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Evaluation of illustrative ConOps and Decision Matrix as tools in concept selection

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Abstract. Low oil prices and cost reduction initiatives are currently affecting the oil and gas domain. At the same time, the industry struggles with budget and schedule overruns. The high focus on generic requirements tends to overshadow the operational needs for the system. Previous research points out insufficient acquisition of operational needs as a main contributor to costly late design changes. This paper explores the use of an illustrative Concept of Operation and Pugh matrix as tools when evaluating concepts in the subsea domain. We apply the tools to a conceptual study of an interdisciplinary system expansion to encourage an unbiased holistic mindset of the decision makers. We also aim to answer if the project engineers can use these tools to expose showstoppers and opportunities at an early stage of the system development process. The result of our research indicates that an illustrative ConOps supported by a high-level Pugh matrix can serve as a trigger for discovering opportunities and constraints not initially considered. An Illustrative Concept of Operation and Pugh Matrix show potential when used as tools in communicating qualities of conceptual solutions between project members and stakeholders.

Introduction

The subsea oil & gas domain mainly concerns unmanned systems to recover hydrocarbons from reservoirs under the seabed and safely transport them to the surface. Subsea production systems as seen in Figure 1, typically comprises subsystems such as subsea completed well, seabed wellhead, subsea production tree, subsea tie-in to flowline system, and subsea equipment and control facilities to operate the well (Bai 2010). These subsystems provide a safe, controlled way of transporting the hydrocarbons from the reservoir to either land, or a topside processing facility. Common for subsea systems is a long life span and high initial investment (Capex). Safety, installability, operability, and maintainability are the main factors and concerns with these systems, which add to the complexity of the system architecture. Due to the water depth, it is most common to perform inspection and maintenance of the system with Remotely Operated Vehicles (ROVs). This factor also affects the design since the user interfaces target machines and not humans.

This paper is based upon research conducted in Aker Subsea, a Norwegian based international supplier of Engineering, Procurement & Construction (EPC) in the subsea oil & gas domain. Aker Subsea is part of Aker Solutions (AKSO), a company that has delivered equipment to the oil and gas industry since 1965. AKSO employs approximately 17,000 people and had a revenue of 33 billion NOK in 2014 (Aker 1 2014).

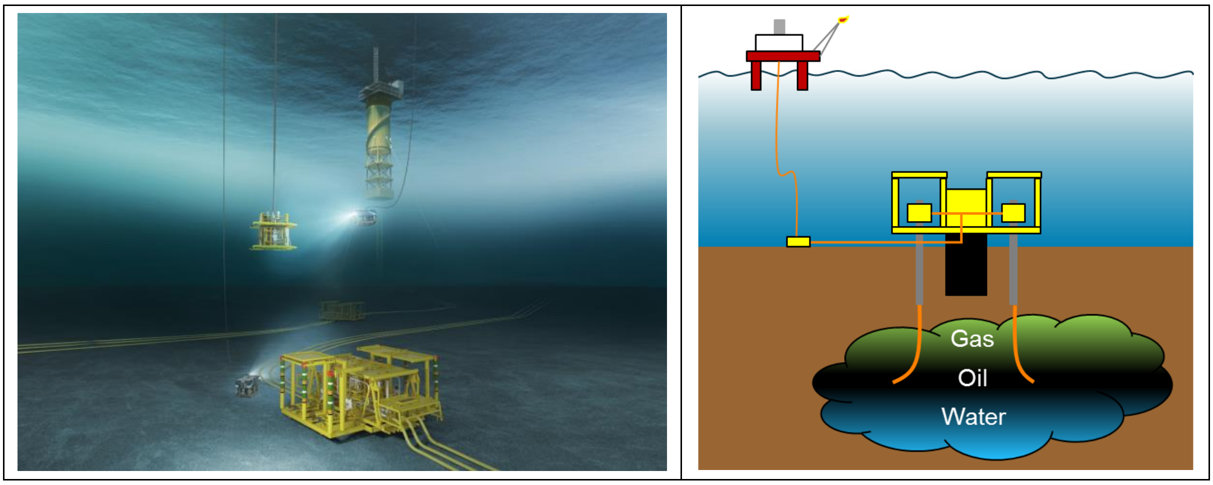

Figure 1. Left: A deep-water subsea production system (Aker 2 2014). Right: Schematic view of a subsea production system and the reservoir composition.

Background

Changes to design late in the project execution are common for subsea system projects. This leads to increased cost and schedule overruns. Thorough, high quality work in the early phase is crucial for the rest of project implementation to succeed (NPD 2013). Development of a major subsea systems project in AKSO begins with a concept and feasibility phase initiated by the customer oil company. The concept study group evaluates several system concepts and layouts, and selects the most feasible concept for the oil/gas field. The oil company invites contractors to tender on the selected concept followed by contract award after 4-5 months. The project execution phase begins at this stage with decomposition, requirement allocation, and detailed design. AKSO implements a high degree of System Engineering (SE) effort early in the system definition phase (shown in Figure 2) to ensure a fully integrated system. Late changes are still a challenge, despite the effort, and AKSO needs methods to catch late change issues to reduce overall cost of the projects. Recent research has shown that for some projects, up to 74% of late design changes could have prevented by early need analysis (Tranøy 2012).

Figure 2. The AKSO project execution model (Tranøy 2012).

Even though the system concept is defined when the system definition phase starts up, design choices for sub-systems and components remain to be made. AKSO uses a comprehensive global procedure to verify new engineering designs and modifications to existing design. The procedure splits the verification into conceptual-, detailed-, and final design reviews that are conducted by the department responsible for the sub-system/component (Piciaccia 2014). However, findings in System Integration Testing (SIT) show that errors slip through this process. Previous research performed by Eldar Tranøy and Martin Moberg highlights the root cause for late changes to be: late identification of operational needs, tight schedule, knowledge transfer, and technology qualification (Tranøy 2012) (Moberg 2014).

As seen in Figure 3, the cost to extract defects increases exponentially through the system life cycle. Sorting out defects or concerns in the conceptual phase could only take a few engineering hours, while correcting the same defects during testing could endanger the entire project schedule. Starting off right with a thorough validated concept will increase the chance of delivering on time and budget. The concept shall be validated towards both the requirements and the operational needs through the design process. However, the complexity of the system and number of interactions complicates the process. Tools to gather and structure the qualities of the design towards the needs may assist engineers during validation

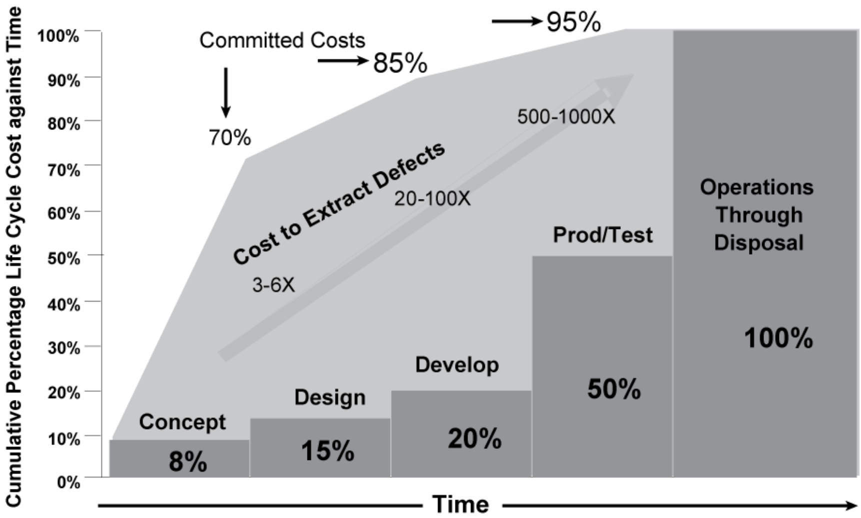

Figure 3. The cost of extracting defects compared to the project commitment (Haskins 2011)

As stated, one of the main triggers to late design changes in previous projects is the lack of knowledge about operational needs (Tranøy 2012). The researchers want to see if there are methods in the System Engineering toolbox that can improve awareness of operational needs and assist in the process of reducing late design changes. Two methods that we identified were the Concept of Operation and Pugh Matrix.

The research described in this paper is based on the initial plan to study and investigate the application of an illustrated Concept of Operation (ConOps) and a simple Pugh Matrix as tools in this early concept evaluation. The research focused on three questions:

- Can AKSO utilize these tools to perform an early validation of the proposed concepts?
- How do these methods affect the engineering mindset when it comes to holistic thinking of new solutions?
- Can these methods result in late-change reduction?

Concept of Operation. Concept of Operation is a method that originates from the military and aerospace domain, and is applicable in the early need analysis phase of a project (see Figure 4). ConOps is a System Engineering technique for analysis and understanding of system needs throughout the system life cycle. The term system life cycle refers to the stepwise evolution of a new system from concept through development and on to production, operation, and ultimate disposal (Kossiakoff 2011). Each life cycle phase has specific needs to be considered, and ConOps is applicable to them all (Haskins 2011). This paper uses the term ConOps to describe all conceptual documents, such as Concept of Production, Concept of Deployment, Concept of Operation, Concept of Support, and Concept of Disposal. Together, these early documents describe the intended use of the system throughout its life cycle and from the user's viewpoint, from production to decommissioning (Haskins 2011).

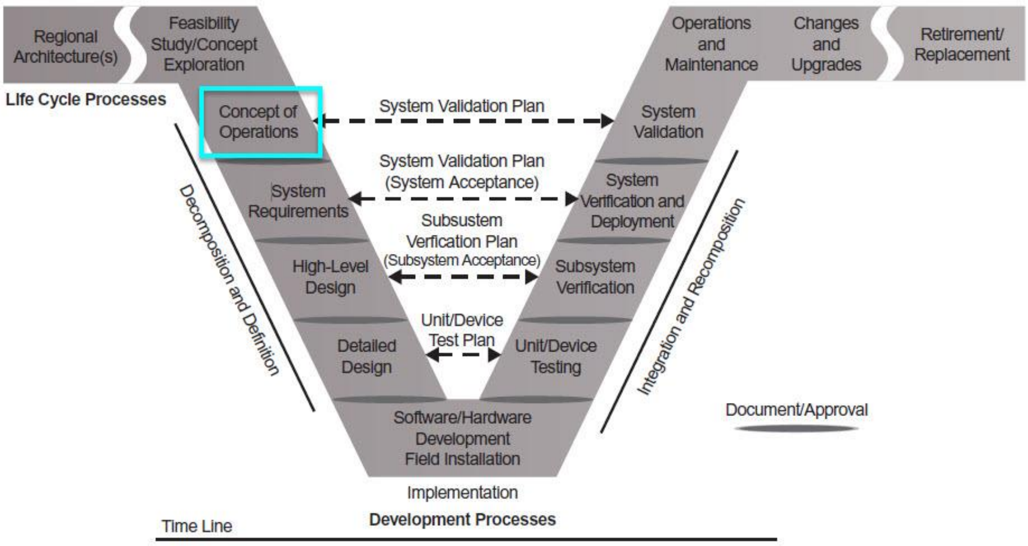

Figure 4. A typical Vee model of the SE development process with the Concept of Operation phase top left (Kossiakoff 2011).

However, it is important to communicate the benefits of the method as a tool to ensure that the ConOps add value to the development process. A team from Systems Engineering Research Institute at Stevens Institute of Technology investigated 23 different ConOps documents (Cloutier 2009). They discovered that in most cases the ConOps seems to have been produced only due to documentation requirements rather than as a strategic/tactical system planning tool. This defies the original purpose of the ConOps, which is to meditate between user and developer communities and other stakeholders in a way that a system can be designed holistically and in an integrated fashion (Cloutier 2009).

Several templates for creating a ConOps exist, and three commonly used by different industries are:

- ANSI/AIAA G-043-1992 – guide from American National Standards Institute.
- IEEE 1362-1998 – IEEE guide for CONOPS document
- DI-IPSC-81430 – DoD data item description for CONOPS document

Common for these templates is that they use mostly text to describe the quantitative and qualitative system characteristics. The main use of a ConOps is to communicate these characteristics to the stakeholders and help create a "meeting of the minds" before the requirements process (Cloutier 2009). Due to time limitations, this research focused mainly on the installation and retrieval part of the system, which was not elaborated in the initial study. An operational ConOps was created in graphical form to communicate the holistic picture of the concept of operation and to create a common understanding often not possible to achieve with plain text. By graphical form, we mean a step-by-step illustrative document explaining each necessary operation. The ConOps becomes the basis for criteria evaluated later through the Pugh Matrix.

Pugh Matrix. Pugh Matrix (PM) is a multi-criteria decision making method that allows for the comparison of a number of design candidates leading ultimately to better understanding of the concepts (Honkala 2007). It is a System Engineering (SE) tool to extract the knowledge and experience from the team, and display the complexity of the interwoven factors in a comprehensible way (Burge 2009). The PM consists of columns listing the proposed concepts, and rows with evaluation criteria. This set-up forms a matrix with cells ranking the concept per criteria. The output from the PM is an overall score of the concept performance based on the evaluation criteria. The PM is expandable with weighing and prioritizing of criteria, and it is possible to show the output with percentages and advanced graphs. However, the quality of output from the PM is highly dependent on the input. Incorrect, incomplete, or inadequate evaluation criteria or ranking will corrupt the value of the performance score. On the other hand, the PM gives the involved users a greater view of the strengths and weakness of the concepts, and where to focus improvements. Research shows that one of the most positive applications is where the concept selection matrix is used as a communication tool (Muller 2011).

This research focused on keeping the PM as simple as possible for two reasons:

- The matrix should be easy to use on a day-to-day basis, and have a low threshold for use.
- The purpose this matrix is limited; intended to serve as an aid in discussions and communication rather than a justification for selecting a concept.

Research Method

The research was based on analysis of current concept studies in AKSO as industry-as-laboratory. The methodology to be tested is applied in the industrial setting and the results from these experiments are observed and used to evaluate the hypothesis (Muller 2007). The focus is on how a broader understanding of the need and concepts would affect the decision-making in a subsea project. The contingency satellite study is used as a test case for the research due to the system relevance and similarity to a larger subsea EPC project. The research was formulated as action research after the plan-do-check-act (PDCA) principle. This involved preparing and planning an initial ConOps, testing the method with relevant personnel, checking, and acting on the result. Action research applies to real-world situations, rather than contrived, experimental studies, since its primary focus is on solving real problems (O'Brien 1998). The use of interviews, observations, and experimentation amongst relevant personnel supports the analysis.

Case

In 2014, a client asked AKSO to conduct a study of a contingency satellite well as an expansion to an existing system in the completion phase. The Client's need was to be able to connect a new satellite well to any branch connections in the manifold in the case of a lost well (Papandrea 2014). Uncorrectable damage, such as stuck equipment or a well that has collapsed on itself would trigger the scenario. The contingency satellite would provide the opportunity to move existing equipment to a new location and tie it back to the original connection point, thus saving procurement time and maintaining production. AKSO delivered an initial report describing two concepts of reposition a subsea well as a contingency alternative late 2014. The researcher participated in this initial study, which aimed to evaluate the two alternative concept approaches:

1. Focus on requirement compliance and re-use of engineering.
2. Focus on minimizing equipment and cost.

A system expansion of an existing subsea gas production system forms the scenario for this research. This early multi-disciplinary evaluation would act as input to a more detailed engineering study. A situation that would trigger such a contingency option is uncorrectable damage in the well during drilling or installation of downhole casings and equipment (Figure 5). Templates, guiding, and protection structures form the foundation for the X-mas Trees (valve packages) and the distribution manifolds. Templates also act as a guide base when drilling the production wells and have usually spare slots. In this case, production wells and X-mas Trees (XT) populate all slots on the template. This means there are no spare slots to reposition/re-drill a well. The client suggested investigation of two options:

- a fully-compliant solution (concept A)
- a minimal low-cost solution (concept B)

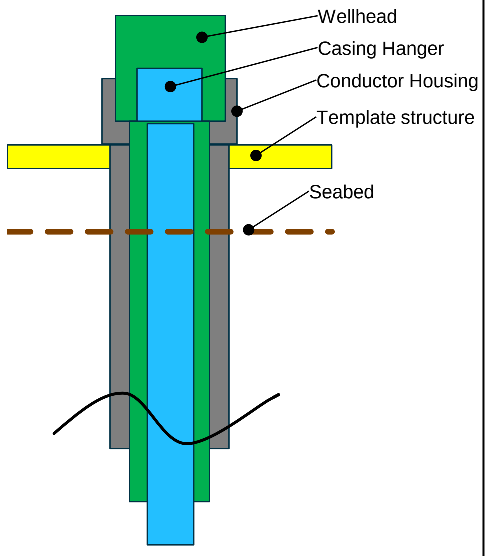

Figure 5. Typical composition of a subsea well before installation of XT

Specifications from the existing system were still applicable, and the same main constraints affected both concepts. One main constraint was the harsh weather and deep water at the location. It is common to utilize guide wires to install subsea XT in weather-affected locations such as the North Sea. Guide wires run from the installation vessel down to guideposts at the installation location, and ensure that the equipment does not drift off target. Use of this method is limited to approximately 700-meter water depth due to the size and weight of the guide wires. Deep-water fields are on the other hand mainly located in areas with calm weather and require minimal guiding. Both deep water and harsh weather conditions are present on the location of the existing system. A new guiding system solved this issue. The new guiding system utilizes a fixed guide structure on the template, and a bumper frame on the installed XT.

A second constraint was the limitation of signal jumpers from the existing system to the contingency satellite. To ensure the proper signal strength, the jumper length is restricted to 50 meters and forced a constraint on the distance between the original system and the satellite.

The 83-page report on the contingency satellite study describes the two concepts from both a system view and from each of the engineering disciplines view (Papandrea 2014). This report investigated price, delivery time, intervention activities, complexity, re-use, and testing requirements. The report concluded that both concepts had advantages and disadvantages and described a second derivation of concept B (concept B.2) and a third concept (concept C) described in Figure 6 (Papandrea 2014). The report covered details of component design suggestion, fabrication limitations, and thorough description of system considerations. However, a holistic view of the use and operation of the system were lacking. If initiated, this system expansion would include personnel from several disciplines and with varying level of project commitment. The goal of this study was to see if System Engineering methods such as an illustrative ConOps and a Pugh Matrix could supplement to the original study in two ways:

- Create a common understanding of the concepts amongst the project personnel and stakeholders.
- Act as an early validation of the proposed concepts.

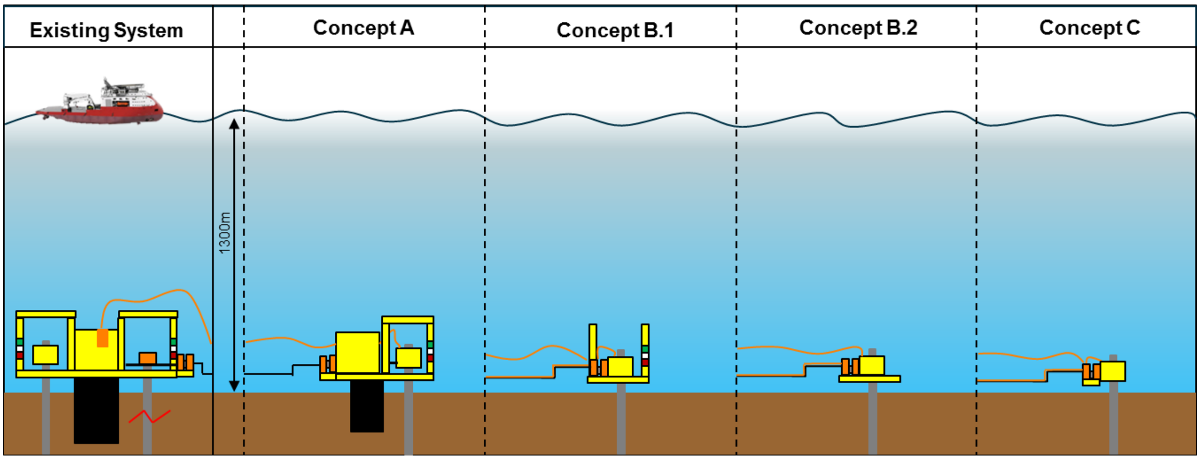

Figure 6. Schematic overview of the evaluated concepts and their main characteristics.

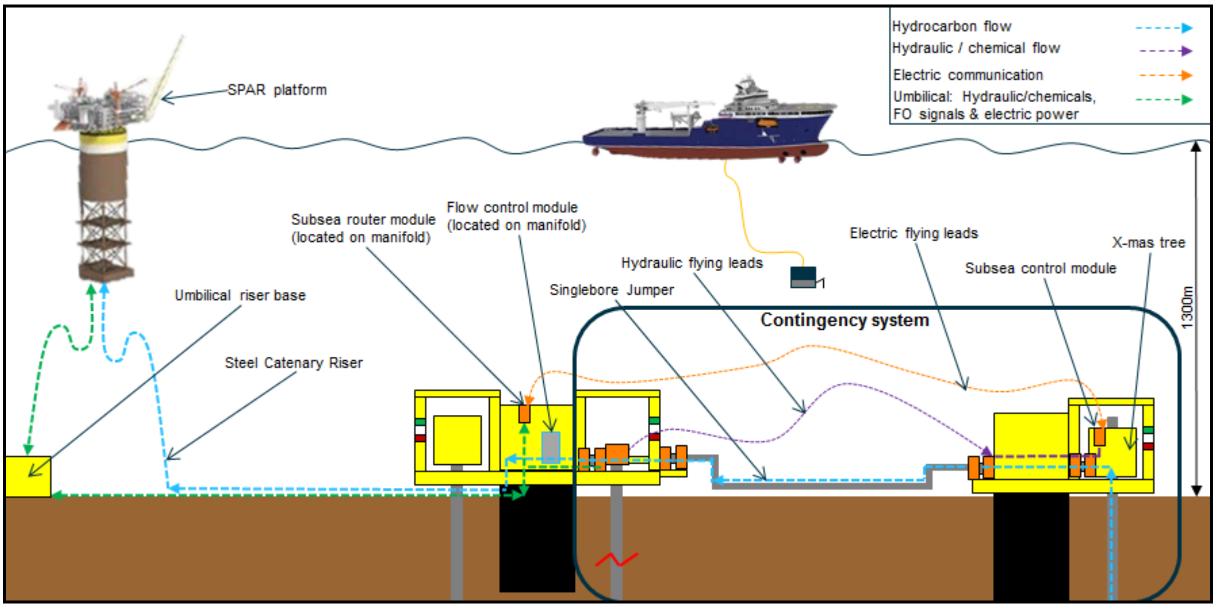

Figure 7. Operational view of Concept A.

Concept A. The baseline of concept A is a commercial-off-the-shelf (COTS) system that is fully spec- compliant. To fulfil these goals, Concept A utilizes a 1-slot template design, engineered and tested for the existing system. The original 1-slot template design accommodates a single XT and a manifold with future connection points. Future connection points would not be necessary for the contingency satellite scenario, thus allowing a stripped-down system (Figure 7). This concept utilizes the same guiding philosophy as the existing system and retains the XT. The stripped manifold connects the XT with a single bore production jumper that runs back to the existing system. A bypass frame, positioned in the lost template slot, enables a landing frame and connection point for the production jumper. Two bundled flying lead hoses supply hydraulic control and injection chemicals to the satellite. ROV installed Electrical Flying Leads (EFLs) establish electric control from a router module on the existing manifold.

Concept B.1 & B.2. Equipment simplification and cost minimizing was the main driver behind concept B. The proposed concept consisted of a Production Guide Base (PGB) solution. A PGB is a landing frame attached to the Conductor Housing, which forms the foundation of the well. This solution removes the need for a separate installed structure to support the XT, thus reducing complexity and materials. With no manifold present, all connections with the existing system go directly to the XT itself. A new multi-bore jumper transports the hydrocarbons back to the branch connection, and supply the XT with chemical injection and hydraulic control. The jumper would connect to the bypass frame in the manifold side, and then be guided into the XT by the PGB. Electric control of the satellite is maintained by ROV installed EFLs. The difference between version B.1 and B.2 is guiding of the XT onto the wellhead. B.1 involves mounting the same guiding columns as used on the existing system. B.2 removes these columns and utilizes traditional guideposts without guide wires for the XT installation.

Concept C. The conceptual study mentions a third solution without further investigating this option. This alternative is included in the research to broaden the evaluation. Concept C proposes to install the XT directly onto the wellhead without any support or guide structure present. Concept C challenges the requirements and the normal subsea philosophies on the Norwegian Continental Shelf. However, it reduces the amount of necessary support equipment to a minimum, and strips down the system to the essentials. The solution uses the same multi-bore jumper as in concept B.1/B.2 to transport hydrocarbons and supply hydraulics and chemicals. EFLs provide electric control of the satellite.

Application of ConOps to the case

After examining the initial report and identifying information regarding installation sequences, constraints, possibilities, and differences in the proposed concepts, the focus turned to create a graphical ConOps describing the installation and retrieval operations because the operation phase is similar for both situations. The study report acted as a backbone for our ConOps. The researcher created a framework in Microsoft Power Point ™ consisting of two frames per slide. Figure 8 depicts step 3 (contingency frame installation) and step 4 (contingency frame connection) for concept A, using this framework. Each frame included a text box for supplementary information of that specific operation step. The text box included a short description, involved parties (stakeholders), required operational platform, constraints associated with the operation step, and an early estimate of the operation time. A common set-up with seabed, surface and water depth were included in each frame. To this were added basic models of the equipment in each frame supported by arrows to illustrate each operational step. By repeating this process for each of the concepts, a high-level picture of the installation scenarios for each concept emerged. After constructing the document for each concept, they were shown to members of the study team and external systems engineers.

During the second iteration, while investigating the logical installation sequence, it became clear that the ConOps needed an overview of the required vessel class used in the operations to catch constraints beyond the equipment. Generally, an installation ship/vessel is less expensive to hire for the client than a drilling rig, but some operations require a specific type of vessel. A rapid change between vessel types is inefficient, and the concept itself would affect these operations. For this reason, the framework highlights the possible operation platform for each step to show the interactions between vessel types and operations. In the third iteration, AKSO offshore personnel were solicited to offer their point of view. As a stakeholder to the system, they provided valuable information about the operation steps and sequences. The ConOps was adjusted to reflect their point of view and with the addition of a page describing the operational side of the four concepts.

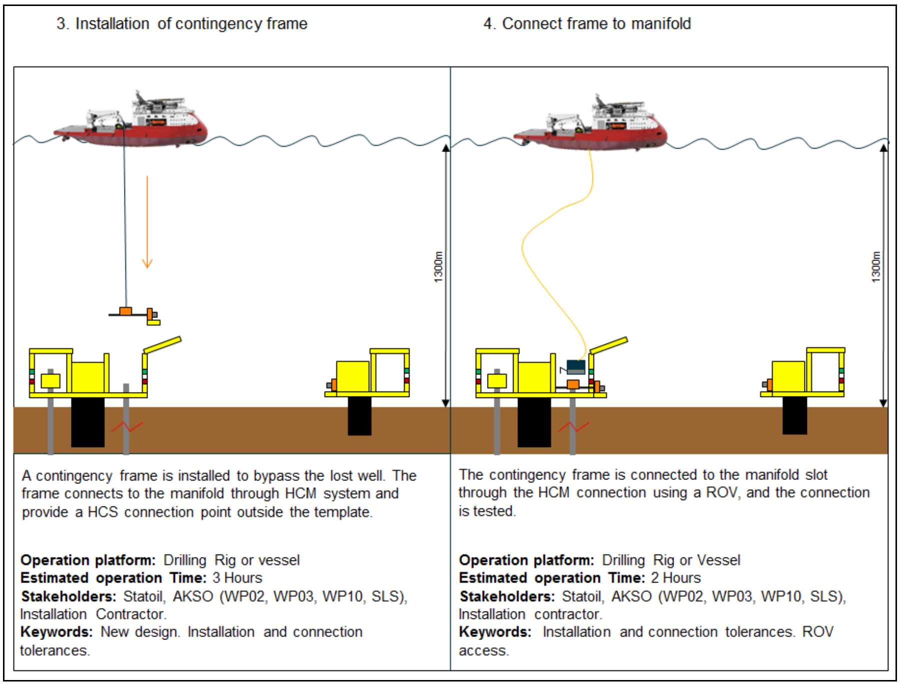

Figure 8. Framework of the illustrative ConOps.

The initial assumption was that the operation of the concepts would be the same for A, B.1, B.2, and C. The reason for this thought was that the central part of the operational system, the XT, was the same for all four concepts. The main difference between them was the installation and guiding philosophy, and the production jumper that connects the contingency system back to the existing infrastructure. For a fourth iteration, we invited a panel of experts on systems engineering, concepts and feasibility studies, and system operation, for a session to review the ConOps. This ConOps review triggered three new concerns regarding the concepts:

- The use of Hydraulic flying leads in concept A, restricted possibility to bleed off the satellite during shutdown and retrieval of modules downstream in the existing manifold due to smaller diameter on the service lines. The reduced diameter increases the risk of hydrate formations (hydrocarbon ice plugs) that can plug the lines and force a production shutdown.

- The distance limitation between the new and existing system dictated the size of the rigid production jumper for all concepts. These jumpers need some built in flexibility due to thermic expansion and connection tolerances.

- The additional pipe length in the form of the production jumper means a larger volume to dewater before production start-up, and requires means to bleed down the system from both sides in the case of hydrate formation.

The final version of the ConOps was created as an A6 paper-size booklet. The front page showed the name of the concept and the qualities associated with it. The first page included a schematic overview and the mission need, followed by a summary of the installation steps. The main body was a stepwise walkthrough of the installation and retrieval operation including an operational view of the concept. A text box listing operational platform, stakeholders, estimated operation time, constraints, and a short description, supported each illustrated step.

Pugh Matrix analysis and results

A simple Pugh Matrix was created to communicate a semi-qualitative holistic picture of the concepts, and to evaluate how client priorities would affect the different concepts. To construct the matrix, a set of criteria must be selected. Each concept then is ranked numerically from 1-5 against each criteria, and the priority setting of each criteria needed to be adjustable to compare different views. The criteria are based on the ConOps checklist in the internal design review procedure (Piciaccia 2014). The basis of the ConOps is INCOSE and ISO standards and the checklist provided a solid foundation for further work. The checklist was adjusted based on findings from the illustrative ConOps to fit the criteria to this specific case, and then sorted into four top-level categories: Cost, Design, Installability & Retrievability, and Operability. Each category had specific sub-criteria. The set-up allowed the user to rank each concept and select a priority on each criterion from low, through standard, to high. Low priority multiplies the ranking value with 0.5. The standard priority keeps the ranking as-is, while the high priority multiplies the ranked values by a factor of 2. This set up reduces the differences between a high and a low prioritized score on a criterion, while a high priority favors high ranking values compared to a low value. Traffic light coloring on the ranking values increases the communicative expression of the matrix. It paints a clear picture on the positive and negative attributes for each concept as shown in Figure 10. An additional bar chart provides the users with a graphical comparison of the concepts. The chart summarizes the qualities of the concept for each main category.

A sensitivity analysis was performed to validate the configuration of the weighting in the matrix (Kossiakoff 2011). The purpose (of the matrix) was to communicate the qualities of the concepts, but we needed to see if the evaluation system was stable or unstable. One criterion was set to zero to measure its specific impact. Then the process was repeated for each criterion and the change to the rating logged. The matrix proved stable as seen by the result of the sensitivity analysis in Figure 9, which is showing the reference position compared to the mean position after the sensitivity analysis.

	Concepts			
	A	**B.1**	**B.2**	**C**
	Simplified Snefrid	PGB with Toast rack	PGB with GP's	Satellite XT on WH
Reference position:	4	3	2	1
Average position after sensitivity analysis:	3,82	3,14	2,00	1,00

Figure 9. Results of sensitivity analysis

User input

	Criteria	Priority setting	A Simplified Snefrid	B.1 PGB with Toast rack	B.2 PGB with GP's	C Satellite XT on WH
			Concepts			
Cost	Hardware Cost	High	1	3	4	3
Cost	Installation Cost	High	2	3	4	5
Cost	Operational Cost	High	1	2	3	5
Design	Engineering hours (Amount of new engineering, re-use, analysis)	High	3	3	2	2
Design	Design familiarity (Is the design known in AkSo? Previously delivered?)	Standard	5	3	3	3
Design	Requirement compliance	Low	5	3	3	2
Design	Deliverytime from call-off (Long lead items, fabrication time)	High	2	3	3	3
Design	Amount of new qualifications (TQP's)	High	5	3	3	1
Design	On-shoreTestability (Availability of necessary equipment and procedures)	Standard	4	3	3	3
Installability & Retrievability	Number of installation runs required	Standard	2	3	3	4
Installability & Retrievability	Installation time	Standard	2	3	3	4
Installability & Retrievability	Weather vulnerability (Metocean constraints, Hs)	Low	4	3	2	3
Installability & Retrievability	Need for special tools	Low	4	3	3	3
Installability & Retrievability	Guide system robustness	High	5	4	3	3
Installability & Retrievability	Size of vessel required (Rig, heavy lift vessel, installation vessel)	Standard	1	2	3	5
Installability & Retrievability	Weight & Size	Standard	1	2	3	5
Installability & Retrievability	Retrieval flexibility of equipment	Standard	3	3	3	2
Operability	ROV access	Standard	3	3	3	4
Operability	Flow assurance (Hydrate/Scale, pipeline friction, pressure bleed-off)	Standard	2	3	3	3
Operability	Dewatering & start-up (Service access, injection points, etc.)	Standard	3	3	4	4
Operability	Reliability	Standard	3	3	3	3
Operability	Interchangeability	Standard	4	2	2	1
	Indicating summary:		**77,5**	**79,5**	**84**	**89**

The concepts listed are ranked on a scale from 1-5 based on their attributes for each criteria. 3 is the mean value and describes a good enough performance to the criteria. A higher number shows a better performance, while a lower number shows a worse performance on the criteria listed.
The priority setting enables you to prioritize individual criteria to a higher or lower importance. If the priority is set to low for a criteria, that criteria will count less compared to a standard or higher prioritized one.

Rating	Description
1	Unfavorable performance
2	Less than satisfactory performance
3	Satisfactory performance
4	More than satisfactory performance
5	Excelent performance

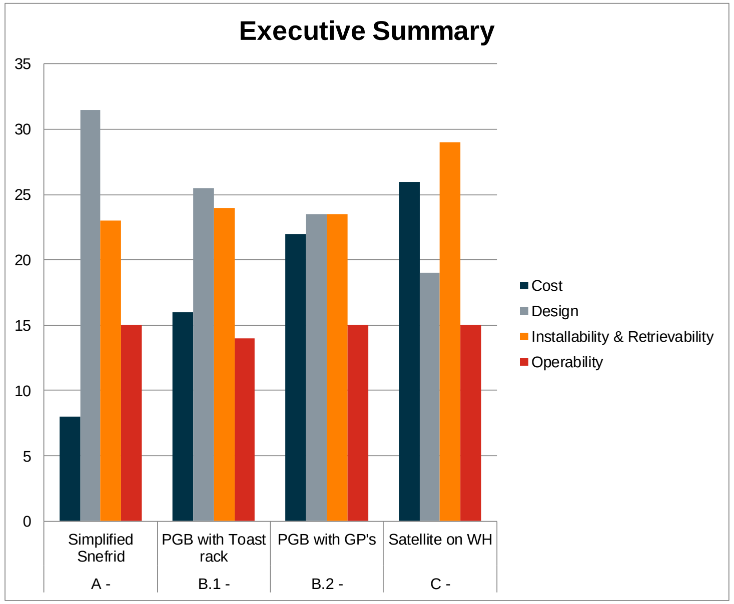

Figure 10. The final set-up of the Pugh Matrix.

ConOps analysis and results

Interviews and objective reviews of the concepts with expert personnel provided a qualitative assessment of the ConOps. A quantitative method was constructed to analyze the effect of the ConOps on the project engineers, and how the ConOps affected their mindset towards the concepts. Since concepts A and B.2 were the only two concepts fully evaluated by the initial study, they were, therefore, the only valid references. The test was simple and consisted of two sessions. Session 1 was a walkthrough of the initial concept study with the test subjects. Each test subject was asked to evaluate concept A and B.2 by completing a Pugh matrix after the walkthrough to collect their point of view on the concepts. Session 2 involved a walkthrough of the ConOps with the same test subjects. After session 2, each test subject was asked to evaluate the concepts again through the same Pugh Matrix. Even though the number of test subjects is too small to draw any conclusions, some indication on the effect of the ConOps was anticipated.

Test subject 1 is an experienced systems engineer without any connections to the initial concept study. Concept A varied little before and after the ConOps looking at the total score on the Pugh matrix. Concept B however, shows almost 10% reduction in score, and was perceived to be the less attractive solution after the subject saw the ConOps. Figure 11 summarizes the overall change in confidence between session 1 and session 2 for each subject and concept. The most significant change found place in the Installation & Retrieval category, which was the focus area of our ConOps. Concept B.2 shows the same tendencies, but is overall more stable than A.

Test subject 2 is an experienced systems engineer who participated in the initial concept study. Looking at the total score of the two concepts presented to this test subject, the overall change is less than for test subject 1. Concept A shows a marginal reduction of 1.23% in the total score. Concept B shows a 4.7% reduction in the total score. As described in Figure 11, the changes happened in almost the same categories as for test subject 1. However, the Installation & Retrieval category remains the same before and after the test.

	Test subject 1		**Test subject 2**	
	Concept A	Concept B.2	Concept A	Concept B.2
Cost	Slight improvement	No change	Slight improvement	No change
Design	Slight reduction	No change	Slight reduction	Slight reduction
Installation & Retrievability	Reduction	Reduction	No change	No change
Operability	Slight reduction	Slight reduction	No change	Slight reduction

Figure 11. Summary of the test subject's change in confidence**.**

Discussion

This study began with the intention of examining three questions.

Can AKSO utilize these tools to perform an early validation of the proposed concepts?
Comparing the results from this study to the research from the initial concept study an interesting trend appear. While concept A and B.2 were proposed to the client to fulfil the stated scope of the study, concept C was not even analyzed. The initial study report chose Concept A to satisfy the request of a spec compliant solution, while the report suggest concept

B.2 as the low-cost, minimized alternative. However, analyzing the populated Pugh matrix in Figure 7, indicates that concept C shows great potential. It scores overall better on the prioritized criteria than B.2 which was the proposed low-cost solution. The result suggests that concept C should maybe have been investigated further as the low cost alternative. Had Concept C been proposed as a late change, these methods, applied in an earlier phase would have had a positive effect on an eventual project.

How do these methods affect the engineering mindset when it comes to holistic thinking of new solutions? While such a short study does not support any conclusions about the influence of using the illustrative Conops, a positive picture emerges when reviewing the results with feedback from interviews and reviews. All personnel subjected to the ConOps quickly grasped the differences between the concepts and the operations. The engineers tended to respond promptly to the operational process and express concern or curiosity about the steps. It was also observed that people tended to concentrate on the final score of the Pugh matrix, but by performing several iterations of the Pugh matrix it was possible to adjust focus from the summary score at the bottom to how the qualities of the concepts reacted to each criterion. Attention was drawn from the final score to the concept qualities for each criterion by adding traffic light coloring to the ranking. This created a powerful visualization of the concepts weak and strong sides. The involved personnel reacted by focusing on the main attributes that concerned the scope, and an overall more holistic perspective.

Can these methods result in late-change reduction? This research reaffirms that implementing validation tools for systems engineers is vital for to discover potential late-changes at an early stage. Alignment of project personnel towards the operational needs behind the design is fundamental. An illustrative ConOps and a Pugh Matrix may be candidates in this process. An illustrative ConOps can take the design into the operational environment and show a joint holistic picture to personnel from different departments.

One of the drawbacks of these methods may be the perception of additional workload amongst the responsible engineers. An already tight schedule can cause resistance to utilize the methods and lead to a situation where the methods are used as documentation after the validating process. Clear communication on the benefits of the tools and commitment from top management are necessary to motivate these changes.

Conclusion

Tools to assist engineers in validating solutions against the operational needs are necessary to reduce the amount of late design changes. A common understanding of the operational needs amongst the involved parties in a development process will increase the chance of revealing weakness in design at an early stage. Through this research, we find that both the illustrative Concept of Operation and the Pugh Matrix show potential to be used as tools in communicating qualities of conceptual solutions between project members and stakeholders. Using the ConOps as a dynamic tool to capture the system needs from the beginning of the system definition phase, can increase the understanding of the concept amongst the involved parties and highlight concerns early in the development. A holistic picture of the concept quality is created when using the Pugh matrix as a mean of communication and discussion. Project engineers can utilize this to determine the concept most suitable for the scope. Drawbacks of the methods may be increased workload on the responsible engineers. Another aspect worth mentioning is the risk of the methods being used as pure documentation of a predetermined choice. Mitigating actions such as clear communication of the benefits and upper management commitment may ease implementation.

Future research

Positive aspects of implementing the abovementioned methods as tools in exploring conceptual solutions were observed throughout the research. Limitation in schedule restricted a more comprehensive test of impact of the methods. It is therefore necessary to collect and analyze additional data on the effect of these methods. This research has been conducted in-house in a single firm, and further investigation on the communication through these methods towards client and other stakeholders is required.

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References

Aker Solutions Annual Report 2014: Evolutions. Accessed 10-05-2015. https://www.akersolutions.com/Documents/Investors/Annual%20reports/AkerSolutions_AnnualReport_Interactive_2014.pdf

Aker Solutions Quarterly Result 2014: Q3. Accessed 10-05-2015. https://www.akersolutions.com/Documents/Investors/Quarterly%20reports/2014/Aker_Solutions_3Q_2014_quarterly_presentation.pdf

Yong Bai, Qiang Bai. 2010. Subsea Engineering Handbook. Elsevier.

Burge, S. 2009. The Systems Engineering Tool Box. Accessed 12.01.2015. http://www.burgehugheswalsh.co.uk/uploaded/documents/Pugh-Matrix-v1.1.pdf

Cloutier, R. Mostashari, A. 2009. Investigation of a Graphical CONOPS Development for Agile Systems Engineering. In SERC 2009

Kossiakoff, A., Sweet, W. N., Samuel, J. S., Biemer, S. M., ed. 2, 2011. System Engineering Principles and Practice. Wiley.

Haskins, C., ed 2011. System Engineering Handbook: A Guide for System Life Cycle Processes and Activities. Vesion 3.2.2 edited by: Michael Krueger, CSEP, David Walden, ESEP and R. Douglas Hamelin. San Diego, CA (US): INCOSE.

Honkala, S., Hämäläinen, M., & Saloon, M. 2007. Comparison of Four Existing Concept Selection Methods. In International Conference on Engineering Design, ICED'07.

Moberg, M. 2014. Need analysis and requirement handling in Oil & Gas industry with complex systems and tight schedules; Mitigation of late design changes. Master project paper at HBV, Norway

Muller, G., Klever, D. G., Bjørnsen, H. H., & Pennotti, M. (2011). Researching the application of Pugh Matrix in the sub-sea equipment industry by. CSER 2011 in Los Angeles.

Muller, G. Heemels, M. 2007. Five Years of Multi-Disciplinary Academic and Industrial Research: Lessons Learned

NPD Norwegian Petroleum Directorate. 2013. Evaluation of projects implemented on the Norwegian shelf. Accessed 19.04.2015 .http://www.npd.no/Global/Engelsk/3-Publications/Reports/Evaluation-of-projects.pdf

O'Brien, R. 1998. An Overview of the Methodological Approach of Action Research. University of Toronto http://www.web.ca/robrien/papers/arfinal.html#_edn2 (retrieved 24.04.2015)

Papandrea, J. 2014. AHA – Contingency satellite study. AKSO internal document.

Piciaccia, L. 2014. Design Review Global Procedure – Rev.08, AKSO internal document.

Tranøy, E. 2012. Reduction of Late Design Changes Through Early Phase Need Analysis. INCOSE 2014 in Las Vegas.

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