concept

DNV GL initiatives regarding thruster-assisted position mooring

The development of the enhanced POSMOOR-ATA class notation is one of the DNV GL initiatives in the thruster-assisted position mooring field. DNV GL just launched a joint industry project called Thruster Assisted Mooring Joint Industry Project - TAM JIP in September 2019. This is somehow related to the challenge described in the introduction regarding the little correlation between mooring analyses and how the system will be operated in reality. Another initiative is the development of a web-application for submittal and approval of mooring analyses. Both initiatives are described below in this article.

Enhanced POSMOOR-ATA notation

The new DNV GL class scheme has different goals and objectives, trying to solve the challenges described in the introduction. This results in different efforts during a unit life cycle, from the new build phase to the vessel in service phase. Below a description of the different elements and benefits for the various unit phases.

Assurance of the control systems and issuing of the class notation at new build phase

As described in the introduction, one of the challenges is that the POSMOOR-ATA class notation is typically not assigned at the new build (or retrofit) phase. If the notation is required by the owner or the operator before the unit leaves the yard, running the tests for granting the class notation is very costly. Moreover, tests are typically performed with mild weather reducing the ability to test the system robustness upon different environmental conditions. A large share of these tests focusses on functionality rather than failure handling capability, thus limiting the test effectiveness. Running extensive failure testing at sea will also be unpractical due to the high costs. To solve this issue, in the new DNV GL class scheme, DNV GL will assign the class notation at new build phase upon performing a simulator-based test of the position mooring control system (software test). It has been proven that quantification methods used for hardware cannot be applied to software. The standard for safety integrity level (SIL), IEC 61508 has recognized this, and focuses on software development and testing. However, SIL is much less widespread in the maritime industry than in the automotive, railway, and nuclear industries. It has been identified that in order to improve the risk assessment of software [9][12], the industry should focus on improved risk assessments (in particular software FMEA and software HAZOPS), software engineering processes, and the verification of these through use of recognized standards such as IEEE 12207, ISDS [14], ISQM [11] and ISIS [18], testing and verification using recognized standards such as IEEE1012 [16]a, ISO 29119, ESV [15] or SV [10], and on life-cycle software change management.

Testing done in the new DNV GL approach follows the requirements in [13] and [15]. Some mechanical tests on the winches will still need to be carried out but most of the functional and failure handling tests will be performed in a lab with a digital twin. This will contribute to the improvement of risk assessment and verification of such systems.

The main idea of simulator-based-testing is to use advanced simulators (see the test setup shown in Figure 5) capable of simulating the dynamic response of the vessel with its power plant, thrusters, mooring lines and other relevant equipment. In this way, the control system will not experience any difference between the real world and the simulated world. Full-scale validation and information on digital twins can be found in [3] [6] [8]. The simulator interfaces to the target control systems and is capable of simulating a wide range of scenarios defined by operational modes, operational tasks, and single and multiple failure modes in order to verify correct functionality and performance during normal, abnormal and faulty conditions. More information on testing of control systems can be found on [2][4][5][7].

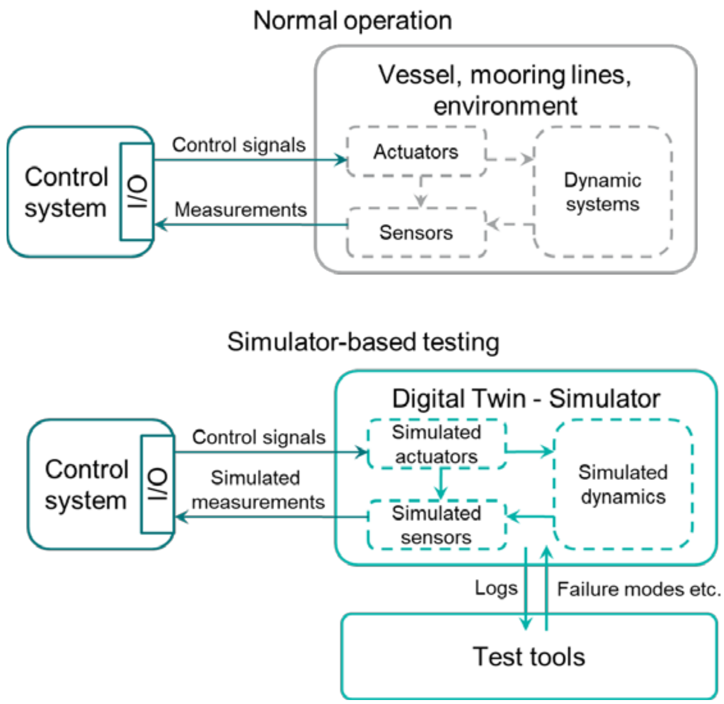

Figure 5:Simulator-based testing concept

As today, a simulator-based position mooring test lasts five days. Some of the typical tests that are performed are shown in Table 1. Functional tests are typically 30% of the total test effort, while the remaining 70% is devoted to failure tests. The aim of such test is also to enable a virtual commissioning of the control systems at an early stage before it is taken into operations. It has been proven that a thorough simulator-based test can also reduce the commissioning time at sea resulting in reduced cost for the rig owners.

Table 1: Typical simulator-base tests for POSMOOR-ATA control systems

Activity	Functions
Functional testing	• Position Mooring control algorithm tuning and functionality (normal load conditions, modes, and gain settings) • Vessel states estimation (Kalman filter, vessel model) • Monitoring, settings, and configuration • Thrust allocation modes and transitions • Wave filtering, current estimation, dead reckoning • Wind sensor feed-forward • Blackout prevention and load reduction/limitation • Online motion prediction, capability and position mooring consequence analysis • Power and thruster system modes and transitions • Changeover of functions between controllers • Position Mooring computer GUI and operator panels • Anchor handling in Position Mooring mode • Position Mooring modes and functionality
Failure testing (equipment failure modes, loss of power, signal freeze, wild points, message format and rate errors, out of range signals, loss of signal, signal bias, signal noise and random drift, alarms and warnings)	• Position reference systems • Sensors (tension measurement failures, line length measurement failures) • Power system • Thruster and propulsion system • Position Mooring computer system (handling of wrong environmental inputs, erroneous mooring configurations) • Signal failures on line length and tension sensor • Loss of mooring forces (line break, anchor dragging, winch brake failure, etc.) • System network

A screenshot of the GUI of the digital twin simulator tool is show in Figure 6.

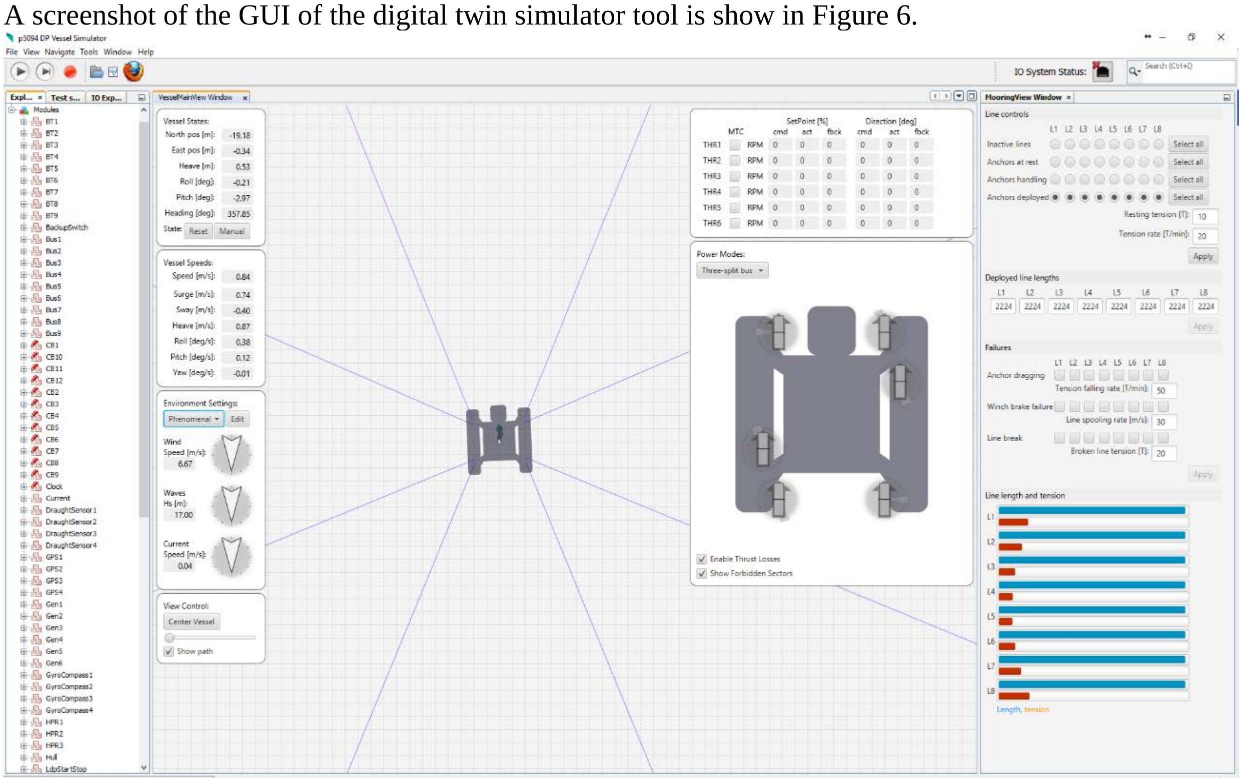

Figure 6: Screenshot of the Digital Twin application for testing POSMOOT-ATA control systems

In-service assurance and virtual commissioning

Once a digital twin is built, it can be updated with in-service asset data and used for assurance of the thruster-assisted position mooring system during the vessel life-cycle. As mentioned in the introduction, mobile offshore units may perform 3-4 moves a year, where a new location requires a new mooring arrangement. This may be due to a different water depth or sea bottom configuration (e.g. line should not lay on production risers). A different mooring arrangement implies different static and dynamic response from the mooring lines. This mainly results in different line pre-tension, line tension characteristics as a function of the rig horizontal motion and line damping. These factors need to be accounted for in the overall control system strategy that aims at controlling the thruster forces in the most optimal way to maintain the unit position and heading. A poorly tuned system may result in unstable rig behavior, increased fuel consumption and need for emergency disconnections from the well head. By employing the digital twin and the simulator setup as used for the test in the new build phase, it is possible to check if the current control system tuning is suitable for the new mooring configuration. The results from the test will provide valuable information to the vendor and the owner regarding the need of a new control system tuning or the confidence that the current tuning will provide sufficiently accurate performance in the new location. In order to achieve this, the digital twin should be calibrated upon full-scale data. This is something DNV GL is working on in collaboration with OEMs and vessel owners. Performing this test prior rig moves aim also a closing the gap between a theoretic mooring analysis and how the actual position mooring control system performs with the provided mooring arrangement. As mentioned earlier, there is a separate JIP for looking at how to improve the mooring analyses. A diagram summarizing the new class approach is shown in Figure 7.

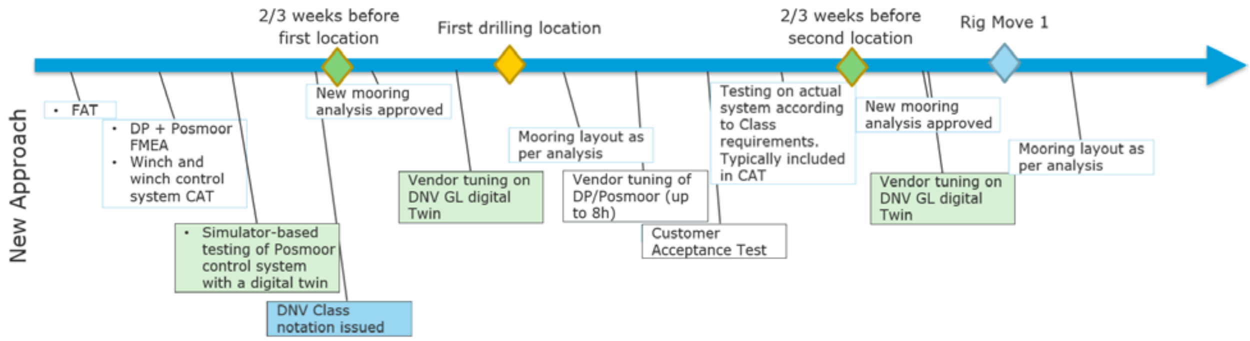

Figure 7: New DNV GL approach for POSMOOR-ATA

Testing with the digital twin can also be performed for control system software updates, to assure that the system works as intended before it is uploaded and operated onboard the rig.

Experience from a pilot project

So far two projects have been partially performed following the new class approach. One of the projects was carried out with the unit Stena Don (see Figure 2). The Stena Don is a harsh environment dynamically positioned Class 3 semi-submersible drilling, completion and workover vessel for worldwide operations. It was built in 2001 and upgraded with mooring lines (work finished in 2019).

A simulator-based test was performed at the position mooring control system vendor for granting the class notation. As the test was performed at the lab, there was not interference with the work that was being performed onboard the rig to get it delivered in time. On the contrary, having assured the control system functionality and failure handling capability thoroughly with an effective test in the lab allowed to skip some of the tested that would be been performed outside the yard in Bergen. These tests would have involved anchor handlers, people and other logistics. By employing the new class approach, not only Stena saved the cost of the test outside Bergen, but it also allowed Stena Don to commence a drilling activity 5 days before schedule, with a significant financial benefit. The second part of the pilot project will consist of mainly 3 activities:

1) Establishing a data connection to the rig to update and calibrate the digital twin.
2) Establish a cloud-based test setup for performing simulator-based testing. This will enable more efficient test activities and reduction of costs (people do not need to travel for the test, test could be run automatically)
3) Perform a test before the next rig move for gaining experience in the in-service assurance of the control system tuning for a new mooring arrangement.

TAM JIP

As described above, there are other DNV GL initiatives related to thrusted-assisted position mooring. The thruster-assisted mooring JIP, has the overall objective to provide guidance on how to perform cost-effective TAM operations with an acceptable risk, and it includes:

- To give guidance on defining relevant requirements to TAM operation.
- To give guidance on how to identify the best strategy for station keeping; taking into account the unit type, intended operation, water depth and environmental conditions
- To give guidance on analysis strategies, strategies that will give realistic prediction of performance
- To improve consistency between assumptions made in design and how the unit is operated.

The JIP has been launched in September 2019 and it is still possible to join and contribute.

Mooring approval via web-app

Another DNV GL initiative in the mooring field is the development of a web-based solution for DNV GL approval of mooring line analyses. A screenshot of an initial application look is shown in Figure 8.

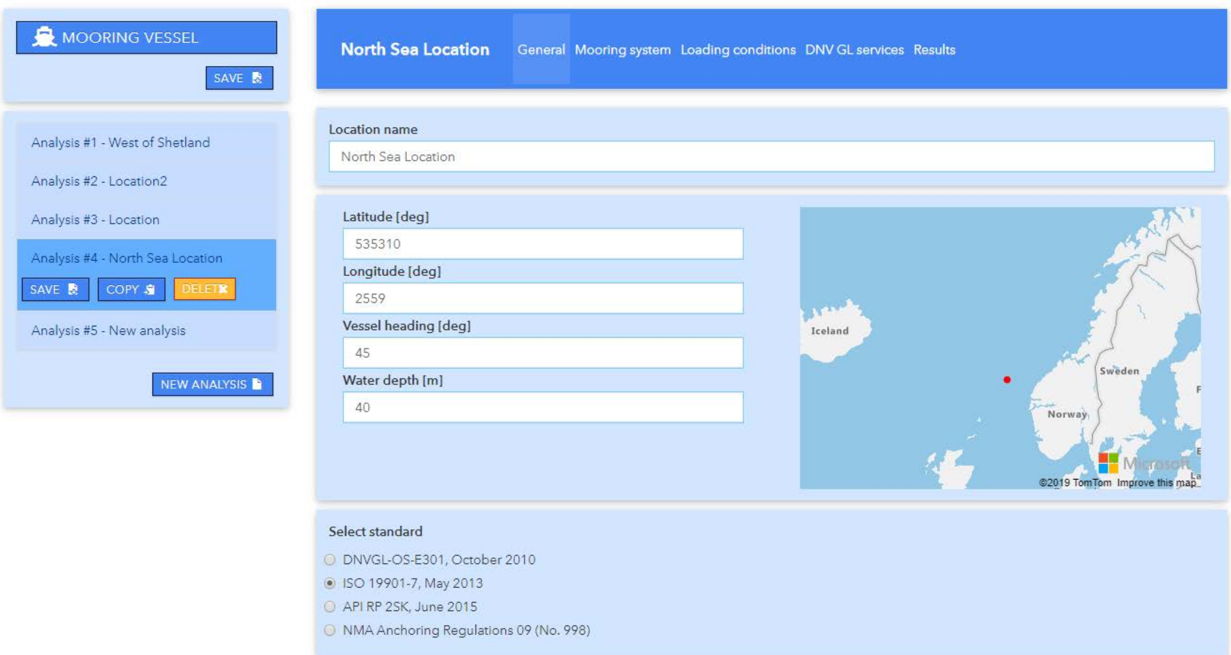

Figure 8: Screenshot of the development web-app for mooring analysis approval

The web-app will enable quicker and a more efficient approval process, removing customer waiting time as the web-app will provide an automated approval. The web-app will be available at the DNV GL platform Veracity (www.veracity.com).

Conclusion and future work

This paper presented a new DNV GL class approach for assurance of the thruster-assisted position mooring system on units to be classed with POSMOOR-ATA(R) notation. The new approach allows the release of the class notation at the new build phase (or after a retrofit) upon performing a thorough simulator-based testing of the thruster-assisted position mooring control system by using a digital twin.

This test is performed in a safe lab environment and does not interfere with the work ongoing on the actual unit. Providing the class notation in the new build phase is a major improvement with respect to today's practice where the class notation is typically issued at the first mooring location. The new approach aims also at assuring the performance of the unit at every rig moves by performing a quick test before a new location. Having a digital twin available in the whole vessel life cycle allows for an efficient testing of control system software updated before the new software is sent to the unit.

Some work needs to be carried out for having the new approach fully functional in all the aspects. The two main technological pillars that will make this concept viable are:

1) Establishing a data connection to the rig to update and calibrate the digital twin.
2) Establish a cloud-based test setup for performing simulator-based testing. This will enable more efficient test activities and reduction of costs.

The paper presented also two other initiatives in the thruster-assisted position mooring field: the TAM joint industry project and the work on the development of a web-app for automatic approval of mooring analyses. The demands for fuel efficient and safer operations is increasing, the technology is progressing quickly and will open for new solutions. We believe that these initiatives are inline with both DNV GL and industry expectations on digital class tools and assurance.

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