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How can simplified requirements affect project efficiency – A case study in oil and gas

Eirik Fallrø
University of South-Eastern Norway/
Aker Solutions
feirik@gmail.com

Kristin Falk
University of South-Eastern Norway
kristin.falk@usn.no

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Abstract. Requirements engineering is a constant challenge for companies executing complex projects. The oil and gas industry has been renowned for stringent stakeholder requirements driving costs. When the oil price plummeted six years ago, the industry had to adapt to make projects economically viable. Over the last four years, a major supplier to the industry has been executing three subsea production system projects as part of a frame agreement for a client. This case study investigates requirements engineering with a focus on cost savings. The paper examines data sources from the contractor and interviews with key project personnel. The main finding is that the contractor and client's efforts to simplify requirements have improved project efficiency. However, it has not been possible to quantify the exact benefit. Furthermore, the requirements engineering has been dependent on soft factors and collaboration during early study activities. This paper contributes with a description of a requirements engineering method. This is a collaborative method where the supplier adjusts the systems requirements, in close collaboration with the client, based on a detailed design in a very early phase of systems engineering. The research can also give additional insight into requirements engineering for other industries executing complex projects.

Introduction

The goal for subsea field development is to transport hydrocarbons from the reservoir to the production facility safely and efficiently (Bai 2009). This goal is achieved by several subsystems, as illustrated in Figure 1. The subsea production system (SPS) is an integral part of field development, providing interfaces for well drilling operations, hydrocarbon transportation, and reservoir control. Laws and regulations, standards such as API (2019) or NORSOK (2019), and operator-specific specifications define the SPS requirements. The chosen system solution and operating philosophy for the production system dictate which requirements are applicable. The value of an SPS contract for a single project is typically between 50mUSD and 500mUSD.

This paper describes research conducted in Aker Solutions, hereby denoted AKSO. The company is a global supplier of oil and gas production systems and renewables technologies such as carbon capture, utilization, and storage (Aker 2019a). AKSO has roughly 16 000 employees in 25 countries and the company revenue for 2019 was 29.3 billion NOK (Aker 2019b).

AKSO has since 2017 executed the Johan Castberg, Troll Phase 3, and Askeladd SPS projects, hereafter denoted the Project Portfolio, for client Equinor. A low oil price leading up to the contract awards resulted in a heavy focus on reducing costs for the three projects. This price environment led to Equinor and AKSO working together to define simplified requirements to improve project efficiency. The cost focus and intertwined dependencies of SPS requirements called for intricate systems engineering to find SPS designs balancing project requirements with portfolio optimizations.

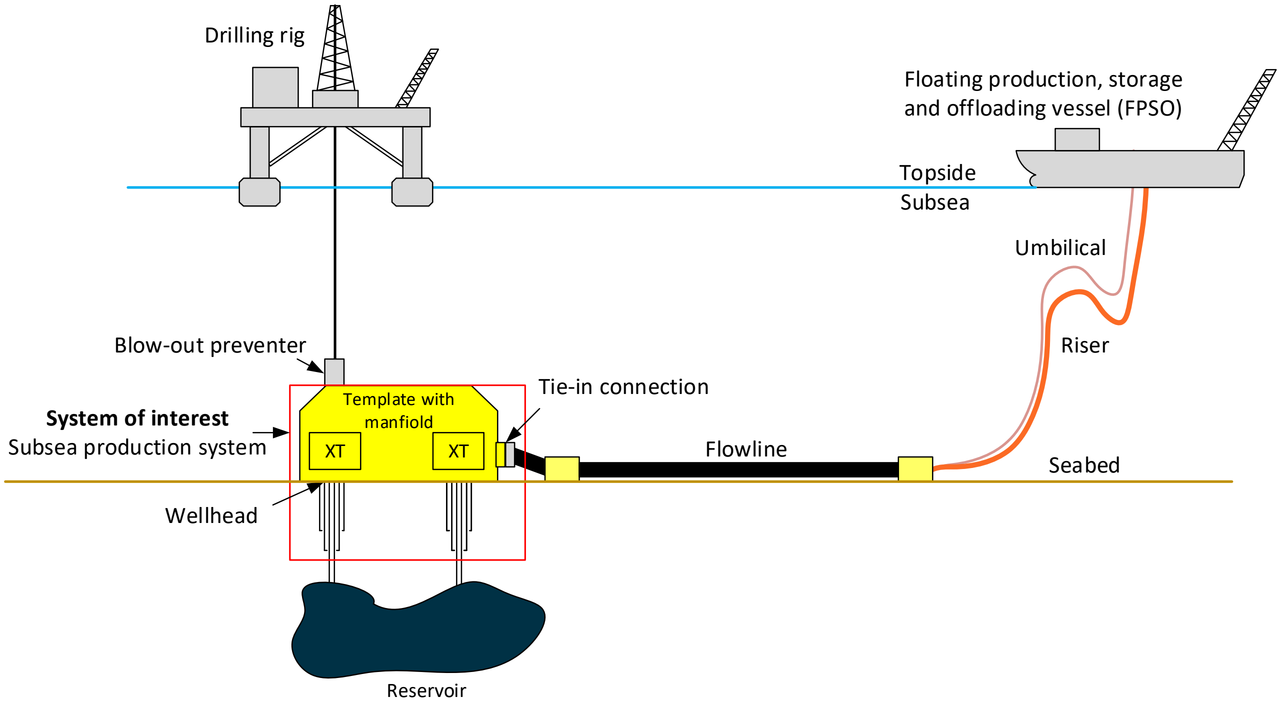

Figure 1. Typical components in subsea field development.

Requirements engineering

Many factors constrain the SPS design. A common denominator for important requirements is the external interface to other delivery scopes, such as a drilling unit operator or a subsea umbilical, riser, and flowline (SURF) contractor seen in Figure 1. Drilling accounts for a large part of total field development expenses. This results in operators defining field layouts and SPS requirements to minimize the time spent drilling wells. The SURF scope is also dependent on the field layout, where the well-slot placement dictates flowline lengths and installation operations. The intertwined dependencies result in complex trade-off decisions when defining the SPS scope and requirements (Nilsen 2018).

Systems Engineering. AKSO practices systems engineering (SE) within an internal project execution model (PEM). Analyzing the PEM and its uses have been the subject of multiple papers (Mjånes 2013; Svendsen 2016). The goal of the papers was to improve the systems engineering processes of the PEM. Figure 2 shows a high-level overview of the different PEM phases.

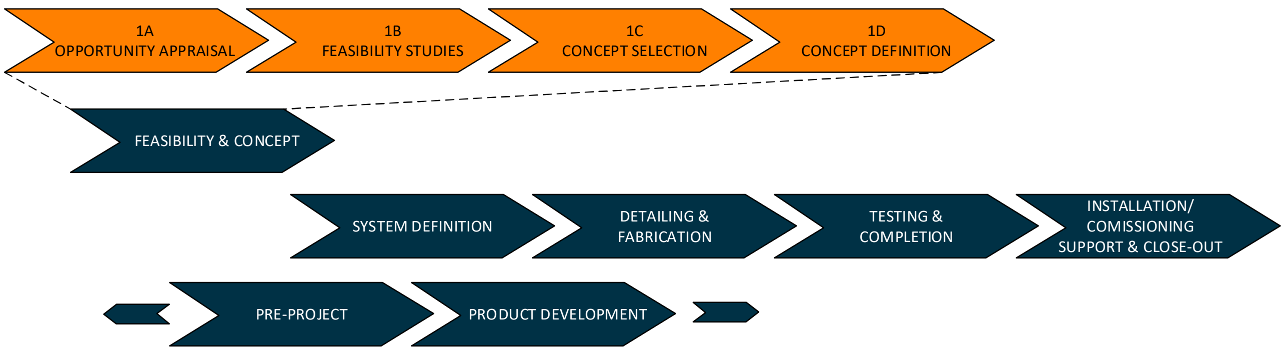

Figure 2. High-level phases of the AKSO PEM.

Feasibility and concept is the main phase for doing early systems engineering work. In this phase, systems engineers work closely with other disciplines to mature field layout concepts and define stakeholder requirements. When a field layout is frozen, AKSO and the client clarify system requirements in the concept definition phase and during front-end engineering and design (FEED) activities. If AKSO wins the tender to execute an engineering, procurement, and construction (EPC) contract, AKSO project teams apply the remaining phases of the PEM.

It can be difficult to determine whether a client requirement is a stakeholder requirement or a system requirement. While clients propose stakeholder requirements in project specifications, the low availability of qualified subsea suppliers for sub-systems often results in stakeholder requirements dictating system solutions.

Problem definition and motivation

The primary motivation for the research is to examine the requirements engineering for the Project Portfolio. Moreover, the collapsing oil price resulted in a change of work processes in AKSO focusing on improving project efficiency. Examining these recent projects is an opportunity to evaluate changes to requirements engineering processes in a large organization. The research question and sub-questions are:

- How have simplified requirements affected project efficiency for the Project Portfolio?

  i. How did systems engineers in Equinor and AKSO define simplified requirements for the portfolio of frame agreement projects?

  ii. How much of the engineering work conducted by AKSO occurred pre-EPC contract award?

  iii. Which factors affect SPS project efficiency in AKSO?

Research method

The research is based on the industry-as-laboratory approach (Potts 1993). Figure 3 shows the different activities connected to the early studies, project execution, and academic process. The background for the research is the early studies and cost savings initiatives. Equinor and AKSO implemented these initiatives during the project execution for the Project Portfolio. The academic process has involved preliminary interviews, literature study, gathering and interpretation of data, interviews of project personnel to validate findings, and finally, a discussion with comparison to literature. The author has gathered data from various sources listed in Appendix A. The enterprise research and planning (ERP) system in AKSO has been the primary source for quantitative data.

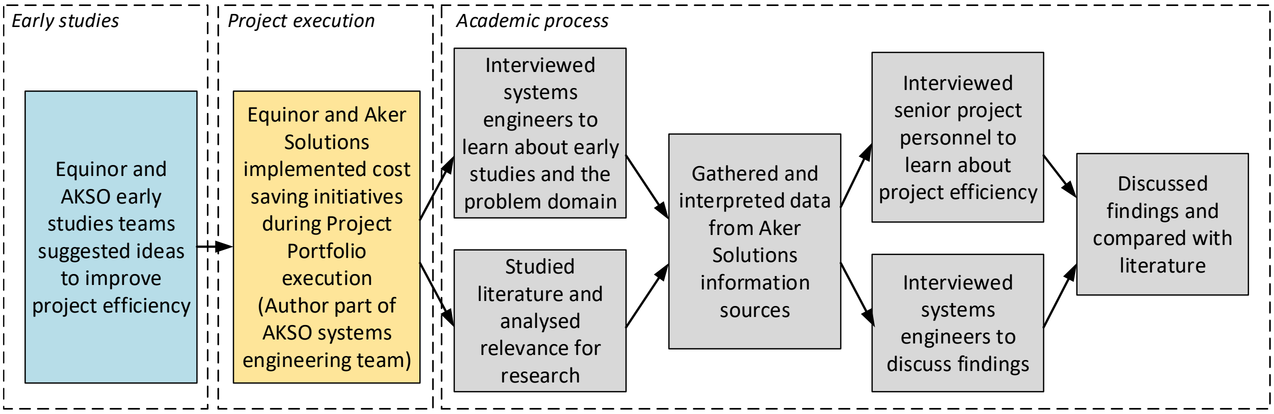

Figure 3. Steps in the research activities.

Stakeholder interviews. The author has conducted semi-structured interviews (Longhurst 2003; Muller 2013) with senior project members working in the Project Portfolio. The semi-structured approach allowed the interviewees to discuss relevant topics for each area of responsibility. The author adjusted the open-ended questions after conducting the initial interviews. These initial interviews highlighted planning and interfaces as important factors affecting SPS project efficiency. The author focused more on these topics in the later interviews to further explore these factors.

Validation. The soft factors in systems engineering can make direct validation of results difficult (Muller 2010). This is relevant for requirements engineering, which depends on human interaction and interpretation of statements between stakeholders. To assist in validating claims and verifying methods, the researcher had frequent meetings with experienced systems engineers in AKSO and an academic supervisor. These meetings have functioned as quality reviews to interpret AKSO data and methods for use in the research.

Literature review

Requirements engineering is an important part of systems engineering because it is costly to extract defects throughout a project (SE Handbook Working Group 2011, Walden 2015). Based on this, Tranøy and Muller (2014) have described how understanding stakeholder requirements at an early stage can reduce late changes and cost overruns in the subsea domain. A possible solution is model-based systems engineering (Baker 2016) or applying configure-to-order methods to make more robust early designs (Falk 2019). Literature has also discussed related topics, such as managing requirements related to subsea power systems (Rajashekara 2017). Zager et al. (2019) suggest that linking requirements to verification activities can improve system integrity for safety systems. As the needs of the customers should be in focus (Yasseri 2014), visual tools such as an architectural overview could help capture stakeholder requirements (Muller 2015). Other methods for requirement elicitation include utilizing the concept of operations (Muller 2018) and adapting stakeholder prioritization in the project to capture the stakeholder needs efficiently (Aasheim 2017).

Papers and textbooks have discussed project efficiency. Shenhar and Dvir (2007) define project efficiency as a measure for whether an organization executes a project within its time, cost, and functionality constraints (Shrnhur 1997). Some papers argue that the project efficiency alone does not result in a successful project as additional parameters affect project success (Serrador 2015; Atkinson 1999; Sundqvist 2014). The pitfalls are plenty, poor management support, poor stakeholder management and lack of contingency planning are some of the reasons behind information system project failures (Dwivedi 2015; Koch 2004). Papers also describe top management support as an important success factor for a portfolio of projects (Elbanna 2013; Dvir 2011) as an organization needs proper prioritization between individual projects (Martinsuo 2007; Fricke 2000). A possible solution is to use an analysis method and compare project efficiency across a portfolio of projects (Vitner 2006).

Requirements engineering consists of a wide variety of tools and techniques to efficiently capture requirements (ur Rehman 2013). As literature lists successful requirements engineering as an important factor for project success (Zwikael 2006; Bahill 2005), it is important to examine the traits of good requirements management. Batool et al. claimed that early engagement with stakeholders and a focus on trust are important (Batool 2013). When challenges arise, it is also important to distinguish between the type of problems. For example, whether it is a context-oriented, human-oriented, or process-oriented factor that causes the problem (Distanont 2012). Kauppinen et al. (2004) have researched the implementation of new requirements engineering processes in three Finnish companies. The main findings were seven success factors that are important when implementing new requirements engineering processes. Many of the success factors, such as motivation and commitment, were interrelated and connected to soft factors (Shahin 2011).

Project Portfolio background

This section provides a high-level overview of the individual project characteristics in the Project Portfolio. The Project Portfolio described in this paper consists of the Johan Castberg, Troll Phase 3, and Askeladd SPS projects. The projects were awarded to AKSO in late 2017 and early 2018 by client Equinor. Table 1 provides a high-level description of the three projects and their corresponding key properties. While AKSO and Equinor expected synergies from grouping the projects into a portfolio, each project also represented distinct challenges and opportunities.

The Johan Castberg SPS is a major greenfield development in the Barents Sea. Due to the low oil price leading up to the contract award, Equinor had to drastically reduce the field development cost to sanction the project. SPS integrity in the Barents Sea is also of high importance as any environmental incident could damage the reputation of the client and contractors.

The purpose of the Troll Phase 3 SPS is to produce gas from the massive Troll West reservoir. Since Equinor will produce the gas reservoir through pressure depletion, additional pressure loss from the SPS reduces the potentially recoverable volume of gas. The sensitivity to pressure drop resulted in a high focus on flow assurance to optimize project economics.

The Askeladd SPS located in the Barents Sea is a tie-in to the existing SPS infrastructure. The main purpose of the development is to extend the steady gas supply to an onshore liquefied natural gas (LNG) plant. Equinor requires reliable control systems and safety functions due to the lengthy step out from the onshore plant. Initially, Equinor is populating three out of eight available x-mas tree slots allowing for flexibility in increasing production as needed.

Table 1: High-level description of the Project Portfolio.

Project	Properties	Description
Johan Castberg SPS	Main SPS driver	Low capital expenditure and life of field costs
	Scope	31 x-mas trees, 10 templates with manifolds, 2 satellites
Troll Phase 3 SPS	Main SPS driver	Maximize gas production through reduced pressure loss
	Scope	9 x-mas trees, 2 templates with manifolds
Askeladd SPS	Main SPS driver	Reliable gas supply to onshore Melkøya LNG plant
	Scope	3 x-mas trees, 2 templates with manifolds

While each of the projects has distinct challenges in addition to typical SPS requirements, the projects are standard from a Norwegian Continental Shelf (NCS) perspective. Equinor analyses predict that the reservoirs will be easy to produce and the SPS water depth of the projects ranges from 250m to 390m. By avoiding challenging high-temperature, high-pressure, or deep-water requirements, SPS products could be standardized and re-used across the projects. The author characterizes the Project Portfolio as a platform, medium-tech, system, and fast/competitive project. This assessment is based on the novelty, technology, complexity, and pace (NTCP) definitions (Shenhar 2007).

Studies and FEED activities

This section describes the activities leading up to the Project Portfolio contract awards. The author has condensed the information based on interviews of systems engineers, Project Portfolio working experience, and AKSO study reports.

The starting point for the Project Portfolio study work was the Equinor discovery of the Skrugard and Havis reservoirs in 2011 and 2012 (Equinor n.d.). In 2013 Equinor contracted AKSO for a concept study to consider different SPS solutions for the field development. As seen in Figure 4 and from Table 2, this concept study was just one of many activities on the road to realizing the Johan Castberg (JC) field development. This section discusses the points in order from (5) – (9). Descriptions for activities (1) to (4) are included in Table 2.

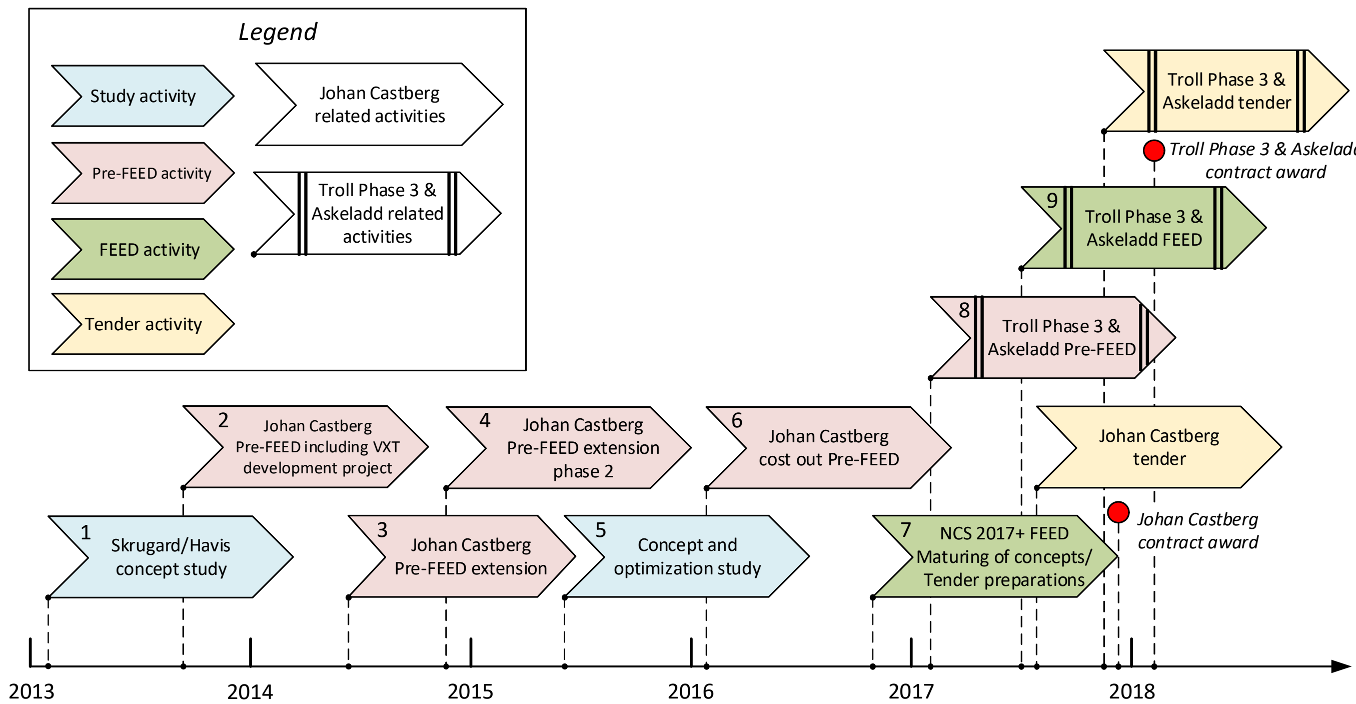

Figure 4. Activity overview for the Project Portfolio before project contract awards.

Table 2: High-level description of the Project Portfolio activities before contract awards.

#	Activity	Description
1	Skrugard/Havis concept study	Initial study for Johan Castberg using standard AKSO equipment and field development plan. The scale of the project was substantial. Aker Solutions proposed horizontal x-mas tree (HXT) technology as a standard offering from earlier projects.
2	JC Pre-FEED	Built on the previous study, and included both standard and re-designed parts. The Aker Solutions team discussed and processed requirements together with the client. In parallel, a vertical x-mas tree (VXT) development project was initiated by Equinor. The potential savings for Equinor were substantial as drilling rig expenses are a large part of the total cost.
3	JC Pre-FEED extension	Delays due to too high breakeven price for total field development. For the SPS scope, this phase focused on improving the wellhead solution and installation of the subsea modules.
4	JC Pre-FEED extension phase 2	Equinor extended the Pre-FEED with a new phase due to an unsustainable price level for sanctioning the project.

#	Activity	Description
5	Concept and optimization study	Continuation study to retain competency and investigate cost reductions for the SPS scope
6	JC cost out Pre-FEED	Radical requirements engineering by challenging historical requirements in cooperation with the client. Many different cost reduction initiatives proposed
7	NCS 2017+ FEED	Maturing of design for improved products, and continued cost focus
8	Troll Phase 3 and Askeladd Pre-FEED	Product adaptations to realize portfolio synergies
9	Troll Phase 3 and Askeladd FEED	Maturing of products focusing on key project drivers

(5) Concept and optimization study (2015). In 2015 the grim reality of the declining oil price started to kick in. This study would not build on earlier work, the AKSO team was back to square one to look for significant cost reductions in new concepts.

(6) Johan Castberg cost out Pre-FEED (2016). This activity was a turning point for sanctioning the Project Portfolio. Equinor kicked off this activity by informing AKSO that their cost level was too high compared to the rest of the market. Representatives from Equinor gave cost targets for standard SPS products. The response from the AKSO team was that Equinor requirements were driving the cost. To analyze the cost versus benefit, Equinor wanted to know the added cost for each requirement. The cost was difficult to provide, as requirements often are interconnected and dependent on many variables. The solution from the AKSO engineers was to start at the end. The team designed new, smarter, and cheaper SPS products and then challenged the Equinor requirements that hindered the new designs from being used for the Johan Castberg project.

The result of the design approach was a fruitful atmosphere for challenging requirements and finding cost reductions for all parts of the SPS scope. A common mantra was only to keep the *need-to-have* requirements while removing any requirements that described *nice-to-have* or *used-to-have* functionality. From the latter two, the *used-to-have* requirements required considerably more effort to challenge successfully. For a large organization with decades of operational experience such as Equinor, it was difficult to trace back to the exact rationale for some requirements. The unclear rationales made Equinor representatives more reluctant to remove certain *used-to-have* requirements. Still, the teams progressed towards the aggressive cost targets due to aligned expectations. For Equinor, Johan Castberg was a prestigious Barents Sea development held up by unsatisfactory project economics. For AKSO, the project was an opportunity to maintain activity during the downturn. Both parties had a common interest in finding better and cheaper solutions to get the project sanctioned.

Equinor and AKSO also scrutinized other project activities for cost reductions. The teams simplified requirements specifications by condensing only the relevant requirements from Equinor TR specifications into a common package specification for subsea production systems. Equinor also reduced the required documentation deliverables by implementing the DNVGL-RP-O101 standard (DNVGL 2016) with some modifications. The teams also found other improvements by challenging historical work processes, such as reducing the number of documents AKSO would send for review to Equinor. The result was many smaller initiatives adding up to significant savings.

In parallel with the Johan Castberg activities, the VXT development project from 2013 had qualified new components for use. Originally, the product development team expected this new VXT technology to have much of the same functionality as the earlier HXT technology available in 2013. Based on the requirements work done in this Pre-FEED phase, AKSO instead attempted to optimize the new VXT technology with a focus on operational requirements and minimizing the total cost of ownership. This optimization made the x-mas tree smaller, lighter and cheaper to produce.

(7) NCS 2017+ FEED. After a successful Pre-FEED phase, the Johan Castberg development entered its first FEED phase. The goal was to mature and integrate the designs that the teams had proposed in the previous Pre-FEED phase. Additionally, Equinor set more aggressive cost targets. These proved difficult to meet as much of the potential had already been realized in the Pre-FEED. The FEED phase also introduced more contractual rigor related to external interfaces. Equinor did not allow any proposed changes to the SPS design to affect external scopes such as SURF. This limitation was logical as the main purpose of a FEED is to mature a system solution. However, it also removed some flexibility in optimizing the SPS design that had been available in the Pre-FEED.

(8) Troll Phase 3 and Askeladd Pre-FEED. While the Johan Castberg development was gaining traction, Equinor contracted AKSO to conduct a Pre-FEED for the Troll Phase 3 and Askeladd SPS projects. These projects were an opportunity for AKSO to secure a portfolio of work with potential synergies. Due to similarities between the two gas projects, a common AKSO team conducted the Pre-FEED. The focus was on repeating the Johan Castberg Pre-FEED work on a tight schedule. With multiple potential projects and aggressive cost targets, the team had to make portfolio-level trade-offs. The product group adjusted the VXT design by improving pressure loss parameters while still re-using much of the Johan Castberg design. Structure engineers designed subsea templates to be configurable and accommodate different sizes of manifolds with connections. The design efforts increased the potential cost synergies of being awarded multiple projects but also removed some flexibility in optimizing for project-specific parameters.

(9) Troll Phase 3 and Askeladd FEED. As for Johan Castberg, the goal of this FEED was to mature and integrate the proposed solutions. A large part of the work was related to optimizing for pressure loss as this was a key driver for Troll Phase 3 and beneficial for Askeladd.

Equinor awarded AKSO the Johan Castberg SPS contract in late 2017 shortly followed by Troll Phase 3 SPS and Askeladd SPS in early 2018. AKSO had spent 6.5% of the total engineering hours before the project awards. The VXT development project is excluded from this percentage as it was a standalone activity.

Project Execution

This section presents key information from the project execution and efficiency data for the Project Portfolio. The section also discusses project efficiency based on interviews with key project personnel.

The multiple contract awards in 2017 and 2018 kicked off the AKSO engineering activities. Systems engineers from earlier phases continued to work in the project teams to guide in discussions and clarify requirements. To solidify the project culture, Equinor defined a set of expectations (AKSO and Equinor 2018):

- Quality, trust, and cooperation with Equinor as a basis for execution
- Align on the execution of the work
- Understand our technical requirements
- Execution based on a lean and cost-effective way of working

- Reduce uncertainties
- Life of field total cost considerations

Equinor also agreed to organize as a common team representing all three projects. The organization structure allowed for more efficient communication by solving common problems at a portfolio level rather than individually for each project. Figure 5 illustrates this shared scope with 11 common TR specifications for the frame agreement projects. The figure also shows that Equinor reduced the use of TR specifications from 73 to less than 30 when compared to a project awarded before the down-turn.

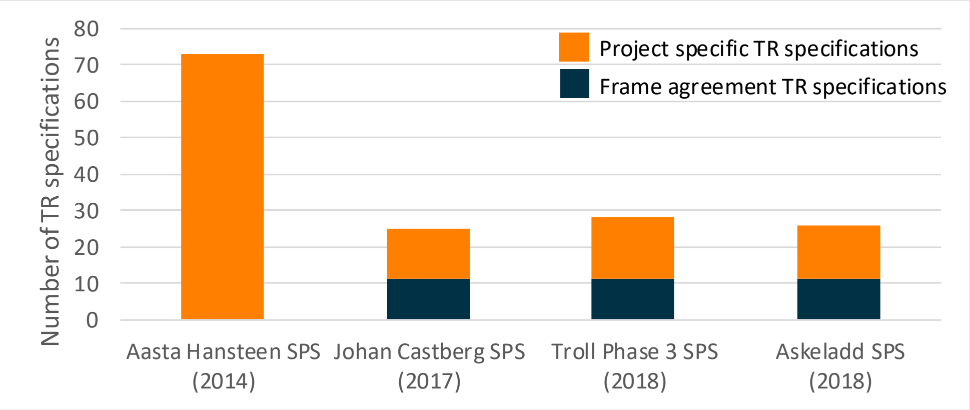

Figure 5. The number of Equinor TR specifications per project.

Project efficiency. Assessing the project efficiency of an SPS project is not trivial due to project complexity and sub-contracting of work. The project hours and NCR data provided in this paper present part of the internal AKSO efficiency related to cost and quality. The author has selected four historical NCS projects, hereafter denoted as the Comparison Projects, with varying scopes as a comparison for the cost and quality data. For the Project Portfolio, the corresponding scope size description is large for Johan Castberg SPS and medium for both the Troll Phase 3 and Askeladd SPS.

Figure 6 shows that the number of forecasted internal project hours for the Project Portfolio is lower when compared to the Comparison Projects. The reduction of 56% is in line with expected efficiency improvements partly described by the study and FEED activities.

Figure 7 shows that the current level of quality is better than the historical average of the Comparison Projects. The reduction of 67% is more uncertain as the Project Portfolio NCRs are based on the current status and will likely increase as AKSO close out the projects. Figure 7 also shows that the number of NCRs for the Comparison Projects has varied independently of project size. This variation can indicate a difference in quality, or that work processes related to defining and labeling NCRs have varied from project to project.

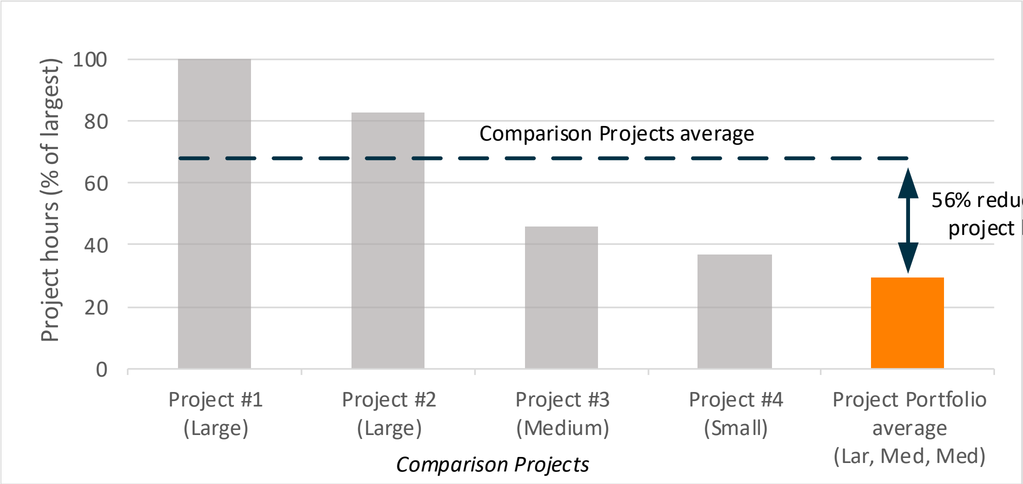

Figure 6. Internal project hours per project. The project Portfolio average is based on forecasted hours.

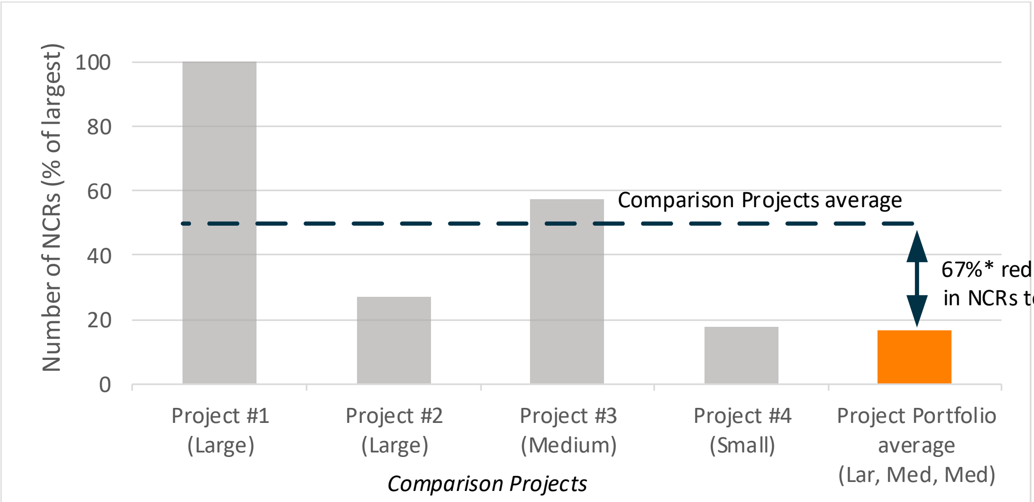

Figure 7. NCRs are labeled as medium or high priority per project. *Current number of NCRs as portfolio projects are still ongoing.

Factors affecting SPS project efficiency. The author has interviewed senior project personnel and asked open-ended questions about project efficiency for their area of responsibility. The lead engineers all responded that the planning priority set by Project Portfolio planners was affecting their efficiency, especially at the start of the project execution.

AKSO sub-contracts a substantial part of the scope for an SPS project and the project management closely monitors the procurement cost. This focus on cost reductions was especially true for the Project Portfolio, which had an ambitious procurement plan. The project planners wanted to incorporate the procurement cost initiatives, but they also had to find the right project efficiency balance:

- Procurement wants to place large and early purchase orders (POs) to get volume discounts
- Engineering wants to spread out POs and engineering by actual need date to utilize engineering resources more efficiently
- Planning wants to add a float to milestone deliveries to reduce the risk of liquidated damages (LD)

Figure 8 illustrates these trade-offs with an iron triangle (Atkinson 1999). The figure shows AKSO procurement, engineering, and planning groups along with selected external constraints. This is a simplified model showing the focus at the start-up of the Project Portfolio. The lesson learned from the engineering leads is that the initial plan should be realistic to complete. If the plan is too focused on optimal procurement dates, it is challenging for engineering leads to having a workable plan. An example of this is the tie-in scope, which includes many hubs in different configurations. The project management expected early, high-volume POs directed at large sub-suppliers to yield cost savings. However, it was not possible to finalize the engineering of the hub designs before relevant internal and external interfaces had been agreed upon.

As the Project Portfolio progressed, there were lessons learned in preserving the float towards critical deliveries throughout the AKSO value chain. The planning manager noted that planners should not communicate float as "available days to be used", but instead communicate the cost of the liquidated damages per day for a milestone. Focusing on the potential penalties would make it easier for purchasers and engineers to understand the consequences of late deliveries and prioritize accordingly.

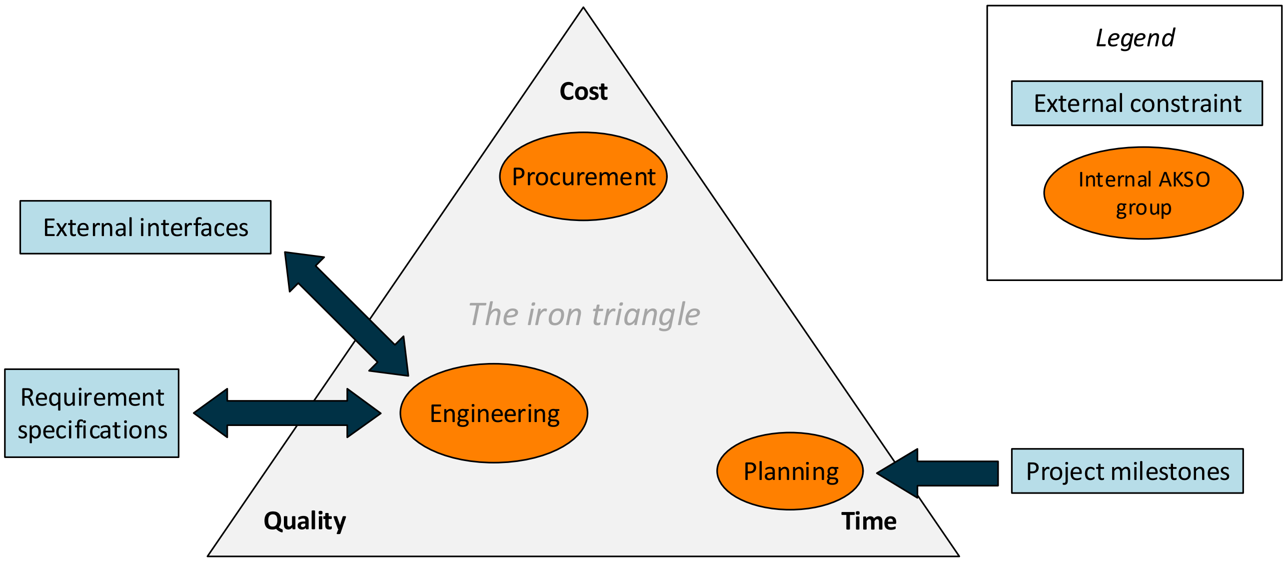

Figure 8. The iron triangle based on (Atkinson 1999) with an overlay of AKSO project groups and selected external inputs.

Six of the interviewees highlighted a mature early engineering starting point as an important efficiency factor. The tie-in work pack did not have the same maturity as other work packs. Activities in early studies did not sufficiently prioritize tie-in engineering as it was re-using designs from earlier projects. This prioritization resulted in challenges related to scope management, requirements alignment, and schedule. The engineering manager also noted that work packs with a good starting point performed better than expected from the tender estimates.

The author also asked the interviewees to describe the effects of the Equinor expectations. All but one of the AKSO interviewees agreed that Equinor had lived up to their expectations regarding cooperation. The interviewees described benefits such as more straightforward requirements discussions, a high degree of trust in designs, and more effective problem-solving. One very senior interviewee said that he had never experienced such a trust-based project environment before. Two of the interviewees also acknowledged a downside to the trust-based environment. When Equinor made changes to their project organizations, the new representatives would not have the same degree of trust in the AKSO team and designs. This made some previously agreed topics resurface and added more contractual discussions resulting in decreased efficiency.

Simplified requirement example

This section describes the method of challenging a requirement by doing a detailed design. A simplified manifold retrieval requirement is used as an example.

SPS maintainability is an important requirement due to the cost of shut down production. Operators such as Equinor want robust product designs to compensate for the response time of subsea intervention vessels. The Equinor TR1230 specification related to manifold requirements describes "…preferred technical solutions related to subsea structures, manifold and choke modules which are not sufficiently covered by ISO 13628-1 or other standards" (Equinor 2009). A manifold requirement from a version of the TR1230 used in projects before the oil price downturn states: ***"The manifold shall be retrievable and re-installable independent of the x-mas tree system."*** (Equinor 2009). As illustrated in Figure 9, this requirement dictates a horizontal connection system as a vertical connection system locks down the manifold once the x-mas trees are installed.

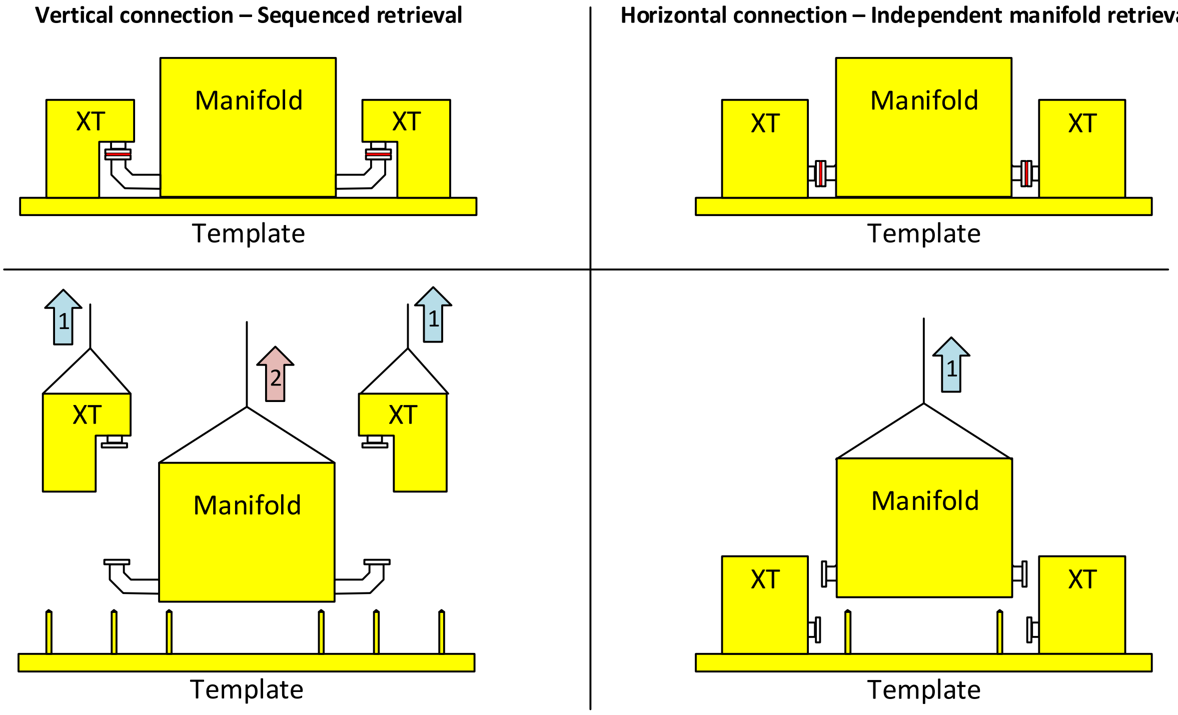

Figure 9. Manifold retrieval sequence differences depending between a vertical or a horizontal connection system between manifold and x-mas trees.

The rationale for an independent retrieval of the manifold is clear. If there is a serious malfunction in a manifold that the operator cannot fix subsea, the module needs to be retrieved to the surface and repaired. For an SPS operator, a manifold retrieval operation is complex and expensive due to shut down production and the chartering of specialized intervention vessels. If the XTs lock down the manifold, the operator would also have to retrieve the XTs before the manifold. This is further complicated if the XTs are horizontal x-mas trees (HXTs). To retrieve an HXT, a drilling rig would first have to retrieve the downhole completion equipment. Once the operator repairs the manifold, all retrieved equipment would have to be reinstalled in the reverse sequence. Summarizing the consequences, it is easy to see that Equinor standardized an independent manifold retrieval requirement with the available technology at the time.

The vertical x-mas tree (VXT) technology proposed for the Project Portfolio had different properties compared to the standard HXT technology available when TR1230 v4.01 was issued. With a VXT, the operator can install the downhole completion equipment before the VXT. This removes the need for retrieving the downhole equipment ahead of the VXT in a manifold retrieval scenario. Still, there was a drawback of having to retrieve four VXTs before repairing a four-slot manifold.

The Equinor and AKSO systems engineers analyzed this manifold requirement and proposed designs as part of the Pre-FEED in 2016. One of the findings was the system impact from using a horizontal connection together with a VXT. The VXT has clear advantages in being installable and retrievable independent of the downhole equipment. However, a drawback is the installation tolerance parameters. A VXT is mounted directly on the tubing hanger in the wellhead and will propagate the installation misalignment of the tubing hanger. Figure 10 shows the resulting offset from the potential rotational tolerance for a vertical connection and a horizontal connection. Manifold designers needed to account for a larger potential offset for the horizontal connection system when connecting the XT with the manifold. In practice, this increased the manifold cost when compared to a vertical connection system.

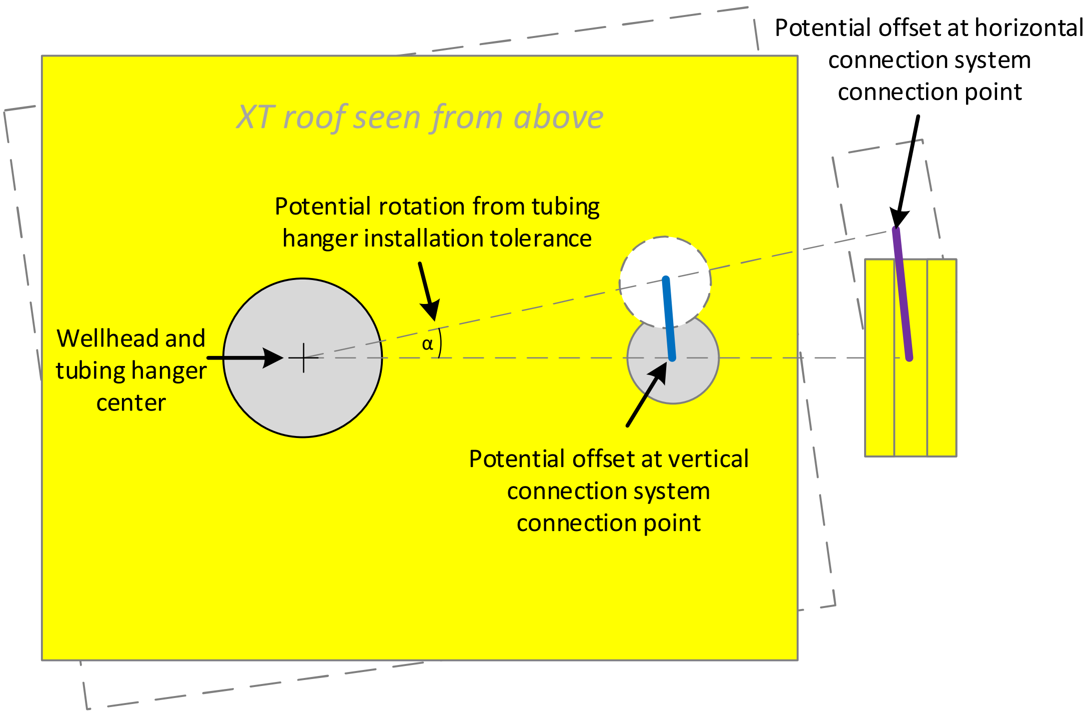

Figure 10. XT rooftop view of tolerance offset the difference between a vertical connection point and a horizontal connection point. The horizontal connection point location requires a more flexible manifold piping due to the larger potential offset.

The Equinor and AKSO teams iterated through different design options. The teams discovered that the vertical connection system would allow for a more compact manifold and template design. Furthermore, the solution also lowered XT weight and cost. After considering the total system solution, Equinor and AKSO agreed to change this *used-to-have* requirement to enable the vertical connection system as "…the cost-benefit outweighs any downsides." (Aker 2016). From the frame agreement specification relevant for the Project Portfolio, this requirement now simply states: ***"The manifold shall be retrievable and re-installable."*** (Equinor 2017).

Discussion

This section discusses the previously described findings and the validity of the research. This section also answers the research questions.

The first research sub-question is; *how did Equinor and AKSO systems engineers define simplified requirements for the Project Portfolio?* The Equinor and AKSO systems engineers used the early phase activities to iterate through SPS concepts and learn about the Johan Castberg field development. The most impactful activity was the Pre-FEED in 2016, where the AKSO team had a good understanding of the field characteristics, while the Equinor team was open to radical improvement ideas. The Pre-FEED phase seems to be an important phase for doing requirements engineering. If attempted too early during concept studies, discussing requirements can seem unproductive as concepts can be scrapped. If attempted later in a FEED, the contractual rigor and need for integration can prevent good improvement suggestions from being implemented.

The working methods for defining requirements were based on the AKSO's flexible workshop culture. AKSO did not follow any typical SE processes such as A3AOs (Muller 2015) or concept of operations (Muller 2018). However, the AKSO team did propose new equipment designs before challenging requirements. This approach contrasts with the Systems Engineering Body of Knowledge (SEBoK), which describes: "Design definition is driven by specified requirements, the system architecture, and more detailed analysis of performance and feasibility." (SEBoK 2019). The author has not found any reference to similar methods describing design ahead of challenging requirements in literature. The stakeholder interviewees describe that the trusting relationship between AKSO and Equinor was a prerequisite for the method to be a success. The method could be useful in conservative industries where the client-contractor relationship is well established and there is a need to redefine requirements.

The second research sub-question is; *how much of the engineering work conducted by AKSO happened pre-EPC contract award?* The reported 6.5% figure is within the typical systems engineering effort (SEE) range of 3-8%, according to Honour (2004), who also proposes an optimum SEE of 15-20%. The lower than optimum SEE for the Project Portfolio can stem from typical SPS project similarities as there was no need to develop conceptual SPS products from scratch. Typical SPS modules are well known to AKSO and the client, which is an argument for lower than optimum SEE. For AKSO, the early studies extensions to the Johan Castberg SPS resulted in a greater SEE than otherwise normal. Including the Troll Phase 3 and the Askeladd SPS projects into a portfolio resulted in a reduction of SEE related to these projects. Stakeholder interviewees reported that an increased SEE would be beneficial to improve project efficiency for certain AKSO work packs. A downside to adding more SEE would be the need for organizing larger early studies teams. The AKSO team size working on the early studies has on average been eight full-time engineers. A larger team might reduce the tightly-knit engineering interactions with Equinor and result in more administration focus during the SEE.

The third research sub-question is; *which factors affect project efficiency for AKSO in SPS projects?* The trade-offs in the project plan influence project efficiency according to the stakeholder interviews. Dvir and Lechter (2004) support this finding. They describe how a higher quality project plan positively affects project efficiency. Furthermore, milestone and procurement targets constrain the SPS planning when there is a dominant cost focus. From this, it is important to have a mature and early starting point for engineering to strike the right efficiency balance in the project plan. Literature supports the value of this early systems engineering (Honour 2004) and avoiding late design changes (INCOSE 2011; Tranøy 2014).

Interviewees also mentioned the positive effects of the Equinor cooperation expectations. The positive effects of such soft factors are outside the strict definition of project efficiency. On the other hand, papers describe customer satisfaction and meeting customer needs as project success factors (Shrnhur 1997; Atkinson 1999). These factors can have a positive impact on project efficiency as Serrador and Turner (2015) have found that the two efficiency measures correlate. It is interesting to note that the Equinor expectations are similar to the success factors of requirements engineering described in the literature (Batool 2013; Kauppinen 2004). The similarities imply that the soft factors may result in improved project efficiency outside the requirements engineering context. An interesting question is whether working integrated on simplifying requirements positively affects these soft factors. If so, it might be possible to realize a larger project efficiency gain than just the direct engineering impact from the simplified requirements.

The main research question is; *how have simplified requirements affected efficiency for the Project Portfolio?* From the 56% reduction in project hours and 67% reduction in NCRs, there is an efficiency improvement for the Project Portfolio compared to the Comparison Projects. As described in the early studies and FEED section, there have been many different cost reduction initiatives that may have affected the project efficiency. The simplified manifold requirement example describes a direct cost saving related to simplifying requirements. Interviewees have also mentioned other examples of simplified requirement savings without any described efficiency drawbacks. Based on this, the author concludes that the simplified requirements work has positively affected portfolio project efficiency. It has not been possible to quantify the efficiency gain. However, the 2016 Pre-FEED report did highlight the simplified manifold requirement as an important cost improvement (Aker 2016). There might also be other indirect efficiency improvements related to soft factors from simplifying requirements. The research cannot conclude if there is a link to the simplified requirements work or if other activities are the reason for the positive collaboration with Equinor.

Validity. The research has described simplifying requirements in one company related to one industry. From this, the research has limited validity in a general systems engineering context. Examining a portfolio of SPS projects has a positive impact on the validity as the information sources are likely less biased by individual project characteristics and events. The Comparison Projects selected for the project efficiency comparison are historical NCS projects conducted by AKSO with the same information sources as the Project Portfolio. This comparison includes uncertainties as to the scope of work and clients vary when compared to the Project Portfolio. The approach has been reviewed by senior AKSO personnel who agreed on the selection of projects for the Comparison Projects.

Conclusion

AKSO and Equinor have managed to improve the efficiency of a portfolio of SPS projects by simplifying requirements. It has not been possible to quantify the direct efficiency impact. However, the AKSO early studies team did underline simplified requirements as an important cost contributor. From early studies activities, AKSO spent 6.5% of the total project hours before the EPC contract awards. Moreover, the AKSO team designed new, cheaper, and smarter products before the team challenged Equinor requirements that hindered the new products from conforming to project specifications. The analysis of the stakeholder interviews concluded that the method was a success. The method could be useful in other conservative industries looking to improve requirements engineering processes.

AKSO and Equinor have improved the project efficiency compared to historical projects awarded before the downturn. The analysis of internal ERP data shows that AKSO has reduced internal project hours by 56% and reduced the number of non-conformity requests by 67% compared to the Comparison Projects. These large reductions show that simplifying requirements is just one of the improvement initiatives that have affected project efficiency. The project plan was in interviews underlined as an important factor affecting the project efficiency. Moreover, the procurement and milestone constraints call for focused systems engineering efforts ahead of a contract award to find the optimal project efficiency balance. A notable finding is that Equinor and AKSO actively have been promoting soft factors to create an efficient project culture. The close cooperation across the companies and project teams has been a key factor during both the requirements engineering and project execution.

Future work. This research describes a method of designing new products followed by challenging requirements. Based on the promising results for Equinor and AKSO it would be interesting to apply the method in other client-contractor relationships. Additional applications could assist in generalizing the method and possibly enable more efficient requirements engineering in other industries. Further research includes a deeper dive into requirements architecture and the influence of the organization on the requirements. In this research, we also discuss the importance of project planning for a portfolio of SPS projects. It could be interesting to examine whether systems engineering tools can aid in "systems engineering planning" of such large and complex projects. Useful tools could give planners a better starting point to optimize project efficiency during the hectic startup of large and complex projects.

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Biography

Eirik Fallrø has 3 years of experience working as a systems engineer in Aker Solutions. Since spring 2020, he is working as a project engineer in the company KONGSBERG. His background includes a bachelor's degree in Mechatronics and a master's degree in Systems Engineering from the University of South-Eastern Norway.

Kristin Falk. Prof. Kristin Falk teaches at the University of South-Eastern Norway where she is responsible for the research group in Systems Engineering. She holds a master's in applied mathematics and a Ph.D. in petroleum production. For twenty years in the industry, she has led technology teams in start-ups, SME, and large corporations, and worked with introducing complex systems for integrated operations, subsea processing, and automated drilling. Her current research focus is 'How to create systems fit for purpose in a volatile, uncertain, complex, and ambiguous world?'