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Transocean's HIL

Experience and Improvements

By

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Abstract

The focus of this paper is to share some of Transocean's recent Hardware-in-the-Loop (HIL) testing experiences and results with the DP community. HIL testing is an effective means of black box system verification tasks during system design, development and system integration.

Our latest experience has demonstrated that with proper planning, execution and the right team, HIL can identify software issues prior to system integration, as well as identifying issues not normally found during Factory Acceptance Test (FAT) or during commissioning. HIL testing is a software-centric effort that involves time and resources. This paper will highlight our findings and provide recommendations on methods of improving the alignment between the HIL software test harness and the software running on the vessel.

We will identify the marine systems tested and those systems associated with the vessel's industrial mission, which have undergone HIL testing, and discuss recommended practices for the vessel owner on tracking findings and ensuring the changes to the software are correctly managed. This paper will also discuss methods of maintaining the consistency between HIL teams particularly when categorizing HIL findings and MOC processes and provide recommendations for improved HIL testing practices from the perspective of the vessel owner.

HIL is a verfication tool with high potential, however, we still see opportunities for improvement. As an industry, we can better leverage this technique.

Abbreviation / Definition

DPS –	Dynamic Positioning System
ESD –	Emergency Shut Down
FAT –	Factory Acceptance Test
FDS –	Functional Design Specification
FMEA –	Failure Mode Effects Analysis
F&G –	Fire and Gas
HIL –	Hardware-in-the-Loop
HMI –	Human Machine Interface
IAS –	Integrated Automation Systems
ICR –	IAS Change Register
I&C –	Implementation & Commissioning
KPI –	Key Performance Indicator
MCC –	Motor Control Center
MOC –	Management of Change
OEM –	Original Equipment Manufacturer
OS –	Operator Station
PMS –	Power Management system
SDS –	Software Dependent System
SPT –	Steering, Propulsion and Thrusters
TRS –	Test Result Sheet
VFD –	Variable Frequency Drives
VMS –	Vessel Management System

Introduction

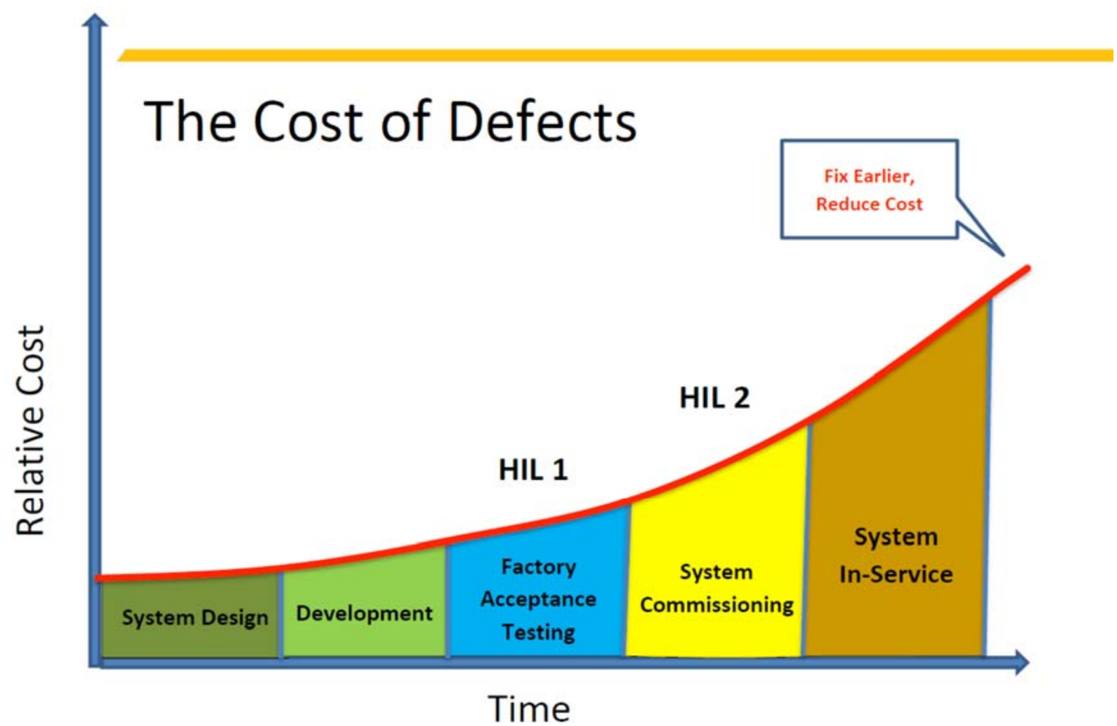
Hardware-in-the-Loop (HIL) simulation is a technique that is used for system development and testing of control systems, primarily for the operation of complex machines and systems. HIL has existed for more than 20 years, originating in the aviation industry and in mission-critical applications, such as nuclear power plants and is now very common in the automotive industry. HIL offers the ability to identify ways to improve processes and minimize risk, while providing further system improvements and system validation.

During a recent new build project, Hardware in the Loop (HIL) testing had two primary objectives related to the Dynamic Positioning system (DPS), Power Management system (PMS), Vessel Management system (VMS), Steering, Propulsion and Thrusters (SPT) systems and Drilling Control system, excluding the subsea systems:

- Minimize to the extent possible, software related risks by leveraging additional model-based testing techniques.
- Minimize to the extent possible, commissioning time by leveraging model-based testing techniques.

Transocean worked with the shipyard to allow direct communication with the HIL vendors on all topics that had no cost or scope impact, and with the understanding that the shipyard and the project team would be included in the information exchange. This protocol expedited updates and was agreed by all parties.

Focusing on our objectives, it was evident early detection was the key. The graph below demonstrates the basic concept of "Cost of Defects," which simply measures the impact of the defects with cost and time. This means the earlier the defect is detected, the less the cost of defect. The cost of finding and fixing defects rises considerably across the life cycle.



For example, if an error is found in the requirement specifications review, it is somewhat inexpensive to fix. The correction to the requirement specification can be done and then it can be re-issued. In the same way, when the defect or error is found in the design phase, the design can be corrected and it can be re-issued with minimal cost impact. However, if the error is not caught in the specifications or during the design phase and possibly through all the other stages of testing (FAT or I&C), the system may be considered to be in a full operation mode. The cost to fix those errors or defects will be much more expensive through inclusive costs associated with the interruption of operations.

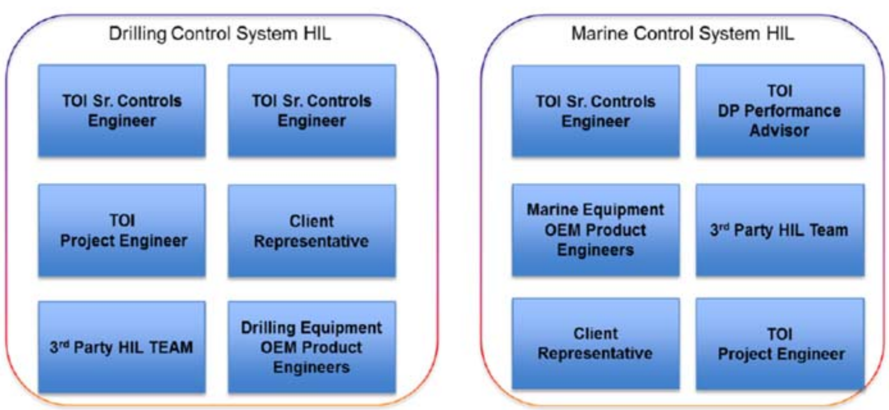
Quite often defects are detected at a very late stage, especially those defects considered as hidden failures. Depending on how serious they are, they may not be corrected immediately because the cost of doing so could be extremely expensive. Cost could be associated with time and resources needed to determine the proper correction and testing method for these kind of hidden failures. In most cases, waiting for the most opportune time while considering operational commitments, would allow for changes/corrections to be implemented as long as the proper Management of Change (MOC) is followed. Sufficient testing provides a high level of confidence that the corrective action will solve the error detected.

HIL systems are an effective means for addressing verification and validation tasks during and after system development and through the longer support phases of a system. HIL verification and validation systems are recognized as cost effective systematic approaches for understanding the effects of software changes to both operational and emergency systems behavior in the following cases:

- When testing or trials with the system are too costly, too dangerous, or some aspect of the system does not exist (especially relevant in change management).
- Variables may be inaccessible. (In a simulation all the variables are accessible, even those that are inaccessible in a real system)
- When access to the real system is limited.
- When use of the real system could harm the environment, damage the equipment or cause injury to workers.

Transocean engaged our vendors in an effort to utilize and maintain the HIL harness for the purpose of vetting recommended software and hardware changes. However, it is understood that maintaining a HIL harness for one class of vessel may not be practical or economical. With industry support, maintaining a HIL harness with the flexibility to be configured for any DP vessel will be beneficial to all.

Transocean realized that in order to have a successful HIL program, key participants had to be assembled. Transocean's engineering control group provided the oversight of the HIL testing process while working with suppliers and stakeholders in this effort. There was a team dedicated to the drilling controls deliverables, as well as the marine control system components, as illustrated in the Figure below.



Transocean's Requirements and Expectations

HIL tests were applied, as follows:

- The HIL test shall be performed on the Dynamic Positioning system (DPS), Power Management system (PMS), Vessel Management system (VMS), Steering, Propulsion and Thrusters (SPT) systems, and Drilling Control system, excluding the subsea systems.
- Results of HIL testing to be made available for review to Transocean and our customer
- HIL shall be an effective means for addressing verification and validation of tasks during system development.
- The software being tested in HIL must be identical to what is running on board the vessel during commissioning

HIL testing is a very software-centric effort. The software that is being tested in the HIL simulator must be identical to what is running on the drilling vessel at the time of the system commissioning, otherwise it can invalidate the entire HIL effort. Many of the HIL test efforts proposed did not happen on the actual hardware at the time of Factory Acceptance Test (FAT) (a result of the contract and shipyard delivery deadlines). By specifying in the contract HIL testing was to be done at the time of the FAT, allowed availability of the hardware being installed on the vessel (make, model, firmware, and revision number). If the HIL test was not done on the installed hardware, the HIL test supplier needed to provide an identical replica of the hardware.

The HIL test was not intended as a mechanism to manage change, however, the software that is tested during HIL is a critical milestone in the software development and testing process. The versions of software being tested during HIL must be uniquely identified. This process would ensure that the commissioning group have a validated software to be implemented to the commissioning system. During the testing effort we expected there to be software non-conformance findings (bugs, missing features, or identify areas of improvements). These would need to be validated to be fed forward into the next software update.

During the development of the HIL test plan, there were additional tests that had to be done, beyond what the HIL provider had originally envisioned. Capturing critical test from stakeholders was important to enable system integration into the HIL test plan. The overall HIL test program was improved, providing findings not expected from the OEMs

Finally, the HIL harness's use has value during the operational lifecycle of the rig. Currently, it is a challenge to validate software prior to installing it on vessels. Much of the software testing occurs on the actual equipment as opposed to testing in a controlled and safe environment. The reason for this is typically because the developers do not have access to a replica of the vessel's control system.

The HIL harness is an obvious and extremely beneficial platform for this purpose, mitigating our software risk and operational risk activities. The team involved in HIL software testing had to establish, a way to make this platform a vailable beyond the vessel's deployment, but due to current market activity, maintaining a HIL harness may not be seen as a cost effective tool. We explored all options in developing a universal HIL system that can easily be converted to meet any DP vessel system in a short time and be considered a cost effective tool while mitigating software risk and operational risk activities.

Execution Philosophy

HIL should be arranged in two parts:

- HIL1 should be performed at an earlier stage of the software maturity, preferably during FAT or prior to system installation on board, with the primary intent to minimize project risk.
- HIL2 should be either prior to proving trials or following systems commissioning, with the primary intent to minimize operational risk.

There is a time commitment involved to coordinate and capture test requirements, oversee the HIL testing, as well as verify the corrections are fed forward into the next development cycle. This makes sure they are integrated into the operational systems, while documenting all steps of this process including changes made.

Schedule and Planning

A HIL schedule must be organized to the point that HIL testing does not fall on the critical path of the drillship's manufacturing project delivery timeline. Therefore, in order to complete the HIL test before it becomes an issue affecting the critical path of vessel completion, there are a number of prerequisites that need to be completed and established. This includes data gathering from the perspective suppliers, shipyard and stakeholders, as well as reviewing and finalizing test documentation, functional design specification and systems technical drawings. If there is no dedicated effort toward the success of data gathering, the HILs execution effort could easily be lost.

There should be sufficient time for HIL simulator development (hardware & software), including development of test exercises based on system data collected and system interfaces (i.e. thrusters VFD's & drawworks VFD's) are captured as part of HIL testing. HIL vendors should also be aware to plan or allocate sufficient time for other specific requirements initiated by stakeholders, as well as allowing time for reviewing and finalizing test procedures.

For this HIL project, approximately 24 months was proposed from the time of the order, until vessel deployed for their FMEA proving trials. The proposed schedule identified key timeline for obtaining information required, kick-off meetings, I/O list requirements, Hardware FAT, engineering freeze date, HIL 1 testing with punch claring period and finally HIL 2 testing with punch clearing period.

Hardware In The Loop – Systems Tested

For both the Marine Control Systems, as well as the Drilling Controls deliverables, certain subsystems / processes had been defined that were included in HIL testing. This was agreed by the respective suppliers and shipyard prior to testing. These are broken down as follows:

Marine System

- Dynamic Positioning system (DP)
- Vessel Management system (VMS)
- Power Management systems (PMS)
- Steering, Propulsion and Thrusters (SPT)

The marine system HIL test program ensured that all key functions were cycled through, verifying that the control system responded according to documented standards and guidelines, as well as class rules. For the DP system, the main test was associated with station keeping and system response while utilizing the HIL simulator to manipulate environment forces (wind & current) while confirming vessel design capabilities. Other tests were associated with the DP system model control and the circumstances that would trigger this function while correcting for wind forces, as wind feed forward function.

The HIL team was very knowledgeable of the DP system capabilities and had a good understanding that the DP system encompasses the complete vessel, meaning that in order to concentrate on the DP system, other key systems must be validated for their correctness, such as: vessel management system, power management system, steering, propulsion, thrusters, sensors, position references and their unique interface with DP. During HIL, each system had its particular function verified as operating according with its system functional design specification and any interaction through the interfaces was verfied as not impacting DP operation.

The hardware portions of HIL test involved the operating stations, control transfer function, sensor failures, DP controllers failover function, communication link (networking) robustness and the verification that with every fault, the proper indication was displayed on the HMI and the corresponding alarms were generated.

Drilling Control Systems (both main and aux wells)

- Piperacker main & aux well
- Fingerboard w/belly-board
- Riser handling catwalk w/tail arm
- Pipe handling catwalk machine shuttle w/tail arm
- Hydraulic power unit (HPU) for ringline system
- Wire-line riser tension
- Anti-collision system (ACS)
- Machine interlocks
- Guide-arm in derrick
- Drawworks main & aux well
- Mud pump control system
- Top drive main & aux well
- Iron roughneck main & aux well
- Hydraulic mud bucket
- Rotary table main & aux well

The drilling control system test program verified that all key functions were cycled through on each tool from the main and auxiliary well station, that the drilling tool responded according to documented standards, guidelines and their own FDS. The HIL team was very knowledgeable of the drilling control system and its capabilities, particullartly during specific tool operation. The operator ensured the HMI represented proper feedback as they operated the tool and delivered the corresponding messages, whether it was an alarm, warning, measurements, etc.

During HIL testing, part of the validation process, we verified that the control system could handle failure situations for every tool interfaced, in a safe method by activating appropriate protection functions, intelocks, activating emergency stop, generating appropriate alarms, and indicating when all is safe. When each tool (listed above) was individually validated, we integrated all the tools associated with each well station, to verify there were no descrepencies noticed. This allowed the opportunity to simulate different type of drilling activities.

The following were the drilling operation activities performed during HIL:

- ✓ Verify trip in & out operations
- ✓ Verify stand build & break operations
- ✓ Verify drilling operations on main & aux well

HIL Findings

Upon completing a series of tests on a given tool or a system (marine or drilling), the results of each test were captured on the test sheet and recorded on the test result sheets (TRS) as one of the following:

Marine group:

- "A" or high level finding – nonconforming with system design, rules or regulations
- "B" or low level findings – nonconformity with requirements, specifications, industry guidelines, standards, stakeholders documentation (such as user manuals), or intended use
- Observation or cosmetic – would indicate valid and/or relevant finding such as HMI or grammatical issues.
- VOID – findings that are not relevant or invalid due to misunderstanding of test items, simulator capabilities and or interface problems outside of the scope of HIL
- TBD – to be determined – basically is an observation that requires further clarification. This category allows time to review FDS or possibly determine an area of improvement, especially if it is a function that was not part of the system deliverables.

Drilling group:

- Cosmetic – primarily related to the presentation or the layout of the data
- Minor – defects that can or have caused low-level disruption of function, but not decreased safety
- Moderate – defects with an acceptable workaround; no impact on safety
- Major – defects that have seriously degraded the performance, caused unintended action or transmitted incorrect data. No workaround exists
- Critical – defects that halt or are capable of halting the operation

MOC Processes / Track Changes

All findings were recorded on the TRS, assigned a number, identified a level of severity, provided a brief description of the fault and the test on which the fault occurred. Suplier engineers reviewed the TRS, and if deemed valid, generated a change registry or rig event change request, which are part of the vendors' own MOC processes.

The marine group utilized IAS change registry (ICR) which is the OEM internal document written for all observations categorized as "A" or "B" findings. The ICR database is the OEM's tracking tool used for registering of all changes occurring in a project. Changes entered in this database will specify the criticality for which the system change is and clearly state where to find the change, i.e. in a specific field station, aparticular HMI mimic or which part of the software code.

The drilling group utilized rig event is the OEM's internal document and database that identifies all changes made with a detailed description or a screenshot of the before and after to indicate how the finding/descrepency was resolved. This also references any associated document that supports why changes were made.

Both the marine & drilling groups, the responsible engineer validated changes made by retesting through the HIL simulator and verified the changes made were valid, before releasing new software version to the commissioning team and for HIL2 testing.

Lessons Learned

- FAT software punch list items should be included for validation through HIL testing.
- HIL1 should start promptly after FAT or be incorporated as part of the FAT.
- HIL2 should start after system commissioning and include all other vendor interfaces (thruster VFD's, drilling equipment motors VFD's, etc.).
- Better tracking of KPIs compared to I&C shipyard findings vs. HIL findings.
- System tools (i.e. for drawworks, top drive, DPS, VMS, PMS, etc.) and respective product responsible engineers should be readily accessible during HIL testing.
- Improved HIL documentation is required during testing (e.g. provide FDS, ops manual, maintenance manual)
- Challenge vendors for higher fidelity HIL Models (i.e. hydraulic models, electrical MCC models, VFD models) and environmental models (e.g. vessel hydrodynamic & wind models, etc.)
- Retain HIL simulator & models available for testing of software updates for the life of the rig.

Method of Measurement

Transocean's concept for determining value of HIL, was basically a measurement that allowed one working day for an individual to address one HIL finding, this cooresponded to:

- ✓ Confirm the finding
- ✓ Determine best resolution
- ✓ Solve the issue / finding
- ✓ Retest in a control environment the solution for its robustness
- ✓ Document action taken,
- ✓ And release as a new version.

Drilling Controls: 377 findings = 377 man days
Marine Systems: 138 findings = 138 man days

Therefore, when considering cost benefit, one must determine the man days used to correct deficiencies found during HIL and assess the correlated risk for encountering a similar deficiency in an operating control system.

Opportunities for Improvements

With industry support and collaboration, we could conceivably leverage vendors to incorporate HIL type testing as part of their standard deliverables and cooperate in defining the next generation of HIL testing.

This team suggests a new HIL summary (high-level) document, developed or collaborated by the industry that clearly defines HIL objectives and processes. This document should be a one page document that supports and works in conjunction with a HIL program / philosophy document, which is descriptive of its structure and processes. The following are suggested topics to be included:

HIL High Level FDS summary document

- ✓ HIL model definitions
- ✓ List of systems – software dependent system (SDS)
  - o Station keeping – DP control system
  - o Vessel monitoring and control systems (PMS, VMS, SPT, etc.)
  - o Safety systems (ESD – F&G)
  - o Industrial mission systems (pipe or cable laying, drilling, construction, diving, etc.)
  - o HIL1 – OEMs should incorporate HIL testing as part of their FAT (FAT/HIL)

- ✓ HIL2 Integrated (all parties) simultaneous (real-time) testing, including all available interfaces possible; involve a third party to aid in validation.
- ✓ Purpose statement: safety, software risk, optimized performance
- ✓ Describe the MOC process – track HIL findings thru commissioning / operating system – life of vessel concept
- ✓ Reference HIL Program document

HIL Program Document

1. Define HIL
2. Life of vessel concept
3. HIL harness availability
4. Integrator / third parties
5. Define / structure of interfaces
6. Interface simulator from all suppliers
7. Test results - standard categorization and documentation
8. Suitability of model testing
9. Specify "integrity" testing
10. MOC process, including settings and parameters
11. Change order / software freeze
12. Ownership / intellectual property
13. Leveraging HIL methodology for development
14. Schedule sequence of events
15. Testing organizational structure
16. ADHOC testing

Conclusion / Benefits of HIL Testing

Based on this example, HIL testing was an effective means of system verification during development and integration. Through proper planning, execution and the assembling of the right team, HIL can assist with identifying system design issues prior to system integration, as well as identifying issues not normally found during a FAT or commissioning activities. Always keeping the focus on the impact of the defects with cost and time, the earlier the defect is detected, the less the cost of defect.

HIL testing is a software intensive effort, particularly with extensively developed system models. Our findings demonstrate the MOC process being followed by both OEM vendors, and provided recommendations on methods of improving future HIL testing. HIL testing is a software tool with the potential of providing a control system with no or minimal defects before a DP asset commences operation. The benefits of HIL should not be overlooked when seeking to:

- ✓ Identify design issues prior to system deployment
- ✓ Shorten validation and commissioning time and processes
- ✓ Retaining HIL simulators for ad-hoc testing throughout the life of the vessel
- ✓ Testing software updates on a repeatable, HIL-based software test bed

As an industry, we can better leverage this technique and participate and collaborate in the development of these documents (HIL FDS and HIL program/philosophy) in preparation for the next build cycle.

Note: The opinions, beliefs and viewpoints expressed by the various authors of this paper do not necessarily reflect the opinions, beliefs and viewpoints of Transocean.