Evaluating the effectiveness of applying a Requirements Management System for a Subsea Oil and Gas Workover System

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Abstract

The accurate elicitation, analysis, and management of requirements throughout the system life cycle of oil and gas workover equipment are essential to the successful delivery of this system on schedule and within budget. There is a need for workover system providers to look for ways to better elicit, analyze, and manage requirements in order to reduce non-conformances and stay profitable. This paper evaluates the effectiveness and effort of using customized software named Requirements Management System (RMS) to process requirements for oil and gas workover equipment. We evaluate the RMS through peer review and guidelines from ISO/IEC TR24766.We receive positive feedbacks regarding the use of the RMS as a platform for managing requirements and highlight several areas for improvement. Finally, we provide suggestions for future research on quantitative means of evaluating the effectiveness and effort to implement the RMS.

Introduction

A workover system (WOS) controls the flow of oil and gas during start up or maintenance of subsea wells. WOSs that do not meet requirements or delivery schedule may have cost and political implications for the owners of the wells. This is due to the high costs associated with increased rental period of the installation rig (with estimated daily rental rate in excess of 500K USD) and contractual obligations for the supply of oil and gas.

Client specific requirements that reference industry and country specific requirements govern the design of the WOS. The subsea system provider (herein referred to as the Company) elicit and analyze requirements for projects through reviewing of Clients' specifications and discussions with Clients. The Company will then derive system level specifications describing the requirements for the WOS followed by subsystem and product level specifications. Figure 1 below shows a typical breakdown structure of the WOS. The left side of Figure 1 shows that the WOS consists of two main subsystems, the *Riser and Well Integrity System* (risers, valves, connectors) and the *Controls System* (hydraulics, electrical, software and computer system). The Design Basis Document (DBD) is the Company's starting point for defining Client and external requirements. The DBD serves as a reference to generate two-subsystem specifications and more than 50 product level specifications.

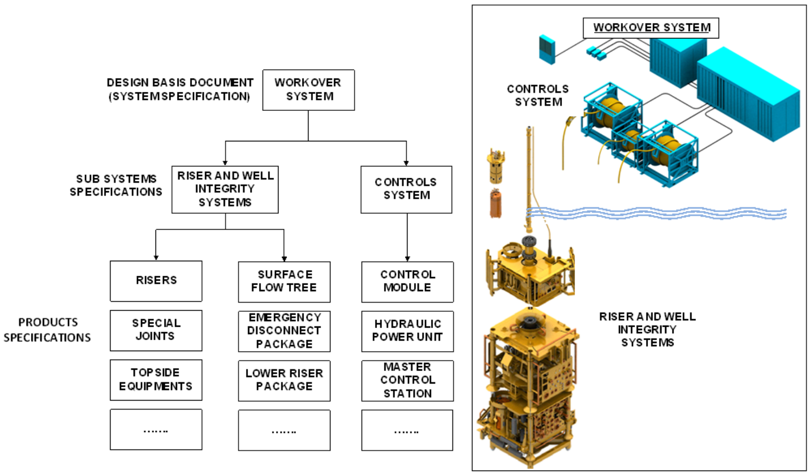

Figure 1: System/product breakdown structure (Left side) and illustration of a typical Subsea Workover System (Right side)

According to the Company's Business Process Management System (BPMS) shown in Figure 2 below, the Company starts to elicit requirements from Clients during the *Perform Sales Phase*. This is where the Company collaborates with Clients on Front End Engineering Design studies that may progress into formal tenders for the project. The Company further defines the requirements during the *Execute Tender Phase*. System and product engineers document the requirements using tools such as Microsoft Word or Microsoft Excel.

The Company utilizes the Siemens Teamcenter Engineering (TCE) system (Customized form of Product Lifecycle Management software) to translate requirements into DBD and specification documents during *Project Execution Phase*. Verification reports after testing and validation reports after commissioning are stored in the Systems Applications and Products in Data Processing (SAP).

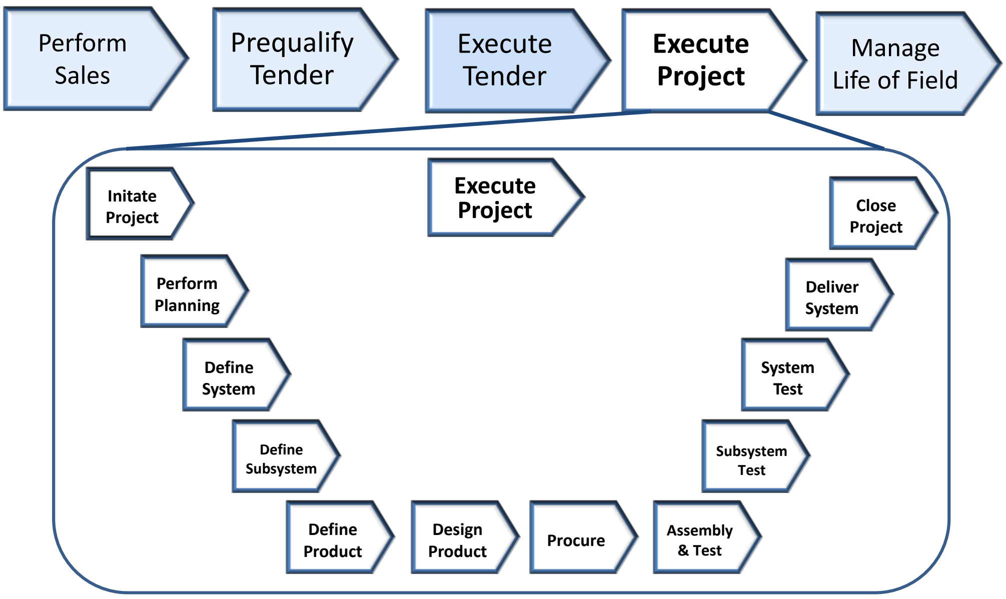

Figure 2: BPMS process (Highlighting *Execute Project* phase)

Problem statement

There is currently no common platform to allow the elicitation, analysis, and management of requirements throughout the WOS lifecycle. The Company utilizes different systems to trace requirements, i.e. Excel or Word files during tender stage and TCE system during project

execution. There is a risk of missing out or mismanaging requirements during the system lifecycle, causing unwanted changes, and rework to the system. This ultimately affects cost and schedule, and quality of the delivered products. The Company quantifies these effects as the price of non-conformance (PONC).
In recent years, there has been an increase in the occurrence of PONC during Company's project executions. Hole [1] provides several of these examples in his paper where the Company needed to perform rework on equipment due to poor clarification and management of requirements during tender phase.

Proposed solution

The Company is developing a Requirements Management System (RMS) to formally elicit, analyze, trace, and manage requirements for oil and gas systems. The goals of the RMS are to increase focus in generating SMART (Specific, Measurable, Agreed upon, Realistic and Traceable) requirements, improve traceability of requirements, and facilitate better communication of requirements to the project teams and Clients. In addition, the RMS will allow for the creation of templates for documenting requirements. Templates will enable potential reuse of requirements and according to Lam et al [2]; this will generate cost savings for future projects.

Research

We aim to look at how effective the RMS is in managing WOS requirements and the amount of effort needed to implement the RMS in a project.
The *Research Methodology* section below will provide an overview of the research methods used to evaluate the effectiveness of the RMS. After that, the section on *Requirements for Subsea Oil and Gas Workover System* presents a general introduction into the typical requirements for a WOS project and the key challenges with managing them. The sections on *Requirements Management Systems and Workings of RMS* provide a summary of the need for requirements management system and how the RMS functions. *RMS Implementation, Findings, and Discussions* provides results and discussion on the use of the RMS on WOS requirements. Finally, we summarize the results of the evaluation and provide suggestions for areas of future research.

Research Methodology

This paper summarizes the research performed during a 5-month period. We research the current engineering processes in the Company to understand the process of capturing and managing requirements throughout the system lifecycle. We also seek to understand the reasons for using RMS for requirements management in the Company as opposed to commercially available requirements management tools.

We apply RMS in one of these projects, extracting requirements from the Client specification to the DBD, subsystem specification and product specification. We also create a template of requirements using the RMS. We document all the requirements in Requirement Specification reports (RQSs) and review these reports with a team of five senior tender and system engineers involved in the project to obtain practical feedback. Potts [3] refers to this type of research where the researcher is researching problems and operating the system at the same time as using the "Industry as Laboratory."

Based on recommendation by Juan, et al [4] we chose to measure the effectiveness of the RMS theoretically using the guideline ISO/IEC TR24766 [5]. We evaluate the effort to implement the RMS by measuring the hours needed to apply the RMS on project and template specifications. We estimate the hours needed to use the RMS in the Company's business process based on our use of the RMS on project and template specifications. Due to the limited research period, we feel that the methodology of active usage of the RMS, getting expert, feedback, and comparison with the industry standard will provide the most practical review of the RMS now. A more realistic evaluation method will be to review the PONCs and hours needed to use the RMS throughout the entire system life cycle of the project. This will however need at least 2 to 3 years or more to provide the relevant data.

Requirements for Subsea Oil and Gas Workover System

Figure 3 provides an illustration of the different stakeholders of the WOS and the categorization of WOS requirements into systems and product related areas. System level requirements such as temperature, pressure rating, directly affect product level requirements, and may result in a less optimal design of the product. For example, the system may have a temperature requirement of 0°C to 121°C; however, some of the products may only encounter 80°C of production oil, as they are located nearer to the surface of the seawater. It will be an additional cost to design these products to 121°C. It is important to evaluate the relevance of system requirements when deriving product requirements. The active stakeholders in a WOS are the Client (e.g. independent or national oil companies), government regulatory bodies, and industry standards. The Company documents the requirements elicited from the stakeholders in DBD, sub system and product specifications.

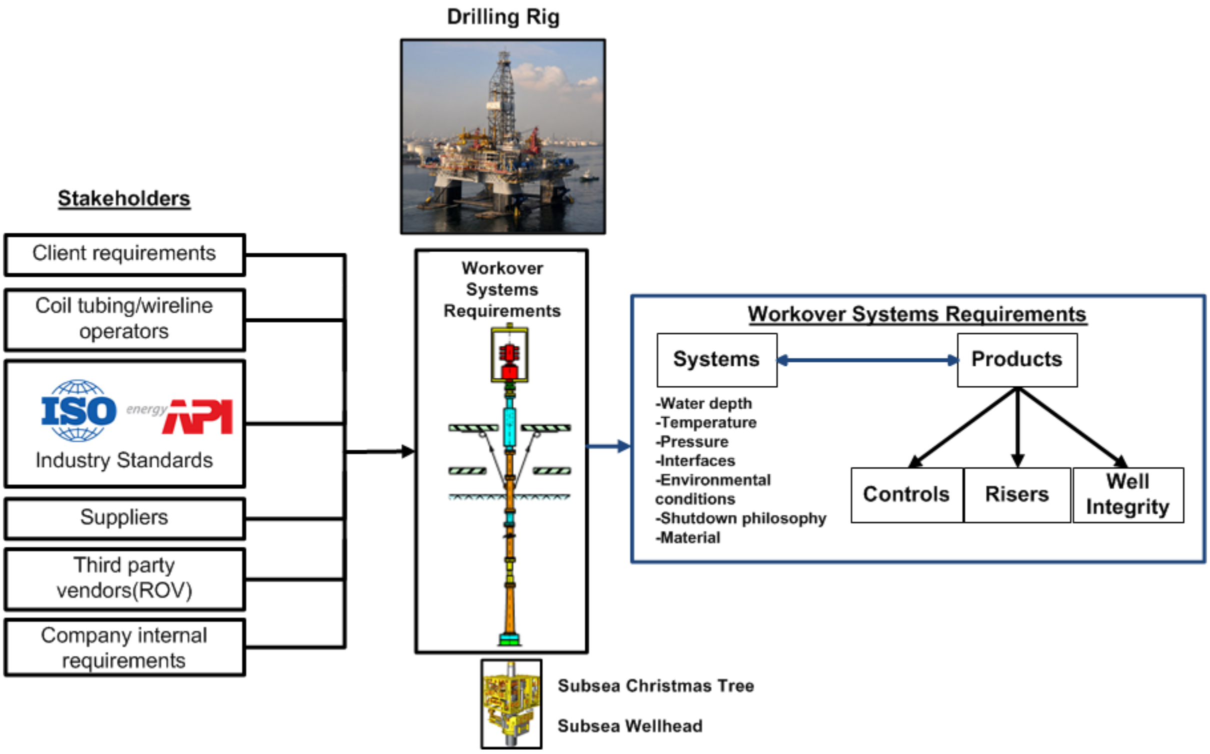

Figure 3: WOS requirements - Stakeholders and Categorization of requirements

From our research, we find that the key challenges for managing WOS requirements are due to the following,

1) Demand of eliciting, analyzing, and managing the numerous requirements
2) Unknown requirements on operating conditions
3) Multiple dependencies among requirements

1) WOS requirements comprise of more than 100 different specifications totaling thousands of requirements. It is difficult to manage all the requirements due to the sheer number of requirements. In addition, the different precedence levels for requirements increase the complexity of handling these requirements. These requirements involve different disciplines and require experienced personnel to review them. Figure 4 below provides an illustration of all the requirements in a WOS project.
The turn-around times for evaluation of requirements during tender phase are typically short (6 to 8 weeks), resulting in a risk of requirements being missed or not clarified.

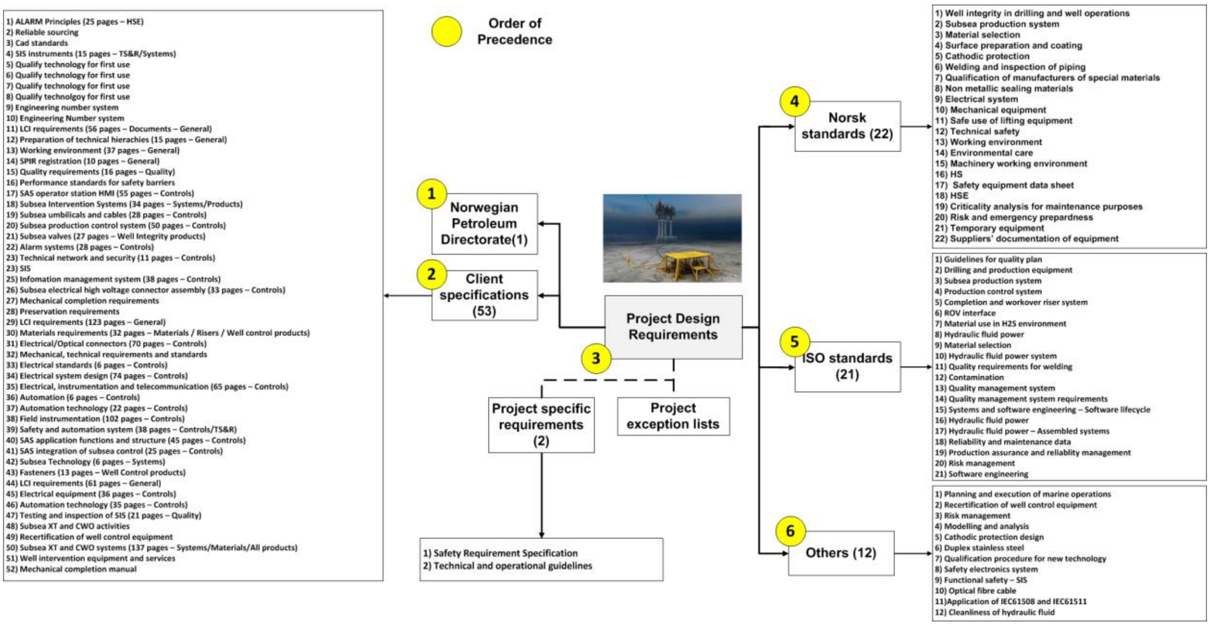

Figure 4: Sources for WOS requirements (Example)

2) The details regarding the operating conditions (i.e. type of operating vessels used, environmental conditions of field) for a WOS are typically unknown during tender phase. In spite of this, the Client often requires the WOS to be flexible in design so that it can function under different operating conditions with minimum changes. An example is "*The WOS may be used on different fields and interfaces shall envisage operations with subsea horizontal trees as well as subsea vertical trees*."

Operating conditions are key inputs for systems analysis such as riser and hydraulic analysis, which drives the product design of the WOS. Changes to operating conditions will directly influence the design of the WOS. The Company needs to clarify this type of requirements during the tender phase to ensure that the Client understands the operating details needed to meet their requirements. One example is regarding the system requirement for the allowable rig operating area (area in which the rig is allow to operate without damaging the WOS). This data is typically not available at the beginning of the project, as the operator has not confirmed which type of rig to use. The WOS provider typically starts designing the WOS using past proven design but risks having design changes when the requirements of the operating limits are determined during project execution.

3) We found that there exist multiple dependencies among WOS requirements. There is generally a lack of clarity regarding dependencies between WOS requirements in Client specifications. Table 1 below provides some examples of these dependencies.

Table 1: Impact of system requirements on product design

Title	Requirements	Impact to product design
Shut down and disconnect functions	Emergency Shutdown (ESD) shall be achieved within 45 seconds from activation Emergency Quick Disconnect (EQD) shall be achieved within 60 seconds from activation	The need to be able to perform ESD and EQD within the time requirement at 1500m water depth may result in additional accumulations on the well control package. This will increase the weight of the well control package and may pose a problem during handling and deployment There is a need to increase the size of the hydraulic/electrical umbilical in order to accommodate for the increase in length and this will result in the umbilical system becoming heavier, causing constraints in transportation and handling.
Water depth	The WOS shall be designed for a water depth of 1500m	
Design life	The WOS shall have a design life 25 years and a service life of 10 years.	The anodes (for cathodic protection) required on the WCP in order to satisfy the design and service life requirements may cause the weight of the WCP to exceed 30 metric tons.
Weight	The Well Control Package (WCP) shall not weigh more than 30 metric tons to allow for handling during transportation and operation.	

Requirements Management Systems and Workings of RMS

A system for eliciting and documenting requirements in a common database is required in order to address the three key challenges stated in Table 1. In addition, Kirova [6] states that a form of automated requirements management system should be in place in order to manage requirements for large complex system (500 or more requirements) efficiently. This is relevant for WOS projects that can amount up to thousands of requirements as shown in Figure 4. There are many different types of tools in the market for managing requirements. Some of these tools include manual tracking of requirements using Microsoft Excel or Microsoft Access Database or with commercial off the shelf software such as the Rational Suite Analyst studio.

Hole [1] mentioned that the Company has embarked on initiatives since 2007 in order to trace and manage requirements more effectively. These initiatives range from creating a Requirement Management Matrix (RMM) using Microsoft Excel to developing master templates for DBDs. Hole [1] claimed that the Company did not continue with these initiatives due to a lack of commitment from the engineers and the poor usability of the different tools. In recent years, the Company has started to look into developing a customized form of requirements management system. According to Grinderud [7], the Company has evaluated the available tools in the market and decided to develop the RMS based on existing requirements management features in Siemens Teamcenter (TCE) software architecture. The reason for this is that the Company is already using the TCE system for documenting engineering specifications and testing requirements. The use of TCE architecture for the RMS will allow for easier linkage of requirements between TCE and RMS, and potentially lowers the cost of maintenance and training. In addition, the Company has tailor made the software of the RMS such that it can provide a structured output of all the requirements and their defining or complying trace-links either in an online format or in pdf. This feature is very important to allow reviewing and discussion of requirements among different parties.

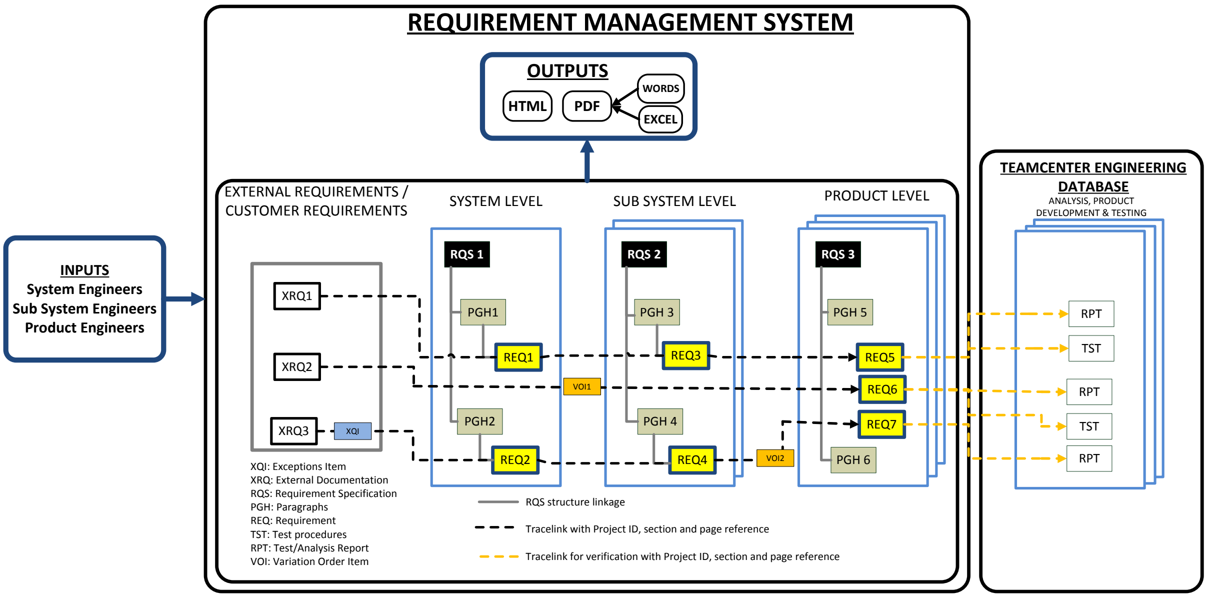

Figure 5: Workings of RMS

Figure 5 above illustrates how the Client requirements (starting from the left of the figure) link to the requirements in the system level, subsystem level and product level in the RMS.

Summary of the workings of the RMS are as follows

- Generate requirements: Users first generate requirements into XRD type documents upon review of Client and Industry specifications.
- Analyze requirements: Users will then analyze each requirement and input them with a unique identifier into the XRD document as an XRQ item. XQI items (blue box) provide itemization of any exceptions or non-conformances to requirements. Users generate a requirement specification document (RQS - black box). The RQS consists of different unique paragraphs (PGH - grey box) and individual requirement (REQ - yellow box)
- Classification: Users classify the RQS into different categories i.e. Internal, Client type, to allow for referencing and reusing in the future.
- Tracing requirements: Users then trace each requirement to the defining requirements in the Industry or Client specifications. Users identify each change in requirement as a VOI item (Variation Order Item - orange box)

The right side of Figure 5 shows the existing Teamcenter Engineering Database that stores all the engineering specifications, reports, and procedures. Users will link each requirement in the RMS to documents in the Teamcenter Engineering Database. This is to provide traceability during design verification and system validation phase.
The Company will review each RQS internally and externally (with Clients) using online HTML (Hyper Text Markup Language) output and pdf reports. The Company had specifically develop the HTML output in order to provide an overview of all the requirements

with their complying and defining parts. This feature is useful for reviewing and discussing requirements with Clients or within the Company.

RMS Implementation, Findings and Discussions

We use the RMS to capture external requirements and requirements specifications of an ongoing WOS project. We evaluate the output results of the RMS with tender engineers, system engineers, and RMS developers to obtain their feedback. Based on this feedback, we then assess the RMS with the guidelines given by ISO/IEC 24766 [5] and Juan et al [4]. ISO states six categories (elicitation, analysis, specifications, validation, verification, and management) for assessing requirements management tools and Juan [4] further expands this by including modelling, traceability and user-ability aspects. We develop 32 assessment points based on these nine categories and evaluate the RMS using these. We give a point scoring system of 0 to 4 to each assessment (0 being "Not useful" and 4 being "Very effective"). Table 4 below provides a summary of the assessment points for each category. The RMS scores 60 out of 128 points compare to the score of 19 points for the current method of requirements management using documentation. We provide details of each assessment category in Table 2 below.

Table 2: Industry Assessment

S/NO	Requirements	Definition	Rating(RMS)	Rating(Current method)
1	**Elicitation**	How effective is the RMS in seeking, uncovering, acquiring and elaborating requirements?	11/24	0/24
2	**Analysis**	Does the RMS allow for decomposition of high level requirements into details, evaluating feasibility, analyzing overlaps or conflicts between requirements, and negotiating priorities?	3/20	0/20
3	**Modeling**	Does the RMS has the ability to provide features for the physical, functional and performance modelling of the system?	0/8	0/8
4	Specification	Does the RMS allow for documenting the requirements in a consistent and reviewable way?	6/8	0/8
5	Verification and Validation	Does the RMS supports the Verification and Validation of requirements (ensuring the system is built to the correct requirements) and Validation	5/8	0/8
6	Management	Does the RMS has the ability to support the monitoring of changes and maintenance of requirements, ensuring that the requirements accurately reflect the product?	11/16	7/16
7	Traceability	Does the RMS has the ability to document the life of a requirement, providing linkage mechanism between associated requirements and tracking changes made to each requirement?	11/24	0/24
8	User friendliness	Is the RMS simple to comprehend and control? Even for non-users of the system?	8/12	5/12
9	Support and Maintenance	Does the RMS allow for multiple users licenses to be used in different projects? The system shall not be overly costly to maintain and support for the system shall be readily available during normal working hours.	5/8	7/8
Total			**60/128**	**19/128**

1) Elicitation - How effective is the RMS in seeking, uncovering, acquiring and elaborating requirements?

The RMS allows import of documents and classification of requirements. It does not allow for any automatic parsing of requirements nor has any ability to support identification of stakeholders and stakeholders' needs.

2) Analysis - Does the RMS allow for decomposition of high level requirements into details, evaluating feasibility, analyzing overlaps or conflicts between requirements, and negotiating priorities?

The RMS allows decomposition of high-level requirements into detailed requirements through the linkage of requirements between the different RQS. It does not have any automatic capability to provide feasibility analysis, or to analyze overlaps or conflicts between requirements RMS users will need to capture these functions manually.

3) Specification - Does the RMS allow for documenting the requirements in a consistent and reviewable way?
The RMS presents requirements in the form of a Requirement Specification (RQS) document in pdf and facilitates web access to this document in terms of HTML output. The RMS will automatically assign a unique identifier for each requirement based on input from the user. The pdf and HTML outputs provide a clear and structured overview of all the requirements.

4) Modelling - Does the RMS has the ability to provide features for the physical, functional and performance modelling of the system?
The RMS currently does not have any capability to provide modelling for the WOS.

5) Verification and Validation - Does the RMS supports the Verification and Validation of requirements (ensuring the system is built to the correct requirements) and Validation of system (ensuring that the right system is built and meets the stakeholders' need?)
Verification test reports and validation commissioning reports are located in the engineering TCE system. We can trace these reports back to the requirements items in the RQSs. The actual verification and validation modules are still being developed and the goal is to create unique identifiers for each verification or validation test results and to trace these back to the requirements in the RQSs.

6) Management - Does the RMS has the ability to support the monitoring of changes and maintenance of requirements, ensuring that the requirements accurately reflect the product?
The RQSs and REQs are revision controlled. The revision of each requirement (REQ) will result in the revision of the affected RQS as well.

7) Traceability - Does the RMS has the ability to document the life of a requirement, providing linkage mechanism between associated requirements and tracking changes made to each requirement?
The RMS allows for bi-directional tracing of each requirement. RMS users are able to check each inconsistency (unlinked requirements) manually. Each requirement is revision controlled. Users can perform impact analysis when there is a revision of each requirement in order to review all other affect requirements.

8) User friendliness - Is the RMS simple to comprehend and control, even for non-users of the system?
The pdf output report and HTML view provides a visual view of all the requirements and shows all the trace links of these requirements clearly. However, the RMS has many functions that are not used. Removing them may create a simpler, more user-friendly view of the tool. We also think that there are excessive steps needed to generate output reports that add on to the complexity of using the RMS.

9) Support and maintenance - Does the RMS allow for multiple users licenses to be used in different projects? The system shall not be overly costly to maintain and support for the system shall be readily available during normal working hours.
The RMS support access for multiple users. There is a need to evaluate the cost to support the RMS throughout different regions and offices with the adequate network. We do not expect there to be a significant increase in the cost to support the RMS since it is operating off similar system as that used for the TCE PLM currently used in the Company.

Effort required to use RMS

Table 3 below summarized the hours we have spent on using the RMS on different specifications. We are interested in the hours needed to use the RMS, hence we did not evaluate hours required for developing the RMS since this is part of a separate research and development budget.

These hours include time taken to populate, format, review, and formally release each Requirement Specification document.

Table 3: Summary of hours in using the RMS

Specifications	Requirements Specification Number	Hours spent (hrs)	No. of requirements
System specification, WOS	RQS80010128	35	78
Subsystem specification, WOS	RQS80010137	80	190
Product specification, Riser	RQS80010163	50	82
Subsystem specification template, WOS	RQS80010181	50	249

We use up more hours (80) when working on the subsystem specification (RQS80010137) as compared to the hours spent on the subsystem specification template (RQS80010181) primarily because we spent additional hours getting familiarize with the RMS. Based on this, we estimate that an engineer will require between 60 to 80 hours using the RMS to generate a subsystem requirements specification. The system engineer who is managing requirements on the system level provided feedback on the hours used for generating the system requirement specification (RQS80010128).

We see that there is a direct relation between the number of requirements and the time needed to generate the requirements specification. We attempt to describe this relationship with the equation below. The training component $\mathbf{t_{training}}$ is the amount of hours engineers need to be proficient in using the RMS. The exact figure for this component has yet to be determined. This duration includes mainly hours for training and may differ based on the skills and experience of the engineer. There will be some time spent for starting up the system or running output reports, we expect these to be in insignificant compared to the actual requirements engineering work. The time required to generate and review each requirement $\mathbf{t_{REQ}}$ also needs to be determined upon further use of the RMS. From our use of the RMS, we find that this duration may depend on the complexity of the requirement at each different lifecycle stage.

$$t_{RQS} = t_{training} + (N_{REQ} * t_{REQ})$$

t_{RQS} - Time taken to generate requirements specification
$t_{training}$ - Time taken to train personnel to use RMS
N_{REQ} - Number of requirements
t_{REQ} - Time taken to generate each requirement

Based on our usage of the RMS, we estimate the hours required to use the RMS in a WOS project throughout the different project execution stages (as shown in Figure 2).

Table 4 below shows the breakdown of hours to use the RMS (excluding overhead hours).

Table 4: Summary of hours to use the RMS throughout the phases of the project lifecycle

Execution stage	Responsible personnel	Workscope for a Workover System Project	Estimated average number of requirements /document	Total Hours (hrs)	No. of documents	Remarks
Perform Sales	Field Development Engineer System Engineers	1) Input requirements and Client specification into RMS (XRDs) 2) Review and release requirements in RMS (XRDs)	**100**	**>80**	>10	Feedback from RMS developers
Execute Tender	System Engineer	1) Create RQS, requirements and system specification for WOS. 2) Update exceptions and clarifications to RQS 3) Discuss with Client on ouptut of RQS 4) Review and release RQS and system specification in RMS	**80**	**15 to 25**	1	Extrapolate from research
Define System	System Engineer	1) Update exceptions and clarifications to RQS 2) Discuss with Client on ouptut of RQS 3) Review and release RQS in RMS	**80**	**25 to 35**	1	Research and partial extrapolate
Define Subsystem	Sub system Engineers	1) Create RQSs, requirements and for subsystem system specification 2) Update exceptions and clarifications to RQSs 3) Discuss with Client on ouptut of RQS 4) Review and release RQSs and subsystem system specification in RMS	**190**	**120 to 160**	2	Extrapolate from research
Define Product	Product Engineers	1) Create RQSs, requirements and product specifications for product level 2) Update exceptions and clarifications to RQSs 3) Review and release RQSs and product specifications in RMS	**90**	**2000**	50	Extrapolate from research
Assembly & Test	Product Engineers	1) Update RQS, deviations, requirements and product specifications after verification testing.	**To be determined**	**To be determined**	50	To be determined
Subsystem test	Sub system Engineers	1) Update RQS, deviations, requirements and specifications for subsystem levels after verification testing.	**To be determined**	**To be determined**	2	To be determined
System Test	System Engineer	1) Update RQS, deviations, requirements and specification for system level after verification testing.	**To be determined**	**To be determined**	1	To be determined
Deliver system	System Engineer Aftermarket Engineer	1) Update RQS, deviations, requirements and specification for system level after validation of system 2) Discuss with Client on ouptut of RQS 3) Review and release RQSs in RMS	**To be determined**	**To be determined**	>3	To be determined
Operation of system (Change management)	System Engineer Aftermarket Engineer Product Engineers(s)	1) Ensure updates to RQSs upon requests from Clients to upgrade WOS 2) Discuss with Client on ouptut of RQS 3) Review and release RQSs in RMS	**To be determined**	**To be determined**	>3	To be determined
(blue)	**Assumed hours**					
(yellow)	**Research hours**					

During the *Perform Sales* phase, engineers need to discuss with the clients on the project requirements and input these requirements into the RMS database. These requirements act as the defining requirements for subsequent requirements generated during the project execution phase. The RMS currently has more than 50 of these client and industry specifications in its database. The feedback we got from the RMS users is that it will require an average of 8 hours to generate each of these documents.

In the *Execute Tender* phase, the engineers will need to start to gather data in order to generate the system requirements specification. We estimate the time for this work to be between 15 to 25 hours as this will take less than the hours required for the system specification to be fully completed.

We were unable to provide any estimation of the hours required for the *Assembly and Test* phase to *Deliver System* phase since the project has not yet been through these phases. In addition, the verification and validation module of the RMS has not been developed fully yet. We also expect that there will be changes to requirements during project execution. These changes may be due to contractors not being able to adhere to detail requirements or if there are changes in the operating conditions, i.e. change in rig. We were unable to estimate the duration for these changes now as there is currently no change management functionality in the RMS.

The current assumption in the Company is that the only additional hours needed to implement the RMS will come from the Perform Sales Phase, where we will need to input new requirements into the RMS. The engineers will need to spend the same amount of hours to elicit and define requirements regardless of the implementation of the RMS. We feel that it is difficult to verify this assumption given that we have not fully implemented the RMS in a project. In addition, we have not evaluated the change management and verification/validation functionalities of the RMS. During tender, we typically assign a system engineer full time to a WOS project for 2 years. This amounts to a total of 3600hrs spread over all his required tasks. There is a possibility that adding the use of RMS to the responsibility of the system engineer will shift his focus away from other tasks, resulting in him using more hours to complete his tasks. We need to measure the hours use by the system engineer over the course of the project in order to make an accurate judgment about the addition or reduction in ours due to the use of RMS.

Results of Evaluation

Peer Review

The general feedback from the peer review is that the RMS is a useful tool for evaluating requirements internally and with Clients. The pdf output provides a structured and well-defined layout to document requirements while the HTML output allows for easy browsing of the requirements and their corresponding defining/complying elements. The bullet points below summarize the key advantages and concerns from the peer review regarding the use of RMS.

Advantages

+ *Enable focus on requirements*. Use of RMS will increase focus on requirements and reduce the amount of unnecessary information in the DBD, subsystems, and product specifications.
+ *Aid in impact analysis*. RMS can aid in verifying the impact towards requirements during a variation order process as it is common to miss out requirements when evaluating the impact of a variation order where the Client requires a change to the original requirements. The use of RQSs and trace links can help engineers to verify all requirements that are impact by this change.

Concerns

- *Unknown amount of hours use on the RMS.* Actual hours needed to use the RMS needs to be determined and budgeted for in tenders and project execution. The Company currently estimates hours needed for system engineering hours by using

50% of the total engineering hours. There is approximately 7000 to 8000 engineering hours for a typical WOS project, amounting to about 3600 hours for system engineering. These hours are inclusive of all the responsibilities of the system engineer. There needs to be a conscious effort to document hours spends on using the RMS.

- *Unclear roles and responsibilities on the use of the RMS.* Company needs to be clear on the roles and responsibilities for maintaining and implementing RMS in projects. The feedback from the peer review is that it needs to be clear who is responsible for creating and maintaining the RQSs in different stages, i.e. System engineers should be responsible for the system level RQS, product engineers should be responsible for the product level RQS.
- *Insufficient experienced personnel to review and approve the RQSs*. The Company needs to make sure that there are available experienced resources to review and approve the RQSs, ensuring that these are of the expected standards

Industry Assessment

We can see that the RMS scores highly on the main functional areas such as Traceability, Specification, and Management of Requirements. It however performs poorly in the areas of Requirements Elicitation, Analysis, and Modelling (highlighted in yellow). We think that there is a need for to evaluate the relevance of these functionalities in RMS. The focus should particularly be on enhancing the elicitation functionality of the RMS. One of the key challenges highlighted earlier for handling of WOS requirements is that it is common for WOS to have unknown operating requirements at the beginning of the project. The inability to document underlying assumptions properly will likely result in inadequate requirements at the product level. A better means of eliciting these requirements can be in the form of stakeholders' needs analysis.

Summary

We have evaluated the current state of the RMS through implementation in a project, peer reviews, and assessment by industry standards. We received positive feedback regarding the effectiveness of the RMS in ensuring the traceability and management of WOS requirements. Several crucial functionalities such as change management, verification, and validation are in development and these still need to be tested. We provided some insights into the hours needed to use the RMS on a WOS project. However, more work needs to be done to measure the effectiveness of the RMS in a quantitative way.

The industry assessment shows that the RMS scores significantly higher than the current method for requirements management through documentation only. However, it also reveals that the RMS lacks development in functional aspects such as Requirements Elicitation, Analysis, and Modelling. We recommend that these aspects be further developed and evaluated.

Through our research, we identify the three key challenges of WOS requirements: numerous requirements, unknown operating conditions, and multiple dependencies among requirements. We believe that the RMS provides the adequate platform to start tackling these challenges within the Company. We think that the RMS's ability to synergize with the Company's existing engineering system and display using HTML or pdf gives it a unique advantage over the other requirements management tools in the market for managing WOS requirements within the Company. We hope that it will continue to develop and mature based on the feedback from this paper.

Future Research

We recommend evaluating the hours needed to use the RMS in a WOS project once the change management and verification/validation modules are completed.

We will also like to re-verify the hours needed to use the RMS on subsequent WOS projects from the same client to determine the possible reduction in hours due to the use of templates and the re-use of requirements. In addition, we can confirm the duration required for training $\mathbf{t_{training}}$, and duration to generate each requirement, $\mathbf{t_{REQ}}$ upon further use of the RMS. The Company should set a benchmark for the required hours for training ($\mathbf{t_{training}}$) in order to ensure that engineers do not spend excessive training time to use the RMS.

Finally, we recommend looking into measuring and evaluating the numbers of PONCs from projects utilizing the RMS in order to obtain a quantitative measure of the effectiveness of the RMS.

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Biography

Damien Wee

Kok Yi Damien Wee received his Bachelor's degree in mechanical engineering with honors from the National University of Singapore and is currently pursuing his Master's degree in System Engineering from the Buskerud and Vestfold University College. He has been working on the engineering, testing, and installation of subsea oil and gas production and workover systems for the past 9 years. His current field of specialization is in the systems design of open water and in marine type workover system. His most recent role is as a Specialist System Engineer for the Well Access Systems group in FMC Technologies.

Gerrit Muller.

Gerrit Muller, originally from the Netherlands, received his Master's degree in physics from the University of Amsterdam in 1979. He worked from 1980 until 1997 at Philips Medical Systems as a system architect, followed by two years at ASML as a manager of systems engineering, returning to Philips (Research) in 1999. Since 2003, he has worked as a senior research fellow at the Embedded Systems Institute in Eindhoven, focusing on developing system architecture methods and the education of new system architects, receiving his doctorate in 2004. In January 2008, he became a full professor of systems engineering at Buskerud and Vestfold University College in Kongsberg, Norway. He continues to work as a senior research fellow at the Embedded Systems Innovations by TNO in Eindhoven in a part-time position.
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