28th annual INCOSE international symposium
Washington, DC, USA
July 7 - 12, 2018

# Reducing Project Cost Growth Through Early Implementation of Interface Management

Magnus André Nilsen
TechnipFMC &
University College of Southeast Norway
magnusandrenilsen@gmail.com

Kristin Falk
University College of Southeast Norway
Kristin.Falk@usn.no

Tom Arnfinn Haugen
TechnipFMC
Tomarnfinn.haugen@technipfmc.com



**Abstract.** This paper presents and analyzes quantitative data on Interface Management in the oil and gas domain from a subsea contractor point of view. To develop subsea oil and gas fields four to seventeen contractors collaborate via Interface Management to ensure that the technical parts fit prior to implementation and integration. This research has both analyzed quantitative data from seven large projects, and investigated the topic in depth using interviews. The results prove that late involvement of contractors contribute to project cost growth during project execution. The detailed analysis of a reference project showed that almost one third of the contractor's contractual changes were due to supply gaps toward other contractors. Early implementation of Interface Management could help mitigating this, and ensure project execution within predicted cost and schedule parameters.

## Introduction

**Domain.** The paper presents research from the subsea oil and gas industry, and pertains to projects executed by a Norwegian based Subsea Production System (SPS) supplier.

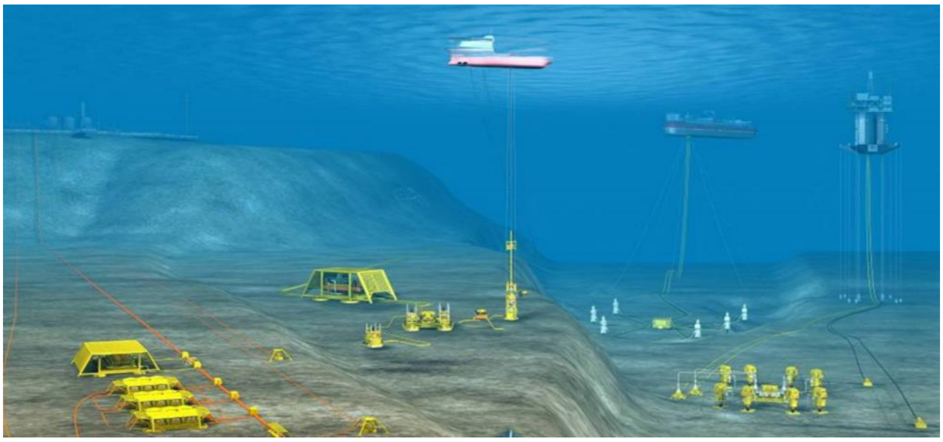

Figure 1: Illustration of different subsea production systems, including connections to the surface.

SPSs typically involve unmanned production facilities located on the sea bed, and they consist of a few core sub-systems enabling the production of hydrocarbons, oil and/or gas. Such systems include: subsea X-mas trees, subsea manifolds and templates, pipelines to facilitate transport topside or to an onshore facility, and pumps and separation units if appropriate to the parameters of the oil or gas reservoir (Figure 1).

In addition to the SPS, a complete field development will also include other services such as drilling activities executed by the drilling contractor and installation. SURF (Subsea Umbilical, Risers, and Flowlines) contractor does installation and secure distribution of control signals (hydraulic, electrical, and optical).  Also required is a topside installation which could either be a platform or a Floating Production, Storage, and Offloading (FPSO) unit with a completely integrated control- and hydraulic system. The oil and gas companies, henceforth referred to as clients, require all these systems during a project. Normally no contractors can provide all these services. Hence, clients place contracts to various contractors, each delivering a part of the total system. Through several years of collaboration between these contractors, there are technical clarifications made and implemented into the production of the equipment. The result is a fully operational subsea production field. It is the relationship between these contractors that this paper targets.

**Company.** This research is conducted for a SPS supplier, henceforth referred to as company, with decades of experience in delivering products and services to the oil and gas industry for subsea field developments, so as such it is to be viewed as a contractor. The company has 14,000 employees across the world in 39 countries.

A SPS is a complex entity combined of hundreds of small parts which are to collaborate to obtain their primary functions. During a normal Engineering, Procurement, and Construction (EPC) project the total scope of work is distributed amongst contractors, involving a substantial number of people across the world. Collaboration is crucial and necessitates cost-driving activities like technical discussions, exchange of documents and travel activities across geographic borders, time zones and cultural/political boundaries. The paper conducts research on seven EPC projects to explore the magnitude of the relationship between contractors during project execution. We chose a reference project to conduct a detailed analysis which provided us with unique results. The projects have all been executed over the course of the past ten years by the company.

An EPC system project typically has four main contractors, where the SPS contract value usually lies in the range of 50-500 mill USD. Recently, however, the business has noticed a shift in the industry; an increasing number of contractors all the way up to 17 contractors and interfacing partners. The scope of several new projects is divided amongst several contractors to lower the investment cost under the presumption that this will decrease the financial risk. What does not surface during the initial cost estimates, are the hidden costs that impact the project because of increased complexity. The Front-End-Engineering-and-Design (FEED) and tender processes define and quote the required scope of work, but there is no specific allocation of interface engineering resources. This makes accounting for the (un)predicted interface work hard to measure. The personnel resources allotted to the different projects are only based on experience by the tenderers. These resources are subject to change during the quotation work to decrease the client's investment cost as much as possible to keep the competitive edge.

**Problem statement.** Contractors in the oil and gas industry are currently challenged by the clients to reduce cost and delivery time due to the decreased oil price. The clients are dependent on several contractors to facilitate a complete development of oil and gas fields, each contractor contributing in some way with product deliveries or vital services. Since a subsea production system is an integrated system, the deliveries from the contributing contractors need to be compatible with each other. Contractors only have contractual responsibilities towards the client; they need to sort out necessary clarifications between each other via Interface Management, see Figure 2. However, if there are gaps in their contracts which prevents proper integration, this needs rectifying. Since this is not part of the original contract this often leads to changes with potential cost and schedule impact to the client.

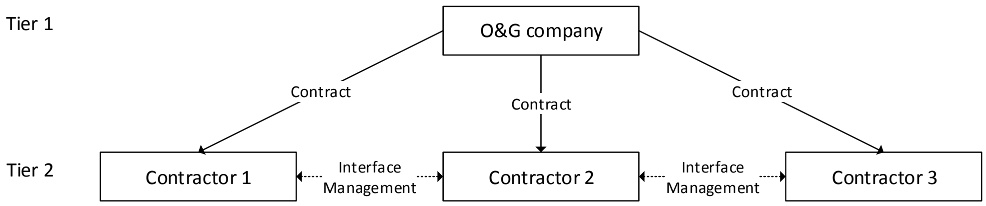


Figure 2: Illustration of the formal relationship between the oil and gas (O&G) companies and their contractors.

This paper researches the following statements:

1. How much of the cost-growth experienced by the clients related to the SPS delivery is due to insufficient Interface Management activity between contractors and contractual gaps between SPS and other contractors?
2. Identify possible reasons for these changes and determine how to avoid them.

## Background

The media has scrutinized oil and gas projects over the course of the last 20-30 years, and there have been many reports highlighting severe cost and schedule overruns, as recently detailed by Bergli (Bergli and Falk, 2017) and earlier by Tranøy (Tranøy and Muller, 2012). Both Bergli and Tranøy investigated sources and impact of these cost and schedule slips and arrived at similar conclusions; that company processes during FEED and tender phases are not robust enough to capture the required input. They both produced quantitative results as to the impact of this; one from the client-contractor perspective, and the other from a contractor-supplier perspective. The intention of this research is to capture the contractor-contractor perspective. Figure 3, similar as Figure 2, illustrates domains of recent research. The search for related literature revealed few results for research highlighting this perspective.

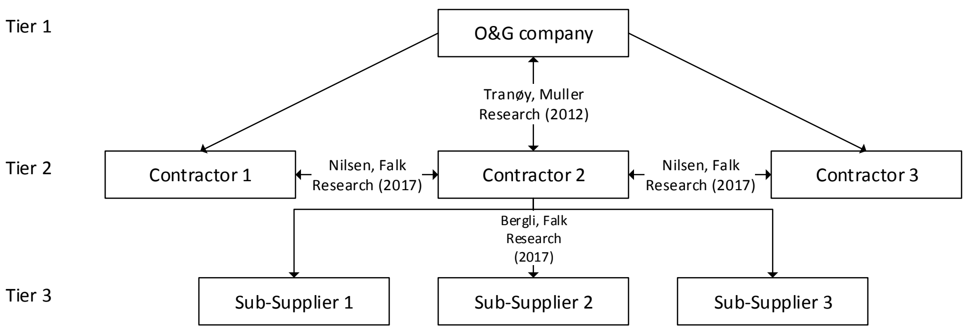


Figure 3: Domain and focus of research conducted in recent years.

The Construction Industry Institute (CII, 2014) conducted a study on 46 capital projects with the goal of establishing correlation between formal vs informal Interface Management and cost-growth in capital projects. What is considered a formal approach is determined up-front of a project and may differ from project to project. The study proved the following: that projects with an informal approach to Interface Management had an average of 18% cost-growth, whereas projects with a formal approach only experienced a cost-growth of 4%. 17 of the projects analyzed were from the oil exploration/production segment of the industry, meaning potential clients for the company. As such, this report proved to be the inspiration for this research.

This triggered us into evaluating how the company's interface partners impact the SPS design. Employees at the company expressed their concern that many contractors influence the SPS design during a project. Considering the four main contract awards by the clients, the SPS contract has the lowest value. The other three are SURF, Topside (platform or FPSO) and drilling, in that order. This "hierarchy" then also dictates where the potential cost impact would be lowest. Since SPS is lowest in this chain, this scope experiences the most changes. Reasons for this is also due to that the clients benchmark their available funds early. Research by the International Counsel of Systems Engineering (Walden) (2015) highlights this in Figure 4. The illustration includes typical invested and committed cost for clients during the life cycle of a project. Particularly interesting to note is that the committed cost is already at 80-85% during the design phase. Experience within the company also shows that the SPS contract is usually the first contract award issued by the clients. This is mostly due to the procurement of long lead items. Considering that changes are 15-20 times more expensive to implement during design than concept, it is understandable that the SPS requires adaption.

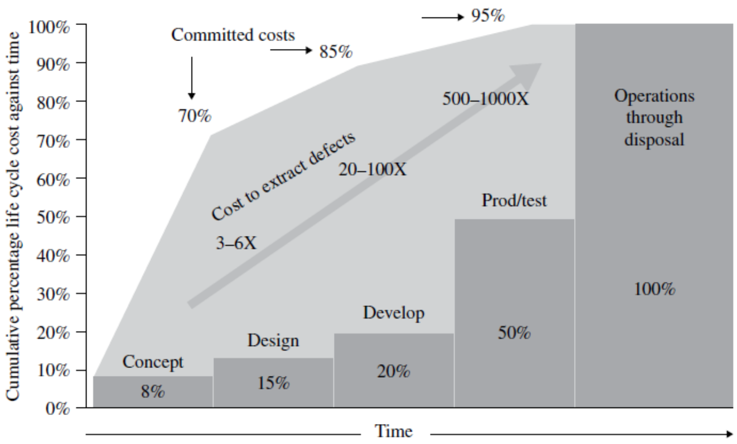


Figure 4: Illustration of client's committed costs during a project life cycle (Walden, 2015).

Research by Eric Honour (2013) proved that the implementation of system engineering (SE) activities contributed to maintain the cost and schedule within predicted parameters. Factors affecting this is not only the amount of SE, but also the quality. Could there potentially be a link between SE effort and cost-growth during project execution? These are factors considered as part of this research.

# Principles of Interface Management

Interface Management (IM) is an integral part of systems engineering according to the latest version of INCOSE's System Engineering Handbook (Walden, 2015). It consists of cross-cutting activities of various nature and as such IM is often present for the duration of an engineering endeavor.

**Definition.** The definition of Interface Management varies in published literature. In their SE handbook, The National Aeronautical and Space Administration (NASA, 2007) states that IM "is a process to assist in controlling product development when efforts are divided among parties (e.g. Government, contractors, geographically diverse technical teams etc.) and/or to define and maintain compliance among the products that must interoperate." The company's clients consider IM as multi-discipline, and places IM under project management. Chen's (2007) definition of IM is "the management of the boundaries among project entities (people /participants, processes/phases, resources, contracts, costs, schedules, systems/functions, and safety/risk) to enable a dynamic and well- coordinated construction system." This definition, derived from the construction industry, fit the project management perspective better.

The company has a separate IM department consisting of professionals called Interface Managers dedicated to the identification, management, control, and follow-up of interface related issues raised during project execution. This department was established in 2012 and is a sub-group of the company's System Engineering department due to its multi-discipline role when assigned to the company's delivery projects. As such, the before-mentioned definition of IM from NASA is more accurate regarding the IM practices at the company, and thus adopted as the definition of IM for this research.

**What is an Interface?** Upon attending any form of meeting in the subsea industry, especially one concerning technical clarifications, the word "interface" is widely used. This suggest that it exists some form of common understanding what it entails. Researchers have arrived at, and cited, various definitions of what an "interface" is. Nooteboom (2004) defined interfaces as "common boundaries between people, systems, equipment, or concepts." One of the four definitions Chen (2007) included as part of her dissertation categorizes an interface as "a point or place at which independent and often unrelated systems or diverse groups interact." Both these definitions soundly resonate with the company's working practices. However, this paper adopts the following definition from Abualfeilat (2011): "there is an interface between two systems or subsystems when one of them needs for its conception or realization to take in account inputs from the other one."

The oil and gas industry uses "battery limits" as a term to aid IM activities. The term is also in use in other industries, e.g. the Process Industry (Brennan, 1998). These limits are the points where the contractual responsibility change from one contractor to another. These points represent an interface between products that need to interoperate, and IM is a process of identifying and controlling this outcome. Simply put, an interface consists of a defined query that requires a comprehensive response to ensure mutual understanding and enable flawless integration of two or more systems, subsystems and/or products. A more elaborate definition of an interface requirement is in international standards, here cited from SEBoK (2017): "Interface requirements include physical connections (physical interfaces) with external systems or internal system elements supporting interactions or exchanges."

An interface requires the resolution of associated clarifications between the involved parties. Parties, i.e. stakeholders, for an interface are often several; the originating person/contractor, the supplying person/contractor (party that will respond to the query), and the clients who have an interest in all clarifications made between contractors. Seldom is an interface solved with only one response, which prompts discussions between the stakeholders. Figure 5 illustrates a simplified interface process which is in use at the company. Each of these activities adds to the required work load to solve the interface, and it is the content and status of these activities that really measures how the interface is progressing. An interface activity is any action required to be taken to solve an interface issue. Sources for these activities vary, but typically they come from Minutes of Meetings, e-mails and formal requests from either other contractors or the clients themselves. The IM department's working practices enables them to measure this progression. The Interface Managers log all these activities under each interface. These data represent the foundation of this research. The company has so far not come across any other contractor or client that measures the interface status based on the activity level.

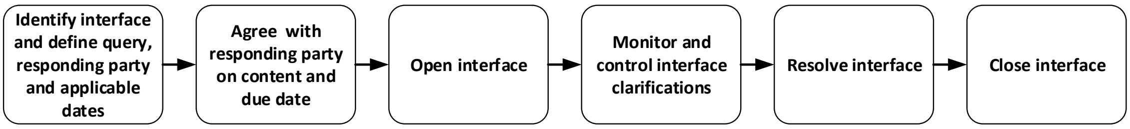


Figure 5: Simplified interface process used in projects at the company.

The formal interface registers contain all raised interfaces between interface partners during project execution. This is a web-based application chosen by the clients. Each contractor can only view the interfaces where they are the owner and where they are the responding party. The client can view all project related interfaces raised in the system. This enables an overview of all contractor's interfaces and ensures the client's control of ongoing discussions.

## Research Methodology

The approach consists of two main factors, namely semi-structured interviews and quantitative analysis. The tools applied to conduct this research include the project specific Interface Databases (IDB), developed in Microsoft (MS) Access, and the Variation Order Request (VOR) registers, created and maintained in MS Excel.

**Semi-structured interviews.** The goal of the interviews was to pinpoint topics of interest regarding project execution and Interface Management. Therefore, we arranged for a series of interviews with eight personnel in the company. Their roles include Engineering Managers, Lead Engineer, Project Planners, Commercial Lead, Financial Controller, and Chief Engineer. All interviewees had at least seven years of experience with partaking in EPC projects in the company. We conducted the interview sessions as semi-structured interviews according to the book by Kvale (2009) on "The Qualitative Research Interview". To avoid bias and influence from other interview subjects, each interview was with only one interviewee. The researchers prepared up-front with a list of topics; some general and other subject-specific topics.

**Quantitative analysis.** The seven projects chosen for this research are all EPC projects which have had significant contribution to the company's portfolios. The owners of these projects are four of the company's largest clients.

The IDB is essential for this analysis. The formal interface register is downloaded and imported into the IDB. The database then serves as the Interface Managers' tool for follow-up and control of the interfaces. Every interface logged in this database includes all the activities required from all involved parties to solve the interface request. Designed to produce various reports, the IDB provided the total number of interfaces and associated activities of interest. We categorized them per contractor to be able to evaluate the difference in magnitude of required interface work, ref Figure 6.

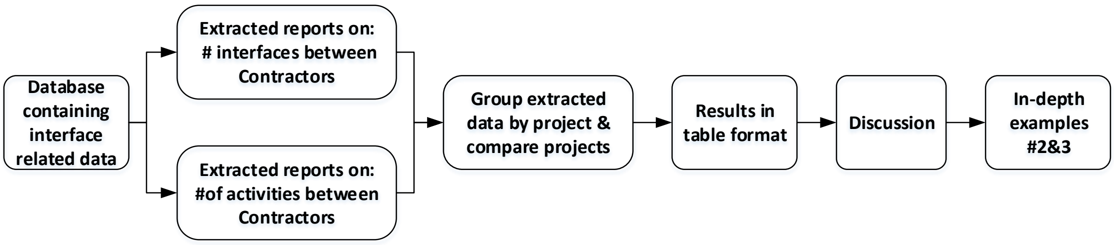


Figure 6: Flow chart for IDB data extraction and process approach.

We also analyzed data from the VOR registers. For each project, there exists one Excel file containing all data related to the formal correspondence between the client and the company regarding potential contractual changes in each project. Figure 7 details the approach applied for this research to extract and categorize the data. Each change has a unique reference number and description. A contractual change is referred to as "variation" by the company's clients during project execution. When either party identifies a potential change to contractual terms between a client and contractor, the contractor often initiates a VOR to the client. This formal request includes details of the proposed change, along with potential cost and schedule impact. When the clients approve the VOR, they issue a formal response called a "Variation Order" (VO). As such, a VO is an approved contractual change by the client and a legally binding agreement toward the contractor.

Since a VO often includes several VORs, the number of VORs are of interest for this research since we want to identify the number of unique changes to the SPS contract. For the reference project, we identified the total number of VORs initiated by other contractors, henceforth called 3rd parties, and the economic impact to the client on the company's SPS contract. To determine the originator for each VOR we read all of them in collaboration with senior engineers. Changes were allocated to either client or 3rd party initiative. Important to note here is that the clients formally initiate all changes. However, we want to identify the changes which occur due to scope/contract split toward interface partners. Such changes are allocated to 3rd party initiative in this research. Since the industry uses IM to solve issues between contractors, we want to see the required formal changes to facilitate the integration of their combined systems. Depending upon this number, it could be possible to deduct if sufficient resources were put into IM or if these changes would have happened regardless. We also wanted to determine if the change was affecting an interface which includes equipment and/or services where the company's portfolio enables the clients to procure both parts of the interface from them.

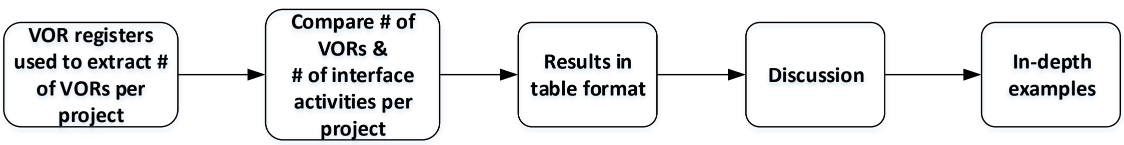


Figure 7: Flow chart for VOR data extraction and process approach.

We targeted three specific cases in the reference project for cost growth evaluation, each highlighting cost growth of a sub-system due to the interface between the company and a 3rd party. The factors considered for these case studies are client approved VORs that impact the company's part of the interface, IM activity between contractors required to solve technical aspects, meeting activity, and actions contained in action logs from meetings. These actions are separate from the IM activities. All these factors combined for each case can pinpoint cost growth due to scope splits between contractors.

## Results

The semi-structured interview sessions provided us with valuable results and insight into which issues the employees consider important. The results in Figure 8 highlight how many interviewees that raised each of the concerns. The interviews were informal discussions on topics related to project execution. Specifically, we asked the interviewees to highlight concerns relating to the company's relationship to contractors and the challenges they have experience with. We also asked them to comment on what type of numerical analysis they thought could be useful for the company on future FEEDs, tenders, and projects. Even though the interviewees have different roles in the company, they all highlighted similar concerns. This illustrates the extent of IM and the company's relationship with interface partners; it impacts all main functions in a project, whether technical, financial, planning or logistics. Five interviewees were interested in how the timing of contract awards to contractors by the clients could impact project execution and IM activity. Three had experience with contractual gaps toward 3rd parties which had impact on the company's deliveries and would like to see numerical values on this. Four interviewees would also like to see some synergies of an integrated SPS and SURF contract. This is probably due to the close cooperation between SPS contractors and SURF contractors which is a current trend in the market; there have been mergers and formal cooperation agreements signed over the course of the past few years. Two had noticed that previous suppliers of the company now are becoming an interface partner due to frame agreements with the clients. This adds to the number of contractors the company interface towards and thus also increase the amount of IM activity required. Two interviewees have prior experience with IM and know that there is a link between this activity and VORs, although no numerical analysis have been done. The same two interviewees encouraged us to highlight this link on a specific project with case studies.

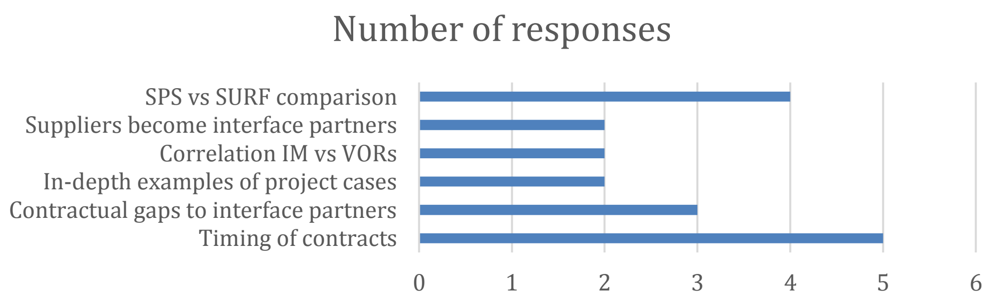


Figure 8: Results from semi-structured interviews.

Some of the responses require careful in-depth studies to evaluate the actual impact on the company's projects. Thus, the researchers decided to investigate whether there existed a high-level correlation between the number of VORs and the amount of IM activity on seven EPC projects.

**Numerical analysis of seven major projects**. By use of the Interface Databases on the seven EPC projects, we managed to extract reports showing the IM activity; number of interfaces and their associated activities. The results are categorized by number of contractors per project. Figure 9 illustrates the results from project A, which had four interface partners including the company. We see that the SPS-SURF domain had 4978 IM activities logged during execution, which is higher than SPS-WELLS (drilling contractor) with 826 and SPS-Topside at 1204.

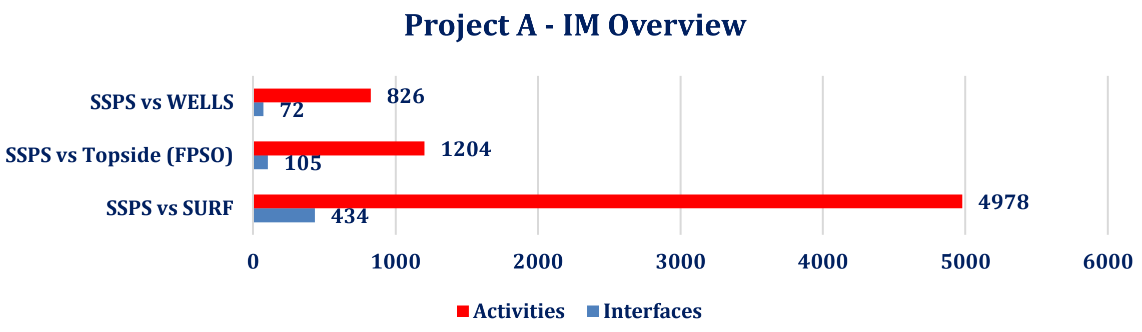


Figure 9: Numerical data on IM activities for Project A.

Table 1 lists the same type of results for all projects, A-G. The first number is the number of interfaces and the second number is the related activities. There is a trend that most of the IM activities are in the SPS-SURF domain which averages at 3200 activities on the seven projects. This is approximately half of all IM activities per project. This is in line with the researchers' expectations based on experience. The two exceptions are project D and E, where the SPS-Topside and SPS-Field Layout domains have the most activities. Reasons for this is that there was much of the company's deliverables in project D integrated on the topside platform, whereas few components went subsea. For project E, the client had outsourced SPS layout engineering. Every change to the layout impacted the SPS which prompted new clarifications.

The number of contractors varies from four to 17 on the projects. For project E, several 3rd parties are included in the SPS, SURF and Topside domain due to the scope of their deliverables. Since the total deliverables to the clients are almost the same for every project, the reason for this is the split of each main part of the scope between several contractors. Interesting to note is that the four main contractors remain constant for every project; SPS, SURF, Topside and WELLS. This could indicate that clients choose contractors who are cost-effective. Every project with more than four contractors then means that one or several of the main contractors has reduced scope compared to the traditional scope split. Project C-F has a separate umbilical contractor (UMB) which removes this system from the SURF scope. Project E has a separate X-mas tree supplier (SPSXT) which SPS usually supplies, and transportation barge contractor (T-Barge) which is usually SURF scope. Project B has a separate Multi-Phase Pump (MPP) contractor instead of including this in the SPS contract. In project E and F, the client (CPY) represented contractors as well, hence the IM activity in this domain.

Table 1: Numerical data on interfaces and their activities for Project A-G.

| Project ID / Domain | SPS vs SURF | SPS vs WELLS | SPS vs Topside | SPS vs UMB | SPS vs CPY | SPS vs MPP | SPS vs Field Layout | SPS vs SPSXT | SPS vs T-Barge |
|---|---|---|---|---|---|---|---|---|---|
| **A** | 434/4978 | 72/826 | 105/1204 | - | - | - | - | - | - |
| **B** | 308/4877 | 186/1231 | 90/1401 | - | - | 66/655 | - | - | - |
| **C** | 673/4453 | 186/750 | 185/937 | 150/921 | - | - | - | - | - |
| **D** | 95/542 | 28/153 | 162/1162 | 34/159 | - | - | - | - | - |
| **E** | 173/2771 | 4/56 | 89/1031 | 57/778 | 102/1106 | - | 236/4614 | 61/1359 | 17/195 |
| **F** | 356/3154 | 31/199 | 134/993 | 58/358 | 90/457 | - | - | - | - |
| **G** | 231/1603 | 36/171 | 120/700 | - | - | - | - | - | - |

Table 2 illustrates the relationship between IM activities and VORs in the same projects; project A and C-E averages at 42 activities per VOR, whilst G is lower with 25, B is higher with 78 and F peaks at 258 activities per VOR.

Table 2: Average amount of IM activities per VOR in projects A-G.

| Project ID | No of IM activities | No of VOR | Average |
|---|---|---|---|
| **A** | 7008 | 179 | 40 acts/VOR |
| **B** | 8164 | 105 | 78 acts/VOR |
| **C** | 7061 | 156 | 45 acts/VOR |
| **D** | 2016 | 50 | 40 acts/VOR |
| **E** | 11910 | 284 | 42 acts/VOR |
| **F** | 5161 | 20 | 258 acts/VOR |
| **G** | 2474 | 101 | 25 acts/VOR |

From experience, we know that IM activities often prompts VORs. Activities linked to the integration of two contractors' design often leads to some form of adoption from one or both parties. Possible to deduct from these numbers is that Project A, and C, D and E apparently have a proportional relationship between IM activities and number of changes; the more activities, the more changes occur. For project B, it is a lower activity/VOR ratio, which could indicate that there were several holes or misalignments in the contracts. Project B and F, on the other hand, show the opposite with a high activity/VOR ratio which could mean that IM identified and helped solve potential changes. It could also indicate that the contracts were better defined. However, as one of the interviewees pointed out, these projects are not necessarily comparable. Considering the contract values, scope of supply, parties involved, currency, market situation and region of the world which the project is in, these projects are hard to compare to one another. There are so many factors influencing them in different ways. Besides, there is no existing links between these IM activities and the VORs so this does not prove correlation between these values. Therefore, we chose a reference project to assess the alleged link between interface partners and VORs.

**Reference project.** We selected an EPC project as a reference project, ref project E in Table 2. This is the project that up until today has the most interface partners in any project ever run out of the company. There is IM activity logged toward 17 different interface partners. The project is still not finished, but the main engineering is complete. We reviewed the VOR register in its entirety to identify the origin of the changes and whether it revolves around an interface connecting equipment which the company could have delivered. An example of this is VORs pertaining to the interface between the company's supplied flexible jumpers and the X-mas trees delivered by an interface partner; the company can deliver both the jumpers and the X-mas trees. As the company handles such changes internally, it would not have been a formal change at the client's expense to ensure the integrity of the system. Figure 10 presents the findings. For reference, the researchers studied all 284 client-approved VORs which has a value of 12% of the company's initial contract value. This is a 12% cost growth to the client on the company's SPS contract.

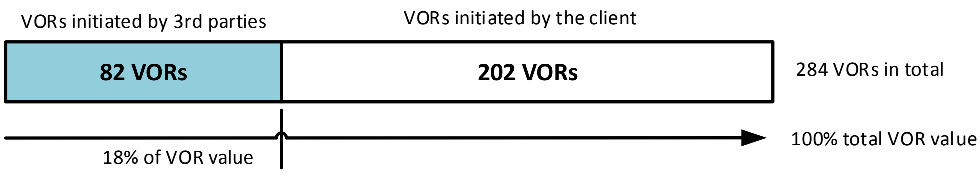


Figure 10: Number of VORs initiated by 3rd parties and the client.

Through the review of all the changes in the reference project, the researchers allocated 82 (29%) VORs impacting the company's SPS delivery to originate from 3rd parties. The calculated associated cost with these VORs is 18% of the total VOR value on the company's SPS contract.

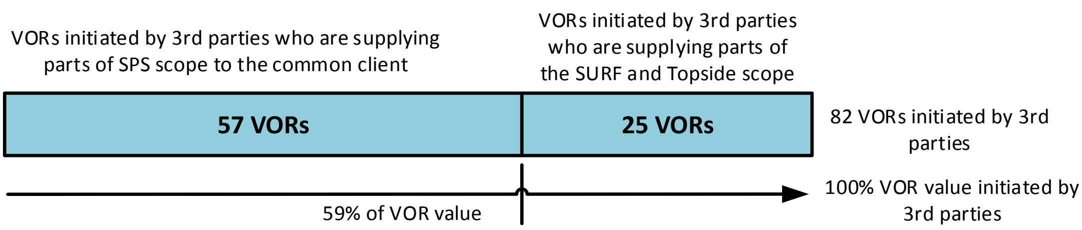


Figure 11: Number of VORs impacting SPS, SURF and Topside deliverables.

The split in scope of supply is between 17 interface partners. Several of these deliver equipment and services as part of the SPS delivery to the common client. Much of this scope of work was part of the company's contracts on previous projects. We identified changes impacting the interface between such equipment and services. The results are very interesting; 57 of the 82 VORs initiated by 3rd parties are in this domain. The associated cost of these changes is 59% of the VOR value of the changes initiated by 3rd parties, ref Figure 11. Had the company supplied this equipment the required clarifications would be resolved internally. Instead, various parts of the SPS is delivered by several contractors with no contractual obligations to one another. Thus, when IM cannot solve the problem, the client issues a VO instructing one of the contractors to change their equipment. Considering the number of partaking SPS contractors in this endeavor, the numbers are not too surprising.

**In-depth case study 1.** We conducted three different in-depth studies, each highlighting a different perspective. The first case, Figure 12, is an analysis of a contractual gap between the topside engineering contractor and the company and relates to the topside hydraulic system delivery. This contractor has the overall engineering responsibility of the platforms in the reference project. Some of the company's deliverables are located here, and thus need to be integrated properly with the rest of the systems on board. The company's equipment affected were the Hydraulic Power Unit (HPU), the Hydraulic Distribution Unit (HDU), the Monoethylene glycol (MEG) Valve Panel (MVP) and the Topside Umbilical Termination Units (TUTUs). Shortly after the company's contract award, a gap in the two contracts surfaced. The result was a change order from the client detailing the required changes. This was to ensure the successful integration of the hydraulic system. The value of this change resulted in raising the investment cost of the company supplied equipment in mention by 31% for the client. The changes revolved mainly around exchanging of hardware on tubing, fittings etc., so this issue was not solved through IM. Hence, only the VOR value impacted the raised investment cost for the client.

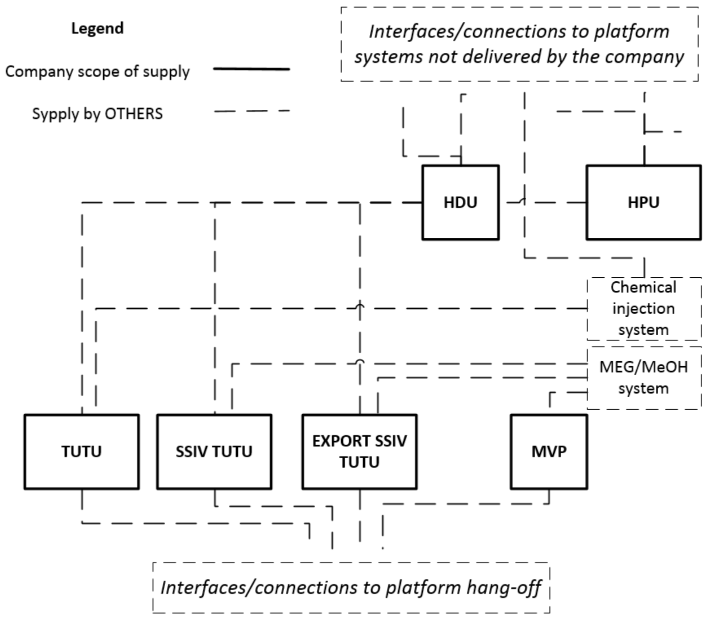


Figure 12: Case study #1 where company hydraulic equipment interface with platform systems.

**In-depth case study 2.** Example number 2 also relates to topside deliveries, but this is relating to the topside electrical scope of work. The Subsea Control Unit (SCU) is the overall controlling unit keeping the SPS operational. It is an integrated part of the topside control system on the production platform. The SCU is also part of the company's portfolio, but in the reference project this system is delivered by another contractor. The company delivers other electrical equipment as part of the SPS interfacing with the SCU, as depicted in Figure 13. This includes the Subsea Data and Processing Unit (SDPU) and the Subsea Power and Communication Unit (SPCU). These are also located on the topside production platform.

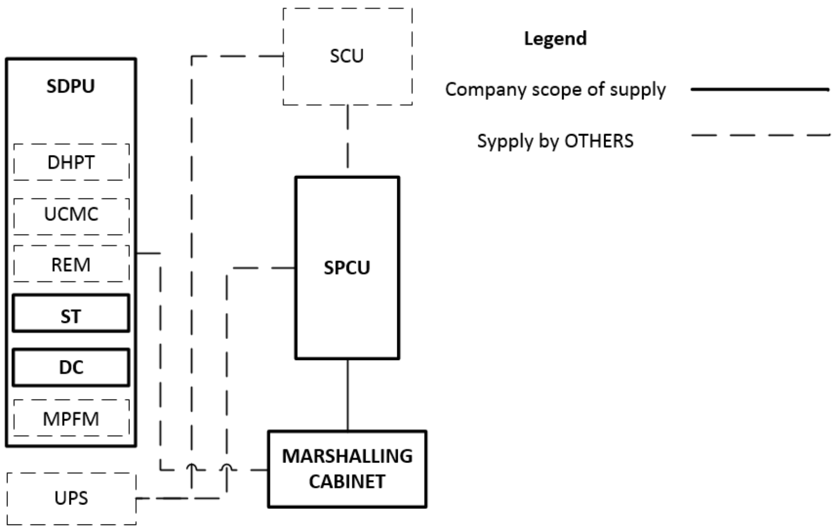


Figure 13: Case study #2 where company electrical equipment interface with platform systems.

The topside control system requires complex engineering to ensure its functionality. If the SCU was part of the company's scope, the work required would have been company scope of work and responsibility. Due to the scope split here, company personnel needed to collaborate with the SCU contractor over a long period of time; this included meetings, action lists and the use of IM. The researchers calculated the total added cost of this work to be 36% of the company's initial sales price of the SCU to the client. The initial sales price accounted for all this work to be performed in-house including all hardware and resource cost required to achieve the same goal. Included in the calculations are 66 meetings, 635 activities from various action lists and through 40 interfaces, and 10 VORs.

**In-depth case study 3.** The last case study describes a scope split on a Hydrate Remediation System (HRS) jumper. Designed to inject fluids to counteract hydrate formations within the production piping, this jumper is a 70-meter-long, 3-line hose. It is a contingency system supposed to stretch from the Subsea Safety Isolation Valve (SSIV) structure to the Production Manifold Assembly on the sea bed. The system uses Multi-Quick-Connections (MQC) on both sides which are part of company scope, but the 70-meter jumper is a 3rd party delivery, ref Figure 14. This split in scope of work resulted in meetings, several clarifications between the opposite sides and a VOR. We calculated the accumulated cost of this added activity to be 47% of the company's sales price of the hose (including required testing of the assembly) if the company had been responsible for the entire assembly, including all the MQCs required and the jumper itself.

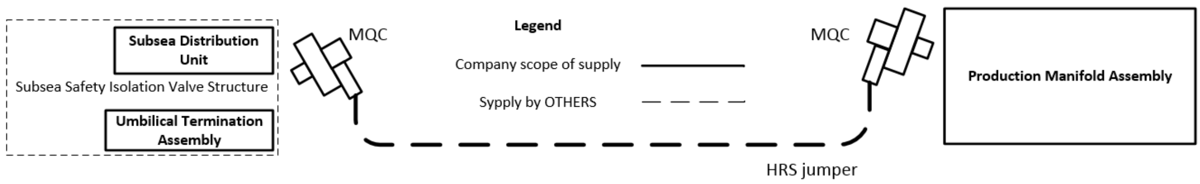


Figure 14: Case study #3: scope split and interfacing systems for the HRS jumper assembly.

**Reference project as combined SPS and SURF.** Considering all IM activity related to the SPS and SURF delivery combined, we get the results depicted in Figure 15. There are six contractors included as part of the SPS, and three representing the entire SURF scope. The 10379 activities in the SPS-SURF domain equals 85% of all IM activities in the project.

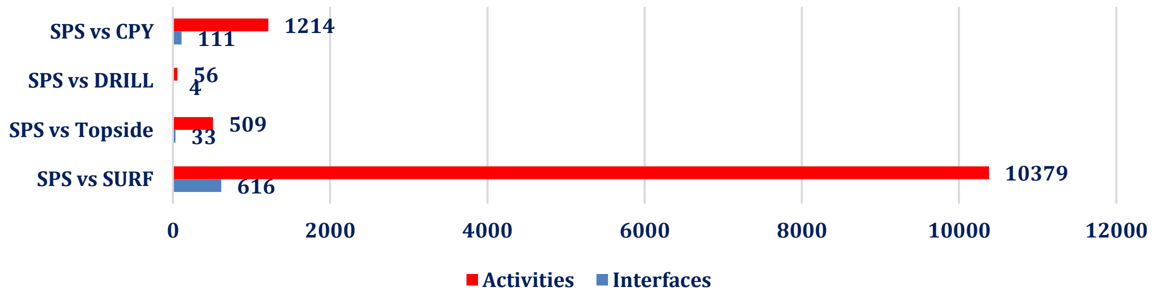


Figure 15: Reference project as combined SPS and SURF - IM Report.

The researchers also did a similar exercise as illustrated in Figure 11, only now also including VORs relating to an interface between SPS and SURF contractor. What is very interesting to note is that 73 VORs (89%) from 3rd parties relate to SPS and SURF deliverables, whereas the value is 69% of the total VOR value from 3rd parties, see Figure 16. These numbers are very interesting and validate the interviewees opinion that synergy effects are obtainable through close cooperation between the SPS and SURF contractors.

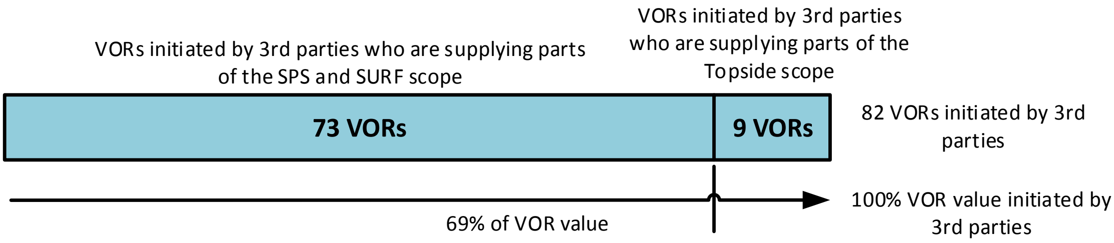


Figure 16: Number of VORs impacting SPS and SURF scope of supply.

## Discussion

**High-level findings.** The high-level analysis of the seven identified projects yielded interesting results, although only partially conclusive. The researchers found it very interesting to see the total amount of activities associated with the interface partners on the various projects. Although the numbers varied in between them, all projects required several thousand activities during execution to ensure a fully integrated and functional SPS according to client requirements. When comparing the activities to the amount of changes in the same projects, we see indications that there might be correlation between IM and changes due to the different results. However, the VORs should be tagged in every project as was done on the reference project prior to us concluding based on these results.

**Management of change (MOC).** From the results, we see that there are many changes originating from the company's interface partners during project execution. Speaking with the interviewees once again upon research completion, none were surprised although the numbers were higher than most of them had expected. The researchers would argue that much of the reason for many of these changes is due to the timing of contract awards to contractors. There is common knowledge that the topside contractor, either platform or FPSO, and the SPS contractor often are the first to sign their contracts. This is due to long lead items procurement. However, since many elements of the SPS interface with other contractors' equipment, this might also be the root of the problem; the SPS contractor does not have an interface partner to discuss with. In addition, the company experience that the clients are reluctant to commit to SPS design on behalf of the yet unselected 3rd parties. During contract award to 3rd parties 6-12 months later, the result is often that the SPS is close to required design freeze to place purchase orders. Changes occurring at this point could potentially impact desired schedule, not to mention the cost involved. In the event of frequent reoccurrence, the cost and schedule impact will only increase. This is undesirable for obvious reasons for all involved. What is also important to consider is that the cost of changes increases exponentially during project execution, ref research by Walden (2015) in Figure 4.

Although not specifically researched here, it would be interesting to see how many of the changes impacting the reference project could have been avoided by proper and timely use of IM. However, the researchers did investigate some of the VORs relating to the SPS-UMB domain. 11 of the 13 VORs allocated to this domain could have been avoided if the umbilical contractor were chosen earlier. These VORs are concerning design changes to accommodate the umbilical design from a company perspective. These can be accounted for during initial design. Instead, it resulted in change orders and delay of delivery from the company. On the other hand, it is also interesting to see that there were only five VORs allocated to the SURF contractor. The general perception of some of the interviewees was that SURF often is the root of many changes to the SPS design, but the results from the reference project show different numbers. Upon researching this, we noticed that the installation contractor was involved early on. Frequent IM activity then solved issues between the company and SURF which removed the need for so many VORs in this domain.

**Scope split.** Eight of the 17 interface partners in the reference project have contributed to changes to the company's design and/or contract terms. The researchers argue that the main reasons for this is the purchase cost for the clients. During tendering, the competitors force their prices as low as possible to win contracts. However, scope splits to so many contractors bear with it "hidden" interface cost which is challenging to predict. Another factor which could influence the amount of contract awards, is frame agreements. These established contracts put obligations both on the client and the supplier. The equipment and/or service in mention is tailored to the client's preferences making cost and schedule more predictable. But is this true? Research in the reference project highlighted this specifically in its in-depth examples, and emphasized on the added cost of the SPS scope split in two different examples (case #2 and #3). We do not know whether frame agreements caused this split, or if it simply was a result of tender competition. The fact remains that these splits incurred cost growth for the client on the company's SPS contract. The researchers do not oppose the concepts of frame agreements, but perhaps altering its conditions to make it more flexible is beneficial? The same applies to which contractors that are invited to tender. If clients were to select contractors earlier and switch between them based on experience and available resources, this could potentially lead to cost-savings for all parties and reduce the clients' investment cost.

Another point of note relating to scope split and contract awards considers the whole oil and gas business; keeping several contractors occupied increases the competition which often drives innovation and new solutions. Arguably, this could enable companies to become "preferred suppliers" for specific deliveries/services which would yield products of high quality. However, there is still the IM perspective to consider; each component must comply with the entire SPS. With only single-product-suppliers, who have the system responsibility?

**Early involvement.** The topics discussed so far, accompanied by the referenced results, indicate that there is a potential for cost-saving initiatives, amongst them IM and early involvement of the contributing contractors. Research by Eric Honour (2013) highlights the value of the implementation of SE activities. IM counts as SE activities due to its multi-discipline approach. Although the company does some system engineering during the FEED phases of a project, it is still limited to the company's part of the delivery. They hold little control over how the client chooses to divide the contracts. Based on this, the researchers argue that early implementation of IM is equally important from a contractor perspective as it is for the client. This means specifically that there could be a potential benefit for the overall endeavor if the clients allow the contractors to interact directly prior to the project's kick-off. A noticeable shift in the industry today is the execution of FEED. Two ongoing FEEDs at the company have already involved both the topside and installation contractor. This enables discussions on technical clarifications from an early stage. From a SE and IM point of view, this is a very positive development. By increasing the amount of work done during FEED, there is potential to reduce risks during project execution since several of the variables already are in place during contract award. This is in line with Honour's research and the results provided as part of this research.

**Integrated SPS and SURF project execution?** Our research showed that 85% of all IM activities are in the SPS-SURF domain in the reference project. Similar analysis of the other six projects verify this trend, with one exception, ref project D in Table 1. Comparing the findings in Figures 9 and 15 it is evident that most of the IM activities are in this domain. Considering the size of both project A and E, they are similar to one another. Interesting to note is that project E required significantly more IM work than project A. The nine contractors in the SPS-SURF domain in project E could contribute to this when compared to project A which only had two. Additionally, 89% of the VORs initiated by 3rd parties were in this domain for the reference project. The accumulated value is 69% of the total value in changes originating from 3rd parties. This cost growth to the client would have been avoided if it was an integrated contract for SPS and SURF. The researchers highlight that this is only an illustration of potential synergies since SPS and SURF cooperation still is a very new development in the market. The client did not have this option during contract award six years ago. What is perhaps more interesting is the huge amount of interface work related to this combined domain. Arguably, since all these activities would be solved internally for an integrated SPS and SURF project, some of the risk is transferred from the client to the contractors. They would then be responsible to deliver according to contractual requirements. However, this also presents an enormous challenge; they will be responsible for a huge scope with many moving parts. When approaching a potential client of the company with these numbers, they raised a concern that they as a client would lose some of the insight and control as opposed to when there are several contractors. Although they thought that closer cooperation between SPS and SURF was a good idea with potentially high rewards, they still believe such joint ventures are too young to back up these potential savings through proven efforts.

**Credibility of research; its approach and required tools.** This research was executed systematically as a top-down approach. The initial interviews were conducted with personnel in the company with long and varied experience, and as such we deem their input relating to the approach of the research valid, although subjective. What makes their concerns more verifiable is that the research uses quantitative data. As the problem statement was to research with the goal of gaining insight, the data were extracted from the required sources and used objectively. As for the quality of the data, these can be considered to be reliable. The VOR register is one of the main tools used for financial reporting, both internally and to the client. The IDBs used to extract data on IM is used only internally in the company by the Interface Managers. Of equal importance is to follow up actions internally and externally since many activities are linked to project deliverables and client milestones.

During the review of VORs, senior engineers were involved with identifying and tracing them to either a 3rd party or client initiative. These engineers have been involved in the reference project for a long duration. Their conclusions as to the origin of a changes are deemed to be sufficient to be included, although not representing the absolute truth.

The research was mainly conducted on the reference project. With more data from other projects relating to sources of change, we could have determined more accurately if the same trends are visible there. Furthermore, the three in-depth case studies are only extracts of the reference project; there are still other interfaces which could undergo the same research. This could lead to more comprehensive conclusions and increased credibility of the potential cost saving initiatives proposed by the researchers in this paper. However, it is the company's intention to use this research as part of future FEEDs and tenders to facilitate more cost-effective solutions. Another possibility was for us to use statistical analysis. However, as this would require a different approach and even more data, it fell outside the scope of this research.

Albeit that this approach and research were identified and conducted within the oil and gas industry, the principles of IM and MOC could be related and adapted to a variety of industries, e.g. the aircraft and construction industries. To use analysis such as presented in this paper could help various industries to identify contributing cost growth factors. This could aid in realizing cost saving initiatives. Companies could become more effective with less disrupting activities during project execution, thus also reducing the risk of schedule delays.

## Conclusion

Project cost growth continues to impact the oil and gas industry. The trend is that oil and gas producers are reluctant to award field development contracts without executing extensive FEED studies up-front. By analyzing a reference project, we have quantified the financial impact caused by scope split and contractual gaps between 3rd party contractors. We found that early involvement of Interface Management (IM), directed towards closing these gaps, could avoid 29% of the changes and reduce the cost growth by 18%.

This paper presents unique data related to IM from seven large subsea field development projects. We have assessed data from 895 contractual changes during project execution and 43794 IM related activities. Our quantitative analysis proves that IM is central in engineering endeavors, and has the potential to mitigate project cost growth. Furthermore, the qualitative in-depth interviews and in-depth studies support this by establishing a direct link between contractual changes and increased IM work between contractors. Based on these findings, the researchers conclude that establishing IM processes between all parties during the FEED stage would have a positive impact in avoiding cost and schedule slips during project execution. Additionally, the paper indicates that an integrated SPS and SURF contract award could yield potential savings and risk reduction for oil and gas companies.

## Recommendation for Future Work

The oil and gas industry would benefit from establishing correlation between Interface Management and project cost growth. This could aid the industry in establishing a common robust IM practice which would help keep project cost and schedule within predicted parameters. Research should also be conducted on the effects of early implementation of IM during FEED and tenders compared to traditional project execution.

## References


Abualfeilat, Y., 2012. *Mapping Interface Management to Project Management - Railway Project Case Study*. Saarbrücken, Germany: LAP LAMBERT Academic Publishing.

Bergli, S. and Falk, K., 2017. "Cause and Impact Analysis of Cost and Schedule Overruns in Subsea Oil and Gas Projects - A Supplier's Perspective." INCOSE Conference, Adelaide, Australia.

BKCASE Editorial Board, 2017. The Guide to Systems Engineering Body of Knowledge (SEBoK), v. 1.8. R.D. Adcock (EIC). Hoboken, NJ: The Trustees of the Stevens Institute of Technology. Accessed 11.04.2017. www.sebokwiki.org. BKCASE is managed and maintained by the Stevens Institute of Technology Systems Engineering Research Center, the International Council of Systems Engineering, and the Institute of Electrical and Electronics Engineers Computer Society.

Brennan, D., 1998. *Process Industry Economics - An international perspective*. Page 45. Warwickshire, UK: Institution of Chemical Engineers. Printed and bound by Antony Rowe Ltd, Eastbourne, UK.

Chen, Q., 2007. "An Object Model Framework for Interface Management in Building Information Models". PhD diss., Virginia: Virginia Polytechnic Institute and State University (US).

CII (Construction Industry Institute), 2014. *Interface Management.* Austin, US-TX: The University of Texas at Austin.

Honour, E. C., 2013. "Systems engineering return on investment." PhD diss., Adelaide: Defense and Systems Institute, School of Electrical and Information Engineering, University of South Australia.

Kvale, S. and Brinkmann, S., 2009. *Det kvalitative forskningsintervju* (2nd ed.). Norway: Gyldendal Norsk Forlag AS. ISBN 978-82-05-38529-0.

NASA (National Aeronautical and Space Administration.), 2007. *NASA System Engineering Handbook* (Rev1). Washington, DC.

Nooteboom, U., 2004. Interface Management Improves On-Time, On-Budget Delivery of Megaprojects. JPT Online.

Tranøy, E. and Muller, G., 2012. "Reduction of Late Design Changes Through Early Phase Need Analysis." INCOSE Conference, Las Vegas, US.

Walden, D.D., Roedler, G.J., Forsberg, K.J., Hameling, R.D. and Shortell, T.M. (Eds.) (ed.), 2015, Systems *Engineering Handbook: A Guide for System Life Cycle Processes and Activities,* (4th ed.). INCOSE, San Diego, CA (US). Published by John Wiley & Sons, Inc.

## Biography

Magnus André Nilsen holds a Master's degree in Systems Engineering and a Bachelor in Mechanical Engineering, both from the University College of Southeast Norway. He has worked as a Systems Engineer with Interface Management in TechnipFMC since 2014. This paper is the result of the research done for his Master's degree in Systems Engineering.

Kristin Falk is employed as Associate Professor at University College of Southeast Norway, where she is responsible for the Subsea track and fronting research on systems engineering. Kristin holds a PhD in Petroleum Production and a Master in Industrial Mathematics, both from NTNU. She has worked with research, development and management in the oil and gas industry for 20 years, both with major subsea suppliers and with small start-ups.

Tom Arnfinn Haugen is employed as Department Manager for Project Interface Management in TechnipFMC, Systems Engineering, Subsea Europe where he, in addition to his managerial duties, is actively taking part in the company's Project execution and tender processes.

## Appendix 1 - Acronyms and definitions

| Acronym | Definition |
|---|---|
| CII | Construction Industry Institute |
| CPY | "Company" - reference used for the client during an endeavor |
| EPC | Engineering, Procurement, and Construction |
| FEED | Front-End-Engineering-and-Design |
| FPSO | Floating Production, Storage, and Offloading |
| HDU | Hydraulic Distribution Unit |
| HPU | Hydraulic Power Unit |
| HRS | Hydrate Remediation System |
| IDB | Interface Database |
| IM | Interface Management |
| INCOSE | International Council of System Engineering |
| MEG | Monoethylene glycol |
| MOC | Management of Change |
| MPP | Multi-phase Pump |
| MQC | Multi-Quick-Connection |
| MVP | MEG Valve Panel |
| NASA | National Aeronautics and Space Administration |
| SCU | Subsea Control Unit |
| SDPU | Subsea Data and Processing Unit |
| SE | Systems Engineering |
| SEBoK | Systems Engineering Book of Knowledge |
| SPCU | Subsea Power and Communication Unit |
| SPS | Subsea Production System |
| SSIV | Subsea Safety Isolation Valve |
| SURF | Subsea Umbilical, Risers and Flowlines |
| TUTU | Topside Umbilical Termination Unit |
| UMB | Umbilical |
| VO | Variation Order |
| VOR | Variation Order Request |
| WELLS | Designation often used for the Drilling Contractor in an endeavor |
| XT | X-mas Tree |