Developing a Configure-to-Order Product in the Subsea Oil and Gas Domain

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Abstract. This paper explores a configure-to-order strategy in the subsea oil and gas industry. A major supplier in the industry is investigating standardization and modularization of their systems and products to shorten delivery times and reduce cost. Consequently, changing from an "engineer-to-order" to a "configure-to-order" strategy.
We have studied part of the Subsea Production System, namely the subsea hydraulic control system and a new product development project as a basis for our research. The new product development project was our case for developing a standardized and modularized design that meets various customer needs. Applying the systems engineering framework together with lean product development principles helped us define a process to decide product specific variants of the new product through a configurator.
Results from our research show that we could configure the product based on functional requirements if the engineers consider modularity during product design. The research gives strong indications that the subsea oil and gas industry can achieve significant reduction in cost and time associated with design, documentation and production of the new product by using a Configure-to-Order strategy.

Introduction

Domain. This paper is based on a real case from the subsea oil and gas industry. The company of interest delivers unmanned systems for subsea oil and gas production known as a Subsea Production Systems (SPS) (Figure 1). The SPS provides a safe and controlled way of producing hydrocarbons from a subsea reservoir to either a land, or a topside processing facility. Typically, a subsea development consists of the following products: X-mass Trees systems (XT), Manifolds, Protection structures, Production Control System modules and Flowlines & Umbilical (API 2015).
In a SPS it is the XTs which control if the hydrocarbon well stream is open or closed. It regulates the flow and injects chemicals into the well stream to stimulate it. Normally a subsea hydraulic control system (Figure 1) supplies and controls subsea valve actuators. It works by placing a Hydraulic Power Unit (HPU) topside to generate enough hydraulic fluid pressure to run the valves found on the XTs and in the downhole well completions. A supply line in the umbilical transmits the pressurized fluid and distributes it to the XTs through the manifolds or distribution modules. A new development product which this research considers is known as a Hydraulic Module (HM). The HM distributes and manages hydraulic power to operate the subsea valve actuators internally on each XT and subsea well.

Company. The company this research considers is a major supplier of equipment to the subsea oil and gas industry. They are the market leading supplier of subsea solutions and specializes in SPSs. The company operates in 39 countries and has more than 14000 employees.
Engineer-to-Order is the Current Way of Working in the Industry. Typically, engineering of SPSs starts with a Front-End Engineering and Design (FEED) study. The FEED study identifies a system architecture concept that include a definition of the main parts of the subsea hydraulic control system architecture. It gives a preliminary product list and cost based on earlier project experience. If the FEED study is satisfactory it passes through a decision gate where a contractor initiates tender phase. In tender phase, suppliers review document-based requirements given by the contractor. The requirements are in the range of several hundred to several thousand and is often based on the FEED concept. The suppliers then develop an explanation for how they plan to meet customer specifications. In addition to gaps in the requirements related to existing technical solutions and they communicate how to fill these gaps to the customer. A successful tender lead to winning a contract and the start of Engineering, Procurement and Construction (EPC) phase. The company is starting the EPC phase with defining the system, then systems engineers communicate projects specific requirements to the product lines, including the HM. The product line engineers tailor existing solutions to fit the new project requirements. Occasionally, misfits and design errors happen. This has led to costly loopbacks where the engineers do all in their power to fix the situation (Tranøy et.al 2012, Bergli et.al 2017).

Problem Statement. The increased cost focus in the market affects the subsea oil & gas industry. This leads to changes in how the industry thinks and do business. There has been research showing that too extensive requirements cause increased cost because it led to comprehensive control over the products and equipment (Jakobsen et.al 2016, PSA 2016, Rystad 2014). This is in part due to the norm of specifying detailed solutions, copied and adapted from previously delivered systems. The challenge becomes clearer when we include government regulations, client specific specifications and industry standards. Often the requirements are contradictory and hard to interpret, causing suppliers to deliver products that fulfill stricter requirements than what the operators expects. The Engineer-to-Order strategy focus is to deliver systems to project specific parameters that cause a complex situation with a growing product and system portfolio. Researchers (Jakobsen et.al 2016, PSA 2016, Rystad 2014) state that standardization and less extensive requirements engineering could be the key to lower costs and deliver on a shorter schedule. We want to research a Configure-to-Order strategy in the industry, where we design the HM to accommodate for various customer needs across projects, to reduce tailoring solutions. We have used the new product development project as a research case to investigate if we could help the industry with these challenges. We chose the new product development HM as our research case because we could affect the product design. In addition, the project team already wanted to implement a Configure-to-Order strategy. Based on the problem statement we came up with the following research questions:
• How can we apply systems engineering framework and lean product development principles to create a configurable HM?
• How does the configure-to-order strategy affect the HM during design and project execution?

Research Findings. We found that the Lean Product Development method, Look, Ask, Model, Discuss and Act cycle could serve as a development process to understand solutions for a modularized HM. The Systems engineering framework and Lean product development principles helped us to define a framework for a Configure-to-Order strategy. We used a knowledge value stream as an operational model to document product variances in a systems architecture. The systems architecture helped to show relations for the product configurability and create a product configurator. We found that a limited number of functional requirements from the subsea hydraulic control systems drive variations on the HM. This will allow the use only of standard components when configuring a project specific HM. A prerequisite is that the engineers consider modularity, component interfaces and map requirements across customers when they develop the product. An analysis of a reference project shows considerable time saving in document creation. In addition, our research indicate that it is possible to streamline production and testing of the standardized and modularized HM.

Theory and Literature Review

Systems Engineering and Systems Architecting. Systems Engineering (SE) is a field of engineering that focuses on how to design and manage complex multidisciplinary systems over their life cycles (Walden 2015). The core of SE is an iterative problem solving method that enables understanding and knowledge about the problem to achieve the goal. When bigger teams are combining their efforts to solve a challenging problem the complexity rises. One process model from SE framework is the "Vee" model (Forsberg et.al 2005). This is a model many companies use during project executions. To handle complexity, there is a need for a Systems Architectures (SA). This is to ensure that the SE effort is effective and coherent. Walden (2015) described SA as a hierarchy consisting of requirements, functionalities, logical & physical elements. They further highlighted that when using the "Vee" model to its full potential, SA is necessary. In agile SE, Walden (2015) discussed that the SA is essential for the goal of Standardization, Modularization and Configuration.

Requirements. In the SE framework, correct translation of requirements is a corner stone in design of complex systems (Walden 2015). It is two main types of requirements: Stakeholder (solution independent) and system (solution dependent) requirements, which occur on various stages in development of a system or product (Sols 2014). There are common elements in the two types of requirements, therefore it can be challenging to separate them. Sols (2014) described characteristics of the requirements and how to engineer them including typical taxonomy. He further highlighted importance of showing the acceptability and traceability between the different requirements. There are several ways to categorize the two distinct types of requirements. A traditional way in literature is to classify them into functional and non-functional requirements (Sols 2014). The functional requirements state what the system shall do or perform. The non-functional requirements set conditions or constraints on how to implement the functional requirements. D.S Raudberget et.al (2015) illustrated how realization of the functional requirements can have many design solutions.

Lean Product Development and Knowledge Based Development. The primary goal of Lean Product Development (LPD) is to acquire increased value for the customers. LPD does this by different methods and techniques to decrease waste, improve quality and reduce time-to-marked & cost (Welo 2013). Knowledge Based Development (KBD) is to structure knowledge so it is easily reusable for several areas to help engineering of product or system. Regarding KBD, Bergsjo et.al (2016) stated: "Actionable reusable knowledge presented in the right time, to the right individual in a digital short
condensed format will lead to better decisions, driving innovation and effectively reduce overall product realization lead-time."

Combining LPD and KBD is a natural approach for a company that wants to create more value for their customers. The two fields help to focus on continuous learning and improvement of the company products and processes. An operational model used to combine LPD and KBD is using two value streams, as shown in Figure 2 (Ulonska et.al 2014).

A fundamental part of the operational model (Figure 2) is the knowledge value stream. Engineers in the company use the knowledge value stream to establish and maintain knowledge of a process, product or system. While captured knowledge has the purpose to solve challenges and streamline the project execution value stream (Ulonska et.al 2014).

The two value streams in Figure 2 use a common system architecture. The knowledge value stream architecture includes all variants and variance. While the project execution value stream architecture makes use of the contents to configure specific variants. Hence, the knowledge value stream must include enough ownerships and management to govern the system architecture outside project executions (Ulonska et.al 2014). In addition, comes the responsibility to maintain and update the knowledge value stream.

**Modularization and Standardization.** The goal of modularization and standardization is to increase the reuse capabilities of the developed products (Harlou 2006). As a result, should design of the products in the knowledge value stream (Figure 2) be following modularization and standardization principles. Configuration of products can then happen more efficiently during the project execution value stream (Ulonska 2014).

U. Harlou (2006) used modularization and standardization techniques as one of the key topics in his work to develop product families based on architectures. S. Ulonska et.al (2014) put U. Harlou (2006) work into practice by using the knowledge value stream. To control the modularized and standardized systems architecture Hansen et.al (2012) described configurators. Where a configurator is a set of rules that defines which modules fit together. The configurator will streamline work in project executions and document internal complexity, while possessing the required customization capabilities.

Regarding modularization and standardization, Pahl et.al (2007) gave some central definitions:

- **Modules** are units described functionally and physically and are independent
- **Modularity** is the degree of purposeful structuring of the product architecture
Modularization is the purposeful structuring of a product to increase its modularity. The aim is to optimize an existing product architecture to meet product requirements.

In general, modularization and standardization can be seen as the process of decomposing products into independent building blocks. The building blocks are the modules and we are doing standardization on the modules. The modularity aims to increase efficiency by reducing complexity and building what the customer needs in a smart way (Schuh 2014). Modularization is creating components that should vary to satisfy different customer needs. By having standard interfaces, it will be possible for different modules to fit in a given slot when building the final product (Bruun et.al 2012). Thereby, the company can deliver distinct product configurations based on the customer requirements (Martin et.al 2002).

**Methods and Models from other Domains.** Several industries have researched various strategies of structuring and optimizing products and systems. Many of these approaches are useful starting points to look for inputs in context of the subsea oil and gas industry. Literature often refers to the automotive and airplane industry for success stories, however little literature comes directly from these suppliers. We have thus done a wide search for methods and models which come from cases in different domains. Our approach in this paper is a combination of several methods and models. These gave us input for how to form our case for the subsea hydraulic control system and HM.

We have summarized methods and models from several industry approaches in Table 1.

**Table 1: Summary of methods and models investigated by other researchers in various industries**

<table>
<thead>
<tr>
<th>Systems &amp; Products</th>
<th>Reference</th>
<th>Systems engineering</th>
<th>System architecture</th>
<th>Requirement management</th>
<th>Lean product development</th>
<th>Knowledge Management</th>
<th>Modularization</th>
<th>Standardization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bobcats</td>
<td>(Bruun et.al 2012)</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water coolers</td>
<td>(Martin et.al 2002)</td>
<td>x x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Defense, automotive parts and subsea products</td>
<td>(Ulonska 2014)</td>
<td>x x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x x</td>
<td></td>
</tr>
<tr>
<td>Electronic products</td>
<td>(Harlou 2006)</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle manufacturer</td>
<td>(Tidstram 2014)</td>
<td>x x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x x</td>
<td></td>
</tr>
<tr>
<td>Aircraft engines</td>
<td>(Stig 2015)</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Tractors, industrial valves and medical equipment</td>
<td>(Pulkkinin 2007)</td>
<td>x x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x x</td>
<td></td>
</tr>
</tbody>
</table>

**Research Methodology**

**LAMDA Process.** We have used the problem-solving cycle Look, Ask, Model, Discuss, Act (LAMDA) as our primary research method. Ward (2014) developed the LAMDA cycle and figure 3 shows how we adapted the cycle in our research.

**In step 1 (Look),** we performed an in-depth analysis of 15 legacy hydraulic systems and one ongoing project development in the company. In the analysis, we applied top-down and bottom-up approaches as described in the paper by Baker et.al (2016). The goal behind performing the analysis was to gain insight in the problem space. **Step 2 (Ask),** we used the legacy mapping to screen functional requirements for the new product development project. We needed to understand why the legacy systems
had different designs. We used the requirements to have a holistic perspective on the rationale behind important design decisions for the new product. **Step 3** (Model), uses the two first steps as input to conceptualize a modular design. Here we made visual aids to show interactions in the product and to show how we developed the new modular and configurable product. **Step 4** (Discuss), with the help of experts and design reviews, the engineers designed the physical components of the new product. Then we created a configurator using the functional requirements as the configuration rules. **Step 5** (Act), we proposed a new process for how to implement the modular product in the company work methodology.

In the LAMDA cycle we had an iterative approach to be able to develop the modular product.

![LAMDA Cycle](image)

**Figure 3:** Research methodology for product development using LAMDA cycle

**Validation.** During our research, we used the subsea oil and gas industry as a laboratory and the new product was our test case. We performed design reviews and conversations with experts to develop the HM during the LAMDA cycle.

To validate our research, we interviewed ten stakeholders who have experience from working with customers, product knowledge as well as how the company works. Each of the interviewees had various experience with the new product which enabled us to gain different viewpoints and thereby give us more confidence with the results. The personnel we interviewed in the organization were a senior production engineer, a lead engineer, two systems engineers/architects, a lead software engineer, a project manager, a program manager, a subject matter expert, a customer responsible and a senior chief engineer. We presented the produced artifacts including a configurator and then we performed semi-structured interviews as described by Muller (2013). In the interviews, we asked open questions to allow the interviewees to state their opinions about the consequences of our work. We asked how and why question without guiding the interviewees, this was to avoid us to affect their answers.

**Analysis of Reference Project.** Based on the findings from our interviews we did a quantitative analysis of a reference project. We got access to the project plans and time estimates of each documentation activity. In the reference project, we analyzed the time and resources spent on the activities. Then we estimated relevant tasks for the HM. We performed a quantitative analysis to verify the potential cost and time savings of the configure-to-order approach on the HM.

**Developing a Configure-to-Order HM**

**Legacy Mapping (Look).** When we considered Figure 3, the first step was to map legacy subsea hydraulic control systems. Here we analyzed 15 delivered projects and one ongoing project in the company. The primary goal of the legacy mapping was to understand the functional variances in delivered projects. Figure 4 illustrated the main products we considered as the subsea hydraulic control system. However, our focus was to identify different design of the HM.

First, we started to develop a representation the subsea hydraulic control system functional architecture. The architecture gives an overview of the functional decomposition, while it also gives
an impression of relations between functionality and physical components in the subsea hydraulic control system. Ulrich (1995) helped us with the definition of a functional architecture. He discussed elements of a modular architecture as: (1) arrangement of functional elements, (2) functional elements relation to physical components and (3) interfaces between these components. However, Step (3) in Ulrich work (1995) we have described in the conceptualization (Model) section. We discovered early that there were several different customer needs which affected the solution. The next step was to screen requirements behind different solutions.

Figure 4: Simplified representation of the subsea hydraulic control system

**Screening of Requirements (Ask).** Next step was to investigate requirements in the mapped projects. We needed to research customer specification and conduct interviews with personnel involved in developing the designs. Our goal with screening requirements was to understand stakeholder needs and to know the rationale behind different physical solutions in the legacy projects. During our research, we noticed that many parameters affected the design. We started by considering the main drivers for the customer when developing SPSs, as shown in the first row of Figure 5. If the company can deliver according to expectations in the 4 main drivers, they win a contract.

The first column of Figure 5 shows our findings in generic design parameters for a typical SPS field development. The second column in Figure 5 shows the functional requirements (or design selections) the customer can choose from. These are selections on the subsea hydraulic control system which impact the HM design directly. Other selections which affect the HM design are directly related to interfacing products, shown in the third column of Figure 5.

All options presented in second and third column of Figure 5 will all create specific variants of the HM. We have the possibility to combine and play with the needs to create different variants of the HM. However, we found dependencies and relations in between the options. This was because of the modularity and the constraints in the product.

Due to that these parameters are directly related to the company's technical solutions, we could not present specific examples of the HM design solutions and parameters. We fabricated the parameters given in column 2 and 3 from Figure 5.
**Figure 5:** Requirement and parameters which impact the design of the HM

**Conceptualize (Model).** After we understood the functional needs and impacts of the design parameters, we needed to set up a modular product definition. We made an overview that shows how we decided to decompose a modular HM. The overview also gives an illustration of HM breakdown in relation to which components that executes the required functionality (shown in Figure 5). The relations are one to many for which components different selections add to the HM.

To fulfill the modular HM, we needed to create an overview of the different components and modules. U. Harlou (2016) work on Product Family Master Plan (PFMP) helped us to define these components. Here we defined all components that will vary (the building blocks). In addition, we needed to document all interfaces in the product. Brun et.al (2013) have developed an interface diagram design tool for supporting the development of modularity in complex product systems. We used this tool to develop a definition of the interfaces in the HM. The interface tool captured structural characteristics of the HM to support its modularity. The engineers can then build various standard building blocks to create different variants of the HM. Due to confidentiality the architectural overview was removed from the paper.
**Detailing (Discuss).** In this step engineers developed a detailed design of the HM components based on our inputs from earlier steps in the LAMDA cycle. It was important that the engineers used the modularization and standardization techniques as we presented in their design work. Based on the engineers’ design and the number components, we could make a product configurator. The configurator works by having a max Bill of Material (BOM) as a configuration source. The max BOM consists of all components possible to use on the HM. The configurator defines a variant BOM based on selections of the programmed rules. In our case the configuration rules are functional requirements from the subsea hydraulic control system and interfacing products (Figure 5). The rules and constrains are knowledge, they are telling you legal variants and combinations of the product.

There are several configurators in the market. We used Microsoft excel when programming the configurator. However, we recommend investing in more sophisticated configurator software. This is because we are using the configurator as the knowledge source for the modularized and standardized product. The configurator helps to achieve customer needs and requirements by using the correct rules. If using a configurator, it is vitally important to manage and maintain the product, its rules and the configurator. If we do not consider this, the configurator will create obsolete product variants or not be useful in project executions.

**Implementation (Act).** The last step in the LAMDA cycle was to implement a work process for how to create project specific HM variants. Figure 2, the knowledge value stream illustrates the operational model for how to handle modular products. Combining this with efficient processes and a configurator, will streamline work in project executions (Bruun et.al 2012).

Figure 6 illustrates the work process for configuration of the HM during projects executions. We have used the systems engineering framework (Walden 2015), the ”Vee” model (Forsberg et.al 2005) and company internal process as guidance. First, customers give the company their project requirements. The company then performs a review of the customer needs. Next, the company starts the systems design, that includes the subsea hydraulic control system in our case. Followed by a systems design review to confirm that the company can deliver according to the requirements. During the design review, engineers present a preliminary product configuration (Shows that the HM product family is within the solution space). If the verification fails, they should revise the systems design or discuss the requirements. An alternative is to start a management of change process. Where new product development or improvement of the HM occur thereby updating the knowledge value stream is a consequence. If the engineers can verify the system, they pass through a critical line where the HM will get its final product configuration and is ready for production. The last steps are system verification and validation testing of the system.

Figure 6 compare the Configure-to-Order and the Engineer-to-Order approach. The company can save the detailed design step. Because the products have pre-engineered components and knowledge stored in the knowledge value stream and the configurator.

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**Figure 6:** Process for Configure-to-Order approach (light gray) including extra work for Engineer-to-Order approach (dark gray)
Observations During Development of the HM

We have presented a method for how to develop a Configure-To-Order (CTO) product. Part of our research results consist of observations done during develop of the configurable HM (Figure 3). The project manager in the new HM development project presented our product findings to a customer. They said that the CTO strategy could be a method to reduce cost and time for the industry. Internal reviews found indications of using functional requirements to configure the HM will reduce the number of product variants and components to manage. As a result, will this decrease the engineer-to-order (tailored) solutions of the HM. As the functional requirements state what the product shall do, no two different solutions can be found solving the same set of functions. We also observed that designing the right components is dependent on the engineers’ ability to interpret and predict customer functional needs. In addition, the engineers must take the products configurability in account during design of the components. Hence, the company must allow the engineers a CTO mindset in projects to prevent returning to tailoring product solutions.

We summarized three of the most significant observations in our research:

- Using functional requirements to configure the product helps the industry to move away from tailoring solutions, while it gives the required product flexibility
- Having a CTO product will affect design of components due to the modularity
- Correct interpretation of the customer needs is essential for the goal of the CTO strategy

Examples of Observed Requirements. By the many conversations, we had with employees it became obvious that customers rely on earlier experiences in population of the requirements. This typically means that the customer dictates technical solutions for the contactors. We discovered a number of solution-oriented requirements many of which could serve as examples. Due to confidentiality, we could not present the examples and how we solved them in this paper.

Results

We gathered data from a qualitative analysis to investigate the effects of our work. The qualitative analysis is based on interviewing ten representative selections of experts in the organization. In addition, we showed posters describing the HM variations as industrial artifacts during the interviews. This was to give further insight in the product. In our qualitative analysis, the aim was to research potential effects of applying the Configure-To-Order (CTO) strategy.

We have summarized our findings for potential benefits and reasons why the CTO approach is successful in the Table 2:

Table 2: Benefits and reasons for the success the CTO strategy based on ten interviews

<table>
<thead>
<tr>
<th>Benefits and reasons</th>
<th>No. of responses</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-engineered solutions</td>
<td>8</td>
<td>By having a modular and standardized product design with pre-engineered components. Enables higher volume and thus cheaper procurement of components</td>
</tr>
<tr>
<td>Manufacturing/testing</td>
<td>7</td>
<td>Automated manufacturing and testing procedures that will lead to shorter delivery times for the HM</td>
</tr>
<tr>
<td>Product planning</td>
<td>8</td>
<td>Helps the product from procurement planning to spare part philosophy, and to create a product with less quality gaps</td>
</tr>
<tr>
<td>Documentation</td>
<td>7</td>
<td>Automate documentation that will lead to shorter development times for the HM and as a result reduces engineering hours</td>
</tr>
<tr>
<td>SE process</td>
<td>7</td>
<td>Simplifies and clarifies the process for engineering of the product and system, which in the end lead to better solutions</td>
</tr>
</tbody>
</table>
Synergy effects of applying the CTO strategy on interfacing products or the SPS, potential for added savings

Knowledge sharing

Benefit of working with less details in projects execution leads to easier decision making

Project timing

Timing of this project, due to the current situation in the subsea oil and gas domain

No history on the HM

It is a product which no customer has experience with, hence they have no preferences of how the HM shall function

We have summarized our findings for potential pitfalls and concerns about the CTO approach in Table 3:

<table>
<thead>
<tr>
<th>Pitfalls and concerns</th>
<th>No. of responses</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Get product overview</td>
<td>4</td>
<td>Challenging to get the required overview of the product, we tend to zoom in on details. In other words: Know the solution rationale</td>
</tr>
<tr>
<td>Implementing</td>
<td>8</td>
<td>Changing the way of working, being more product oriented vs. Project oriented as today. Used to measure revenue on project to project basis</td>
</tr>
<tr>
<td>Person dependent</td>
<td>5</td>
<td>Correct knowledge among employees, challenge to get them to understand the approach (not used to the way of thinking)</td>
</tr>
<tr>
<td>Not ready as industry/company</td>
<td>7</td>
<td>Changing culture in designing solutions that can accommodate for the various needs. The industry is not used to have this approach</td>
</tr>
<tr>
<td>Continuous improvement</td>
<td>6</td>
<td>The company must invest in continuous product maintenance outside project executions</td>
</tr>
<tr>
<td>Capturing needs</td>
<td>3</td>
<td>Hard to predict future needs and having the right solutions. Essential to interpret requirements correct, if not we are going back to tailoring solutions</td>
</tr>
<tr>
<td>Too dependent standardization</td>
<td>3</td>
<td>If there is a special case, the company gets too dependent on the standard solutions, thus might not be able to win the project</td>
</tr>
<tr>
<td>Vulnerable to competitors</td>
<td>1</td>
<td>Vulnerable to competitors, they might get hold of the company solution</td>
</tr>
</tbody>
</table>

Below have we summarized the main findings from our interviews:

- Significant reduction of time to deliver the HM by more efficient processes
- Significant reduction of cost to deliver the HM by having standard components and reduced engineering hours per project
- Synergy effects throughout the HM life cycle (Production, testing transport and installation)
- Further synergy effects if the company have the CTO approach on the complete SPS
- Knowledge sharing of product and system details
- Successful CTO require the industry and company to change the way of working

It is interesting to notice that all interviewees observed benefits for the CTO strategy. However, many of them concluded with varied reasons to why and they also raised different potential pitfalls of the CTO strategy. We found signs that it would significantly reduce cost and time used to deliver the HM. Eight of ten interviews stated that the primary reason is use of standard predefined components when configuring the HM. While seven of ten also said that it would be beneficial for manufacturing, testing and documentation. In addition, eight of ten stated product planning was a potential benefit. We also found possible synergy effects for having the approach to other products in the SPS. Eight
of ten employees stated that the effect of the CTO strategy on the HM is very small when compared to what the company could save to apply it on the SPS. The interviewees stated several pitfalls and concerns. Overall, they said that if the company shall become successful in a CTO strategy, the company and industry way of working must change. They need to become more aware of the CTO strategy and execute projects differently. Based on the responses (displayed in Table 2 and Table 3), we saw a need to investigate more deeply the effect of doing a CTO strategy.

**Analysis of Product Project Documentation.** To assess the value of a CTO strategy we analyzed one specific projects’ documentation during EPC phase with support from experts. We reviewed the engineering plan from a reference project to find typical documentation task. Our aim with the analysis was to find how the CTO strategy would perform compared to the current EPC approach. This included analyzing potential savings for the HM in project documentation tasks. Figure 7 shows our main finding from the analysis.

![Diagram](https://via.placeholder.com/150)

**Figure 7: Product project documentation Engineer-to-Order vs Configure-to-Order**

In our analysis, we included the main documentation about the HM. We did not consider early phase project documentation and system documentation. The total estimated hour usage was 300 over 44 weeks to deliver the first product. However, the estimated 300 hours was only for the A revision documents. The documents had between one and seven revisions. We assumed therefore that the project used more than 300 hours in creating documentation for the reference project. Regardless, our analysis did not include hours used after the first document revision.

During our analysis, we reviewed each document to be able to estimate if the company could reduce the hours used on documentation. By checking the documents, we could also determine if the documents are possible to reuse or configure for the HM to a project specific variant. Our estimates by creating fourteen configurable master documents and nine standard documents is 92% reduction in the hours used on documentation tasks (Figure 7) for a project that fits the defined solution space. We found that the configurable documentation also involved production/assembly procedures and test procedures. The company can then be able to create lean processes for production and testing of the modular HM. In addition, it is possible for the company to reuse assembly, test, transportation and installation equipment between projects, which is usually project specific.

The analysis supports the statements we found during our interview sessions (shown in Table 2). We see that it points out the same benefits of automating documentation and streamlining procedures. Based on the analysis, we can indicate significant reduction of cost and lead time for HM using the CTO strategy during a project execution that fit the defined solution space.


**Discussion**

**Project Findings.** Our research indicates that the industry can exchange fewer requirements for products that are modularized and standardized, and thereby have a successful CTO strategy. From researching customer requirements, we found that there was no clear structure between functional requirements and solutions oriented requirements. This increased the complexity of interpreting the requirements. In addition, was the requirements also often based on earlier experiences, which is causing contractors to dictate technical tailored solutions.

We found that everyone involved must fully understand the potential of standardizing and creating modules to reuse in different contexts. The company culture and strategy must embrace the approach for it to become successful and to get full effect. To what extent to use a CTO strategy is dependent on the business model. We could argue that if mass production of single components is the focus of a company, this will limit the value of a modularization strategy. However, for the HM we showed in our research effects of the standardization and modularization strategy.

Our research discovered that it was a limited amount for functional needs from the subsea hydraulic control system which create variance on the HM (Figure 5). Based on this, if the customer exchanges the functional requirements when initiating a project. We could argue that the company are successful in capturing customer needs earlier, thus reduce design rework. As Tranøy et.al (2012) found, this can reduce costly changes in late design. Other researches (Jakobsen et.al 2016, PSA 2016, Rystad 2014) showed also that requirements are one of the causes of increased cost in the subsea oil and gas domain. We believe that our work is a countermeasure to reduce the impact of costly customization of project specific requirements. Despite the many potential advantages, a CTO approach can also have pitfalls the company and industry must overcome, which we addressed in Table 3.

**Modularization vs. customization.** Working with modular product portfolios or customization of products need a different mindset and culture (Welo 2013). As we discuss in this paper, the subsea oil and gas domain can move towards a product driven organization to reduce cost and time. This is based on the observation that a project in the industry is not solving a new problem (to produce hydrocarbons), but is re-applying existing solutions to new fields with the same overall problem. However, capacity or capability requirements will change from project to project. As the output from design is project specific (e.g. to a specific water depth or a specific value in a requirement), lead to whenever a new FEED or ITT arrives the norm is to copy from earlier delivered solutions. Regardless, there are always small tweaks to adapt the old solutions to the new context.

The company has investigated standardization and modularization, but we argue that they can improve this effort if the industry embraces a new way of working such as presented in this paper. However, this is a complex question due to the nature of the technology and the way of working. Our approach only illustrates the potential effects of the CTO strategy on the HM. Focusing on all products in the SPS with a CTO strategy may affect other products differently. It will need more work and further research in the field. This is because the company must include enough maintenance of the products outside the projects. Hence, the company must finance product developments and maintenance of solution differently.

**Changing Way of Working in the Industry.** Traditional business strategy in the subsea oil and gas industry is to focus on single project developments. This has led the industry to maximize profit and revenue on a project to project basis. We can argue that the company has only maintained product knowledge within the project execution value stream (Figure 2). This results in an ever-growing product and system portfolio because each new project often needs tailoring, which in turn generates new product variants.

Without sufficient overview and efficient strategies for maintaining (including continuous learnings and new product developments) a knowledge value stream, the reuse strategy becomes a significant risk during project executions. Bergli et.al (2016) argued that one of the causes of cost and schedule overruns in projects is because qualification of products that happened in parallel with project executions. This is in part because during tenders the suppliers do not identify all technology gaps in
the subsea oil and gas domain suffer from complex and partly incomplete information flows". They further highlighted that a consequence of this is that most employees lack overview of the systems and how they interact. We argue that usage of the knowledge value stream model, modularized products and an understanding of the SE framework will help the company to get overview of their product and system portfolio. Then it will be easier to see the bigger picture when developing the systems, thereby also perform project tenders and executions differently. A prerequisite for this approach to be successful, is that the company must give enough resources to maintain and update the knowledge value stream. This should be a part of the entire company culture.

Having the complete overview of the system architecture and include it in the knowledge value stream will make it easier to capture variance and variables in the system. This will lead to more efficient processes, leverage on expertise and create a new way of doing business (Welo 2013). We argue in this paper that we did document the architecture of the HM and thereby also part of the subsea hydraulic control system. Therefore, we claim that it will be possible to go from an Engineer-to-Order strategy in FEED, Tender and EPC phases, to focusing on standardization and modularization with a CTO strategy for the industry. Further, we recommend to research how the CTO strategy will impact the company organization in terms of structure and size compared to the current organizational.

Can we Further Extend MBSE Together with Product Lifecycle Management Tools? INCOSE (2007) defined Model Based Systems Engineering (MBSE) as; "The formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases". Haskins (2011) discussed that MBSE can improve knowledge capture and reuse, integrate new team members, decrease knowledge loss, and establish shared mental models. Combining this with product lifecycle management tools, will let the industry be able to keep track of how a change may affect different elements in the system. Based on our research we argue that this will reduce complexity and increase the knowledge sharing of systems and products included in the FEED, Tender and EPC phases. Combining the product life cycle management tools with configurators, we believe that this would be a powerful tool to have a digitalized working set, embracing a visual interface that would ease the documentation and handling of the products and systems.

Use of Data and Limitations of the Research. We have had many conversations with expert employees in the organization to use their experience and knowledge as input in our research. The collaboration helped us to develop the case and discover potential effects of the CTO strategy. Inputs from conversations and interviews are based on opinions, experience and "gut" feelings and may therefore not be the absolute truth. However, our findings in the project analysis correlates with the response of the experts. Thus, we have a good reason to believe that the interviewees input is credible in this case.

We did part of our research in parallel to developing a new product, the HM. Our research was dependent on having a case to apply it on. By selecting a new product development as the case might have affected our results because this is a product that no customers have operational experience with. However, we believe that other researchers can do the same on existing products, but they might experience some deviations in their results.

We recommend further investigations of the CTO strategy to be able to generalize the data, and to conclude whether the CTO strategy is the best economical solution for the subsea oil and gas domain. The company should confirm the data by benchmarking the CTO strategy towards current project execution method. If we were to extend our research, it would be useful to apply the CTO strategy to a pilot project. Then we could conduct a quantitative analysis of the CTO strategy, and be able to consider performance of the CTO strategy during project execution for the HM.

Application of Tools and Methods in our Research. In this research, we applied the LAMDA cycle, as described by Ward (2014). We used the LAMDA approach to develop the configurable HM. This
was a useful process to find the functional needs on the HM, while it also helped to determine a modular design, which could meet various customer needs. We experienced that the LAMDA cycle was a valuable process to use. However, the exact processes and knowing when to move to the next can be challenging to understand. We solved these difficulties by applying an iterative approach. Then we could move between the different steps in the process as we needed.

Systems Engineering (SE) and Systems Architecting (SA) described by Walden (2015) helped us to define how to work when the company shall deliver HMs. SE framework gave us theory and insight for the best processes to follow during projects. The SA principles showed us how to structure the product and system, thereby helping to generate knowledge about the problem. Without SE framework and SA principles we argue that the goal of our work is harder to achieve. Combining Lean product development (LPD), Knowledge based development (KBD), modularization and standardization methodologies has been useful in developing the product configurability. The LPD and KBD methodologies guided us to use the knowledge value stream as an operational model for the modular product. The modularization and standardization methodologies helped us to design the HM and illustrating dependencies in the configurator. The challenging part was to decide all modules (components) on the HM, this is because we are defining the solution space for what the customer needs. Conversations with skilled engineers helped us to interpreted what the customer wants and build this into the HM design in a smart way.

**Conclusion**

We have investigated how the subsea oil & gas industry can increase efficiency and lower cost through systematical and recognized methods, and as a result we have developed a framework for a Configure-to-Order strategy for the company. This framework should be possible to extend to other similar companies, and possibly the whole industry.

Summing up the Configure-to-Order strategy, using the HM as an example, we found that:

- The Look, Ask, Model, Discuss and Act cycle adapted from Lean Product Development theory, worked well as a development process for the modular HM. It did this by first guide us to understand the various customer needs, then develop a design that fitted the solution space, and last develop a process for product configuration.
- A Systems Architecture is necessary to document the HMs configurability and share product knowledge between projects. Using the knowledge value stream as the operational model will help in documenting the systems architecture outside project executions.
- The company should use the “Vee” model and Systems Engineering framework in the Configure-to-Order strategy by first understanding customer requirements, then perform systems design that decides the required functionality and thereby the product configuration.
- By focusing on functional requirements instead of solution-based requirements, operators and supplier can exchange fewer requirements for the HM configuration process within projects. The reason for this is that functional requirements state what the product shall do, and it does not dictate the technical solutions.
- To be able to achieve a Configure-to-Order strategy the company must
  - consider modularization and standardization during product development and design
  - change the way they are executing projects by improve products and systems outside projects executions.

Our interviews indicated that the company will be able to reuse components on the HM in most projects. Since the product components are not project specific, it will be possible to streamline production and testing. We supported the statements of the interviewees by a reference project analysis. Our estimations showed that the Configure-to-Order strategy can lead to 92% decreased time in project documentation as the company can use standard and configurable documents. This research on the Configure-to-Order strategy indicate significant cost and lead time reduction for the subsea oil and gas industry.
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**Biography**

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