25th Annual INCOSE International Symposium (IS2015)
Seattle, WA, July 13 – July 16, 2015

Creating an A3 Architecture Overview; a Case Study in SubSea Systems

Gerrit Muller
HBV-NISE
Gerrit.muller@hbv.no
Kongsberg
Norway

Damien Wee
FMC Technologies
Damien.wee@fmcti.com
Martin Moberg
Aker Solutions
Martin.Moberg@akersolutions.com

Copyright © 2015 by Gerrit Muller, Damien Wee, and Martin Moberg. Permission granted to INCOSE to publish and use.

Abstract. The subsea oil and gas domain suffers from complex and partially incomplete information flows. As consequence, most employees in the involved organizations lack overview of the systems and operations. Using conceptual modeling and A3 architecture overviews, we have reconstructed the overview for the workover system and its operation. The result triggers interest from the suppliers in the oil and gas domain.

Introduction

The subsea oil and gas domain. Large oil and gas companies, such as Shell and Statoil rely on a broad network of specialist companies for the development and installation of subsea and topside equipment. The typical business model is that oil and gas companies send an invitation to for tender (ITT). Suppliers respond to the ITT with a quotation. When the oil and gas companies award the contract, suppliers start an execution project to develop, engineer, and install the agreed systems. Figure 1 shows an artistic impression of a subsea production system.

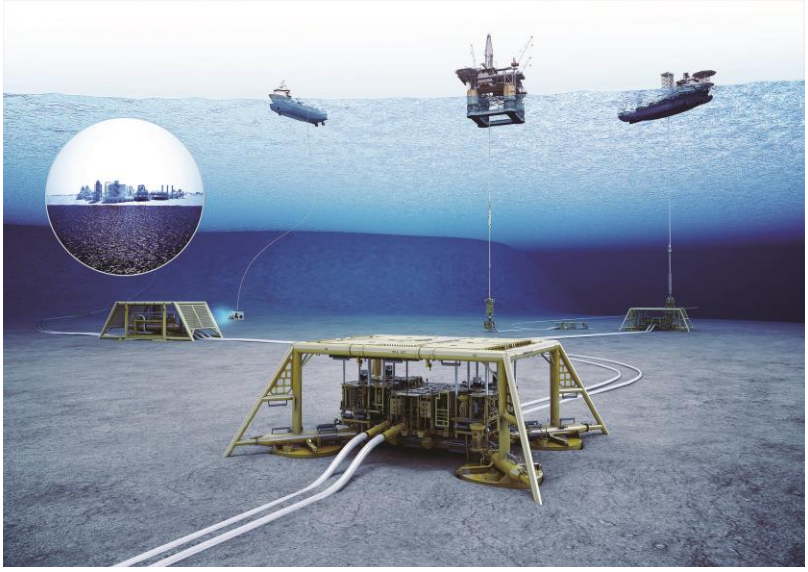


Figure 1. Artistic impression of a subsea production system, by FMC Technologies

The information flow. Many suppliers in the oil and gas domain struggle with the incoming information, which is a combination of customer specific requirements, regulations, and multiple standards. The incoming information is typically a mix of system requirements, design constraints, and predefined solutions. An additional problem is that most inputs violate fundamental requirements management rules, such as requirements must be specific, non-ambiguous, testable, and describe what, rather than how. Finally, the operational needs tend to be missing in the input documentation. Sometimes, the customers do not yet known them during the tender phase, sometimes they consider the needs to be confidential. Tranøy (Tranøy 2014) describes the significant negative consequences of missing operational needs.

A3 architecture overviews. Borches (Borches 2010, 2011) proposes the use of A3s, named after the paper size, to document architecture overviews. The main idea behind A3s is that the format is large enough to support multiple views. At the same time, the limitation in size forces the creators to focus on essential information. Borches provides a cookbook in his PhD thesis (Borches 2011); the cookbook is available as pdf at http://www.gaudisite.nl/BorchesCookbookA3architectureOverview.pdf. Borches ideas have inspired Polanscak, Kruse, and Frøvold[1] (unpublished), and Wiulsrød (Wiulsrød 2012), Kooistra (Kooistra 2012) Singh (Singh 2013), and Nilsen (Nilsen 2014) to apply and evaluate A3s in industrial practice.

Conceptual Modeling. Borches (Borches 2011) proposes a number of elements as standard content on A3s: physical models, functional models (dynamics), and quantification. These elements coincide with the conceptual modeling approach in the SEMA course[2] at HBV, Kongsberg, Norway. This course has triggered related research, see (Muller 2009), (Engebakken 2010), (Rypdal 2012), and (Stalsberg 2014).

Case. A homework project in the SEMA 2013 course modeled the workover operation for subsea systems. The participants of this coursework worked in their companies on part of the workover system, for instance the riser system, Lower Workover Riser Package (LWRP), or the Workover Control System (WOCS). Oil companies use a workover system to start production or to perform maintenance on the well. In the first few days of the course, the participants identified the installation time of the workover system as key performance parameter. The installation time contributes significantly to the cost of workover operations.

A3 Architecture Overview of Workover Operations. The results of the homework were a good illustration of conceptual modeling to an industry that uses either extensive text based documents, or detailed schematics and CAD drawings. We transformed the homework result in an example for the course. Finally, we transformed the course material in an A3, combining the A3 architecture overview research with conceptual modeling research.

Industrial Context and Needs

The subsea oil and gas domain is big business. For example, suppliers Aker Solutions (AkSo) and FMC Technologies (FTI) had a turnover of between 40 and 50 Billion NoK (between 6 and 7.5 Billion US dollar) in 2012. The supply chain for oil and gas companies is a complex ecosystem. Consequence of the financial magnitude and the

---

[1] Presented at KSEE 2011, see http://ksee.no/wp-content/uploads/2011/09/KSEE-2011-Kristian-Frovold-v3.pdf

[2] Course description at http://www.gaudisite.nl/SEMA.html, course material at http://www.gaudisite.nl/SEMAallSlides.pdf

amount of parties is that all players have large interests, while the organization and the flow of information are complex.

Key drivers in this domain are:

- Cost of oil and gas production (to ensure that production of subsea oil is profitable)
- Health, Safety, and Environment (HSE)
- Robustness and reliability in harsh oceanic conditions

In this research, we take the perspective of suppliers like Aker Solutions and FMC and study their needs in terms of knowledge management. Both companies supply subsea equipment and related services. We use one specific operation in the life cycle of a field as case, a workover operation, and the related Workover system (WOS).

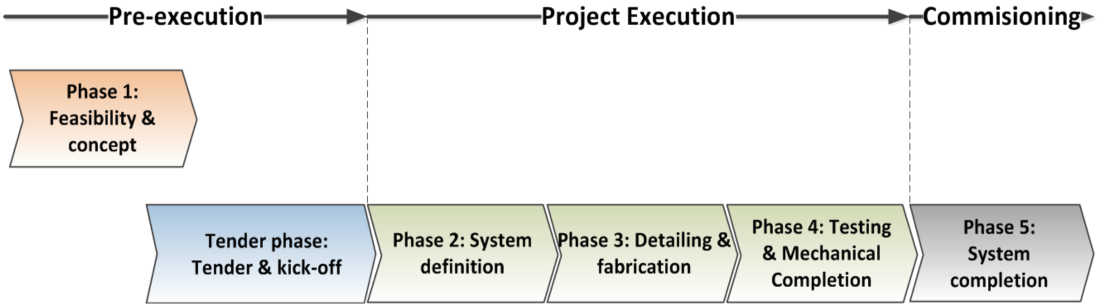
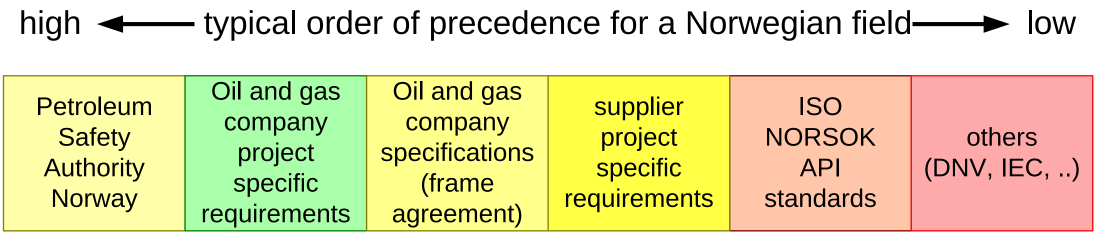


Figure 2. Typical project execution process.

These suppliers use a project execution model such as shown in Figure 2. The oil and gas companies send out an invitation to tender. The suppliers submit the tender within a due date, which can be between a few days and a number of months. The execution phase can take years.



high ← typical order of precedence for a Norwegian field → low

Petroleum Safety Authority Norway	Oil and gas company project specific requirements	Oil and gas company specifications (frame agreement)	supplier project specific requirements	ISO NORSOK API standards	others (DNV, IEC, ..)

Figure 3. Precedence order of input specifications.

The input to the tender phase and the execution phase is a large number of specifications (in the order of 100 specifications, a typical specification has tens to hundreds of pages). These specifications are mostly “layered” standards that can be mutually conflicting. Suppliers use a precedence order to resolve such conflicts, as shown in Figure 3.

Another challenge in the input specifications is that they violate most of the requirements engineering ground rules:

- Many requirements specify *how* (the solution) rather than *what* (black box level function and performance)
- Many requirements are ambiguous

- Many requirements are not quantified and verifiable

Finally, oil and gas companies lack some relevant knowledge at the time of tendering, resulting in variation orders during project execution. These variation orders are costly, may cause delays, and changes may propagate to other parts of the system.

The suppliers have a strong project drive. This is a logical consequence of the tender model and the large economic impact of project success. At the same time, the suppliers try to create reusable assets, products, to increase efficiency. Creation of such product portfolio is strategic, a long-term objective. Projects have a short-term focus.

Current Knowledge Management

Suppliers have large amounts of documentation stored in project, product, and discipline oriented repositories. The dominating forms of documentation are text-based documents, spreadsheets, and schematics. The schematics are typically CAD related, for example 2D (piping and instrumentation diagrams), or 3D.

The documentation works well at detail level, although stakeholders frequently express the need for more interface management and improved traceability. However, this form of documentation lacks a few essential elements:

- Dynamic behavior is lacking (how do components interact, how do they behave in various circumstances, such as installation, testing, and start-up)
- Explicit definition of key performance parameters, and how the system achieves key performance parameters is lacking (examples are capacity, pressure and temperature capabilities, sealing of hydrocarbons, installation time)
- The overview (how do all parts fit together and how will they fit stakeholder needs) is missing
- The overview of the documentation is missing. As consequence, there is an excessive amount of documentation with its related support and maintenance effort.
- Customer and operational needs are missing (the rationale behind most requirements)

A3 Architecture Overviews and Conceptual Modeling

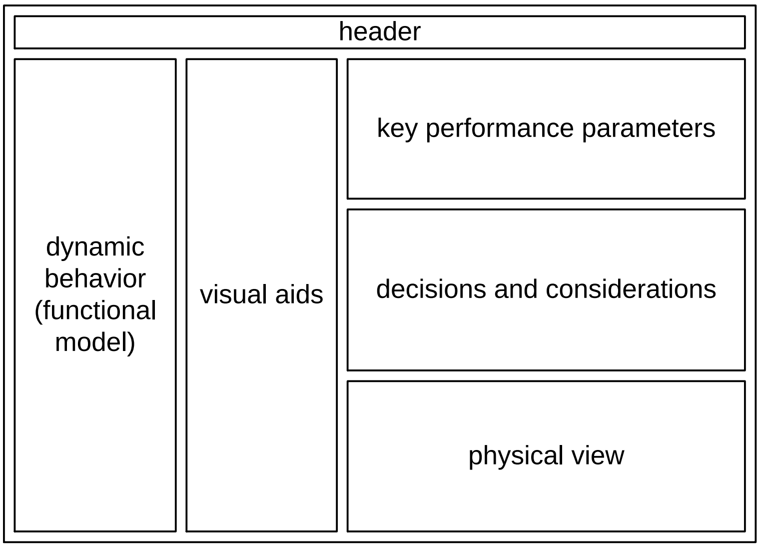


Figure 4. Example A3AO layout

Borches (Borches 2011) proposes to combine at least the following views on an A3 Architecture Overview (A3AO): Physical view, dynamic behavior (functional model), visual aids, and quantified key performance parameters. He also suggests mentioning key decisions and considerations, and relations between all views and elements. Figure 4 shows an example layout for an A3AO.

In conceptual modeling, we use the same views as basis for further modeling. Based on physical model, dynamic behavior, and key performance parameters, we can select topics that deserve further modeling. For example, a mathematical formula that captures how the system achieves key performance using this dynamic behavior and this physical model.

Through our research of A3AO, we have seen that one of the main challenges in making effective A3s is the ability to visualize effectively. Visualization and the human factors of the readers is a research files on its own. Koning (Koning 2008) provides several guidelines for visualization. An example is the use of block sizes to convey information, or, when the size of a bock does not have semantics, the recommendation to keep all blocks the same size. The rationale is that readers may interpret the block size with unintended meaning, such as importance or weight.

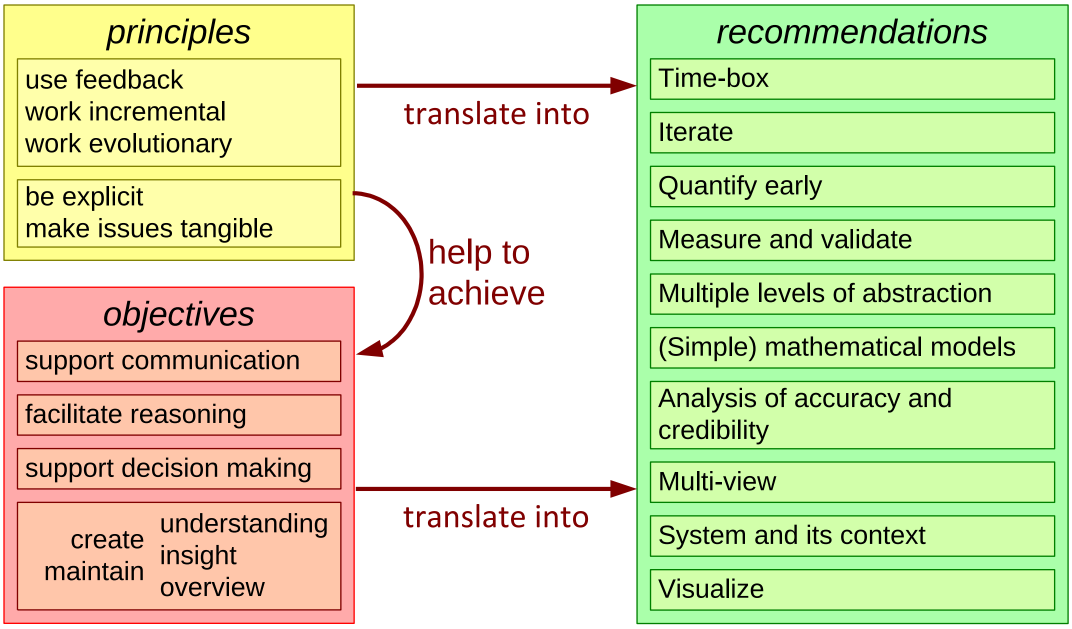


Figure 5, Conceptual modeling principles, objectives, and recommendations

Figure 5 shows the principles, objectives, and recommendations for conceptual modeling. Objectives of conceptual modeling are to support communication, facilitate reasoning, support decision-making, and to create and maintain understanding, insight, and overview. Principles to achieve these objectives are to use feedback, and to make issues tangible by making them explicit.

An essential recommendation for conceptual modeling is to use multiple levels of abstraction. Similarly, we observe that people making A3s tend to discover that they need multiple levels of A3s at various abstraction levels. Figure 6 shows how A3s map on abstraction levels in the system and abstraction levels in the system context. The background of Figure 6 consists of two pyramids, where the vertical axis shows an exponential scale with the number of details. The bottom pyramid is the system itself; the inverted pyramid on top shows the context of the system. The pyramids show that both system and context contain billions of details. Conceptual modeling simplifies that detailed world many orders of magnitude. Figure 6 shows that A3AOs cover a part of the architecture description:

- Top-level A3s connect stakeholder needs to system requirements
- Quality A3s focus on a single quality, connecting specific stakeholder needs to specific solution approaches. An example is installation duration.
- Aspect A3s elaborate specific solution aspects. An example is oil and gas containment design.

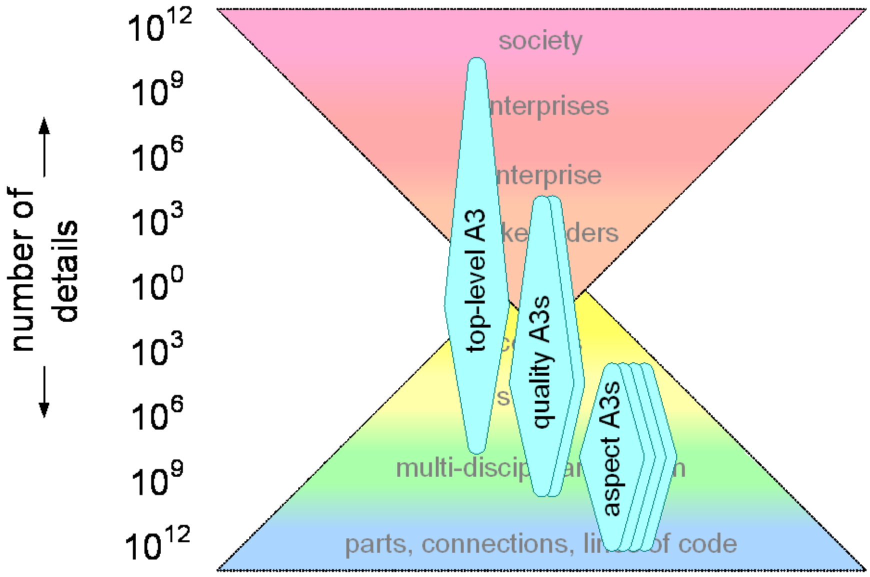


Figure 6. Using multiple levels of A3s to capture multiple levels of abstraction

Case study: Workover Operation A3

Participants of the SEMA course in 2013 selected a workover system as case for the course. Oil and gas companies regularly perform maintenance on the well, for instance, once or twice per year. For subsea systems a workover system, as shown in Figure 7 provides access to the subsea well. A platform or vessel transports the workover system to the well. The crew assembles, positions, and connects the workover system, so that the operator can go in with workover tooling.

Figure 7 shows the subsystems of the workover system and in *italics* the function of each subsystem is briefly stated.

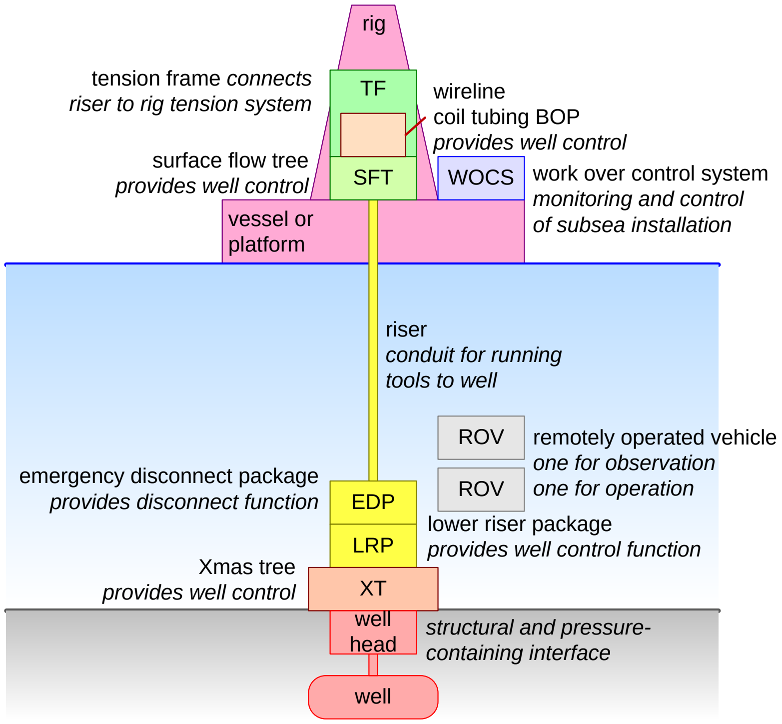


Figure 7. Physical model of a workover system, annotated with function per part.

Figure 8 shows the workflow of a workover operation. The specification and design of the workover system has impact on this workflow, and the time needed for preparation and finishing. The colors correspond with the workflow steps in Figure 10; the numbers correspond to the numbers in Figure 9.

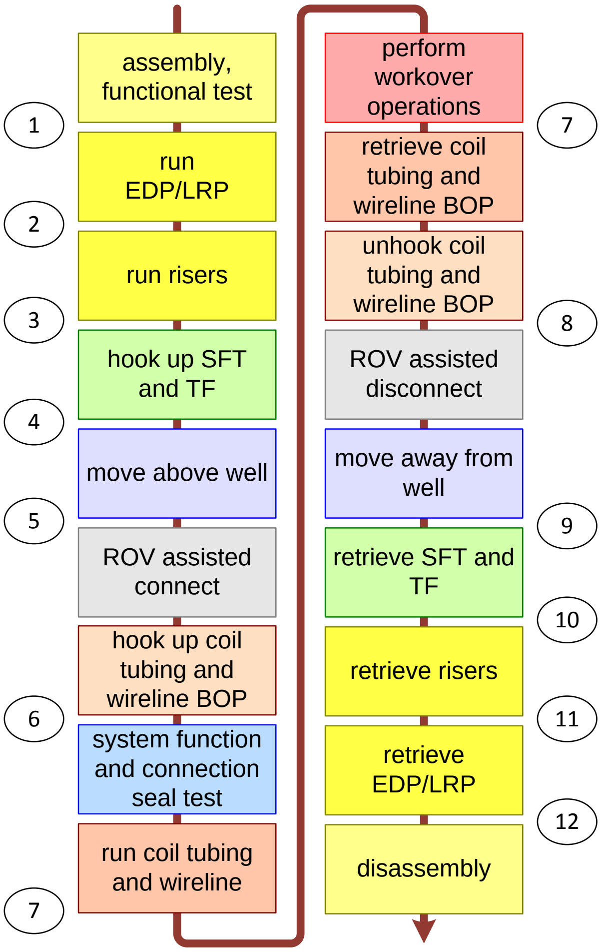


Figure 8. Workflow of a typical workover operation

Figure 9 visualizes the same workflow as in Figure 8, however, now in the form of a "cartoon". This visualization is less abstract than the workflow. We observed that this visualization engages most of the stakeholders immediately. Consequence of the immediate engagement was that the creators updated the represented workflow a few times to get it closer to reality. In one of the other interactions with stakeholders, the response was that they probably could have avoided a past mistake, if they had made such diagram.

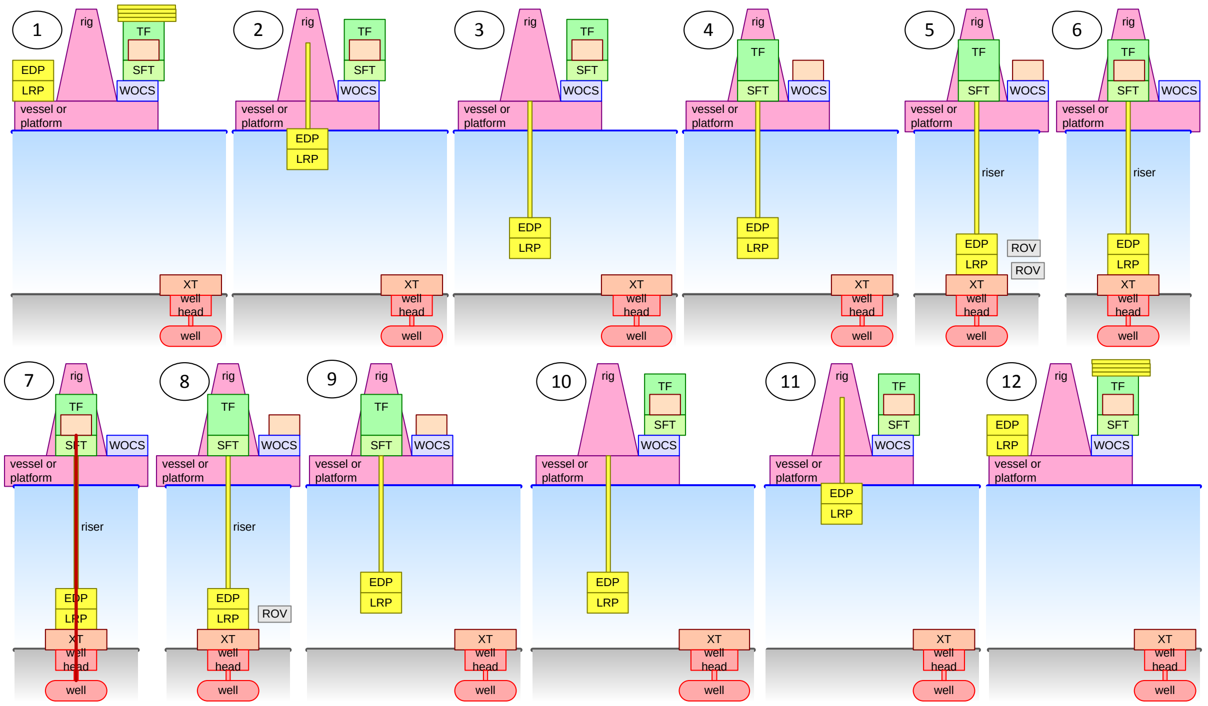


Figure 9. Visualization of the workflow as “cartoon”

assumptions:
running and retrieving risers: 50m/hr
running and retrieving coiled tubing/wireline: 100m/hr
depth: 300m

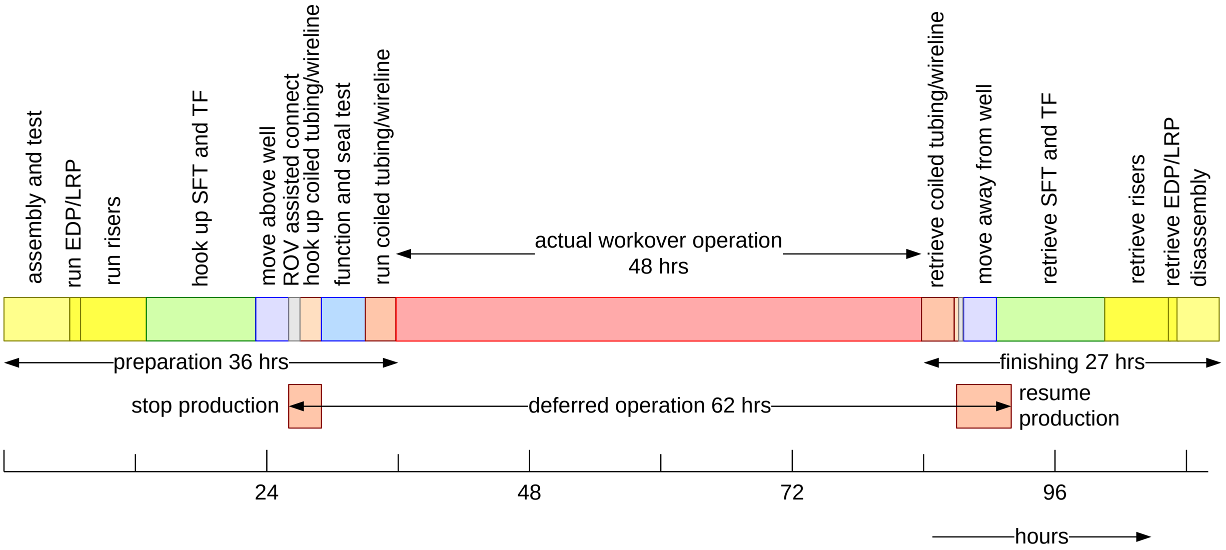


Figure 10. Timeline of the workover operation to facilitate an estimate of the duration.

The workflow is the basis for an estimate of the duration of the workover operation. For each workflow step, the modelers estimated the duration. In some cases, the duration depends on circumstances, such as the depth. The original model is a parameterized model. In this paper, we use a fixed depth of 300m to simplify the entire set of models. Figure 9 shows the duration per step on a timeline. Oil companies need to know how long the workover operation defers the production. Deferred production translates into an operational loss. Figure 10 shows the duration of deferred production as well.

We can now estimate the cost by estimating resource costs, and multiplying them with the duration. Similarly, we can estimate the cost of deferring oil production. Figure 11 shows the cost estimate for a single workover operation.

workover cost per day	*assumed cost (MNoK)*
platform, rig	2
equipment	0.2
crew	0.1
total	2.3 MNoK/day

deferred operation per day	*assumed cost (MNoK)*
production delay	0.1
ongoing cost operation	0.2
total	0.3 MNoK/day

workover duration	*estimated duration (hours)*	*production loss*
transportation	24	
preparation	36	6
workover	48	48
finishing	27	8
total	135 (5.6 days)	62 (2.6 days)

$$\text{cost} = \text{cost}_{\text{workover/day}} * t_{\text{workover}} + \text{cost}_{\text{deferred op./day}} * t_{\text{deferred op.}}$$

$$\sim= 2.3 * 5.6 + 0.3 * 2.6 \sim= 14 \text{ MNoK / workover}$$

Figure 11. Cost model and estimate, using the estimated duration.

The models as we have discussed them so far are highly simplified. They ignore aspects, such as disruptions. The SEMA course calls such simplest model a zero-order model. A zero-order model is useful to get a feel for the numbers and the relations. For example, the duration model shows that preparation and finishing together takes more time than the actual workover operation.

Modelers can expand a zero-order model into a first order model. In workover operations, the effect of disruptions, for example because of weather conditions, is significant. A first order model requires an adaptation in the workflow. Figure 12 shows the disruption workflow, the related “cartoon”, and time-line, in case of an approaching storm.

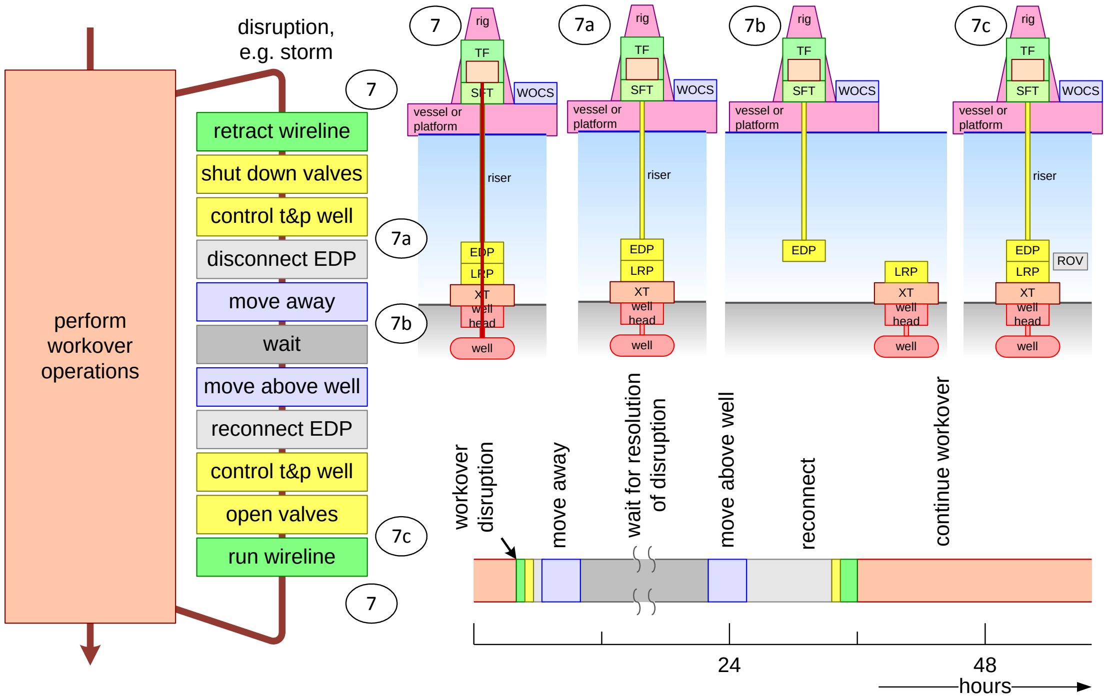
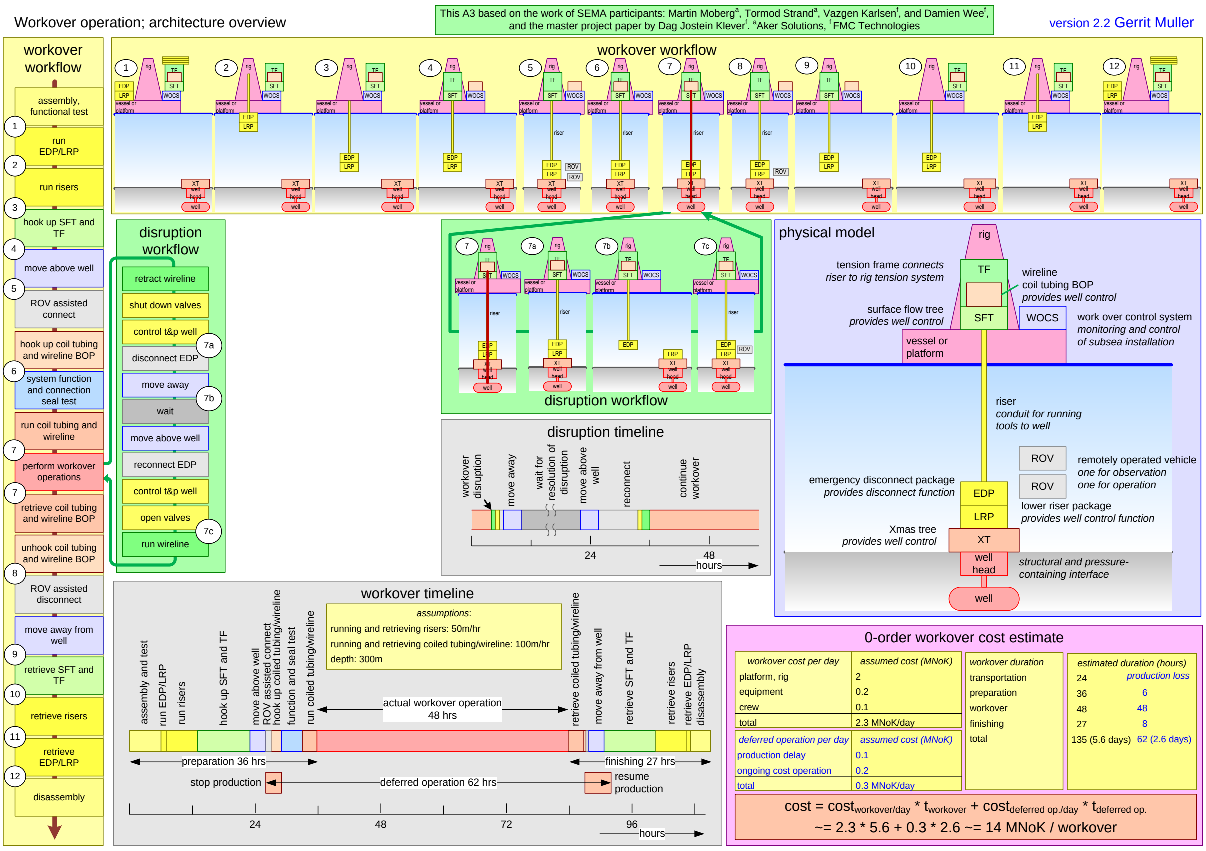


Figure 12. Workflow, cartoon, and time-line when a disruption occurs, such as an approaching storm.



assumptions:
running and retrieving risers: 50m/hr
running and retrieving coiled tubing/wireline: 100m/hr
depth: 300m

workover cost per day	*assumed cost (MNoK)*
platform, rig	2
equipment	0.2
crew	0.1
total	2.3 MNoK/day

deferred operation per day	*assumed cost (MNoK)*
production delay	0.1
ongoing cost operation	0.2
total	0.3 MNoK/day

workover duration	*estimated duration (hours)*	*production loss*
transportation	24	
preparation	36	6
workover	48	48
finishing	27	8
total	135 (5.6 days)	62 (2.6 days)

$$cost = cost_{workover/day} * t_{workover} + cost_{deferred\ op./day} * t_{deferred\ op.}$$
$$\sim= 2.3 * 5.6 + 0.3 * 2.6 \sim= 14 \text{ MNoK / workover}$$

Figure 13. A3 with Architecture overview of a workover operation (full-size A3 is available at http://www.gaudisite.nl/SSMEoverviewA3.pdf)

The course participants used these models to explore improvements that would reduce the installation time of the WOS to reduce the cost of the workover operation. Based on our observation about the state of practice of knowledge and documentation handling, we have used the same models to construct an A3AO for workover operations, as shown in Figure 13. The A3 has all elements as shown in Figures 7 to 12. However, we unfolded the workflow of Figure 8, and the timeline of Figure 9, since an A3 has sufficient space to fit them unfolded.

This single A3 provides now an explanation of the cost of workover operations and all underlying models. Benefit of having all these models concurrently, is that stakeholders can point to complementary models when reasoning about improvement options.

Discussion on extending and using A3AOs in subsea oil and gas

A good moment to create an A3 is when a topic is hot. Systems engineers can facilitate the discussion at such moment by recovering the overview on a single A3. However, while making this A3, the creators rely on a shared understanding of the context of the topic of interest. Unfortunately, this shared context understanding tends to lack as well. Consequently, the “above” A3, providing the context of the topic is needed too. At the same time, the discussion quickly requires more depth, e.g. a more detailed understanding of several aspects. This results in the need for A3s “below” the topic of interest.

In this particular case, cost of workover operations is not limited to work at a single well. In a broader context, several vessels and platforms operating from harbors serve multiple wells, and multiple fields. Figure 14 shows *contextual A3* as workover operations. At the bottom, Figure 14 shows some examples of more detailed A3s elaborating a single aspect that is relevant for the topic of interest. These aspect elaborations will typically address more design and implementation.

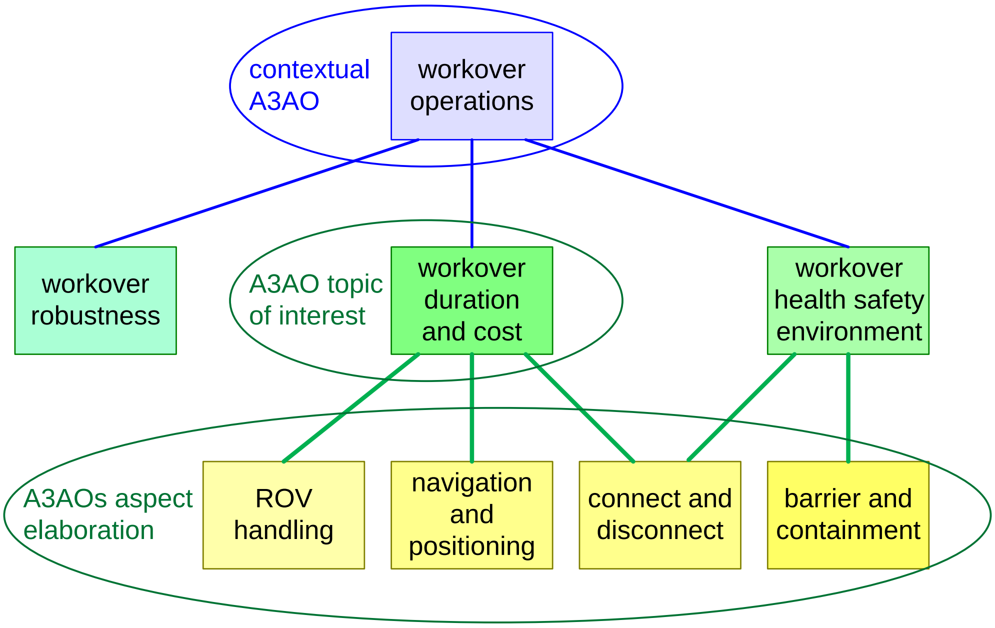


Figure 14. Neighboring A3s

Figure 14 shows that there probably will be similar A3s capturing the other key drivers. These levels of A3s correspond with Figure 6. However, the number of levels depends on domain and its complexity. In this particular example, workover operations, is only part of the subsea oil and gas subsea operations. Hence, we expect at least one higher level A3.

Before building this larger structure of A3s, we need acceptance of the subsea suppliers for the A3 approach. We have seen that the oil and gas industry is conservative. At the one hand, we see that the suppliers are aware that systems engineering may help the subsea oil and gas industry. At the other hand, most attempts to introduce systems engineering methods and techniques experience a lot of resistance. When we use this A3AO in current contacts with the subsea suppliers, we get at least an enthusiastic response.

The current documentation focuses on static, mostly physical, and interface-oriented information. The dynamic behavior captured in the workflow and visualized in the "cartoon" bridges the current *physical-oriented* mindset and the *dynamic* operation of the system.. Stakeholders in the oil and gas industry gave an enthusiastic response to a number of characteristics of this A3.

- The "cartoon" relates immediately to problems they experienced in the past. They recognized that they could have prevented some past problems if they would have followed such approach.
- The A3 connects the technical system to the business interests in terms of time and costs.
- The A3 approach is pragmatic. It fits and complements the current way of working that has emerged under a combination of high cost and time pressure and high demands for safety, reliability, and lifetime at the same time. Approaches that are more formal seem yet to be beyond current domain culture; they are perceived as time-consuming and not applicable (Muller 2015). For example, attempts at using IDEF0 and SysML typically meet skepticism and resistance.

Conclusions

The subsea oil and gas industry is a multi-billion industry that is suffering from delays and cost overruns. One of the causes is a complicated information flow, where overview is lacking. We have applied conceptual modeling in combination with A3 architecture overviews to construct an A3 for workover operations. This A3 combines physical model, dynamic behavior, and quantification. This combination facilitates discussion of duration and cost of workover operations. The A3 is sufficiently close to the mental world of the subsea and gas suppliers that they respond positive to the A3.

Future work

Employees from the suppliers applied conceptual modeling as project for the SEMA course. We have to evaluate conceptual modeling, when applying it in hectic industrial settings. Similarly, we need to evaluate the use of A3s in the same circumstances. Significant effort is required to get support for a broader application and evaluation of A3s and conceptual modeling in the subsea industry.

A research question that needs further study is the amount of levels of A3s that works well. Related research questions are how A3s complement other ways of working, such as conventional documents, knowledge and requirement databases, and Model Based Systems Engineering (MBSE). The work on Dynamic A3s (Singh 2013) deserves follow-up since it makes an attempt at combining A3s and MBSE.

Acknowledgements

Tormod Strand and Vazgen Karlsen participated in the original SEMA project together with co-authors Damien Wee and Martin Moberg. Gunnar Berge stimulated the creation of subsea examples of conceptual modeling. Yang Yang Zhao suggested to transform the A3 into a conference paper.

References

Borches D., 2011, "A3 architecture overviews: a tool for effective communication in product evolution", PhD thesis, University of Twente

Borches D., Bonnema G.M., 2010, "Focusing architectural knowledge to support evolution of complex systems", INCOSE 2010 in Chicago

Engebakken, E., Muller, G., and Pennotti, M., 2010, Supporting the System architect: Model-assisted Communication, Systems Research Forum Vol 4, No2 (2010) pages 173-188

Koning, H., 2008, "Communication of IT-Architecture", PhD thesis, Utrecht University, http://dspace.library.uu.nl/handle/1874/29956

Kooistra, R., Bonnema, G.M., Skowronek, J., 2012,"Architecture Overviews for Systems-of-Systems", CSDM 2012 in Paris.

Muller, G., 2009, "System and Context Modeling -- The Role of Time-boxing and Multi-view Iteration", Systems Research Forum Vol. 3, No. 2 (2009) p139-152

Muller, G., 2015, "Reflective Practice to Connect Theory and Practice; Working and Studying Concurrently", CSER 2015, in Hoboken

Nilsen, A.F., and Muller, G., 2014, "Use Cases and Non-functional Requirements Presented in Compact System Description A3s", INCOSE 2014 in Las Vegas

Rypdal, R.W., Muller, G., Pennotti, M., 2012, Developing the Modeling Recommendation Matrix: Model-Assisted Communication at Volvo Aero, INCOSE 2012 in Rome

Singh, V., and Muller G., 2013, "Knowledge Capture, Cross Boundary Communication and Early Validation with Dynamic A3 Architectures", INCOSE 2013 in Philadelphia

Stalsberg, B., and Muller, G., 2014, Increasing the value of model-assisted communication: Modeling for understanding, exploration and verification in production line design projects, INCOSE 2014 in Las Vegas

Tranøy, E. and Muller G., 2014. "Reduction of Late Design Changes Through Early Phase Need Analyis", INCOSE 2014 in Las Vegas.

Wiulsrød, B., and Muller, G. 2012, "Architecting Diesel Engine Control System using A3 Architecture Overview", INCOSE 2012 in Rome

Biography


Gerrit Muller.

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

All information (System Architecture articles, course material, curriculum vitae) can be found at: Gaudí systems architecting http://www.gaudisite.nl/


Martin Moberg

Martin Moberg is a Systems Engineer in Aker Solutions. He has 4 years' experience from the Oil & Gas industry. His project experience includes involvement in Subsea Productions Systems, Workover Systems and Subsea Compressions Systems, as well as process improvement project internally in the Aker Solutions organization. He received both his Bachelor's degree in mechanical engineering and his Master's degree in Systems Engineering from Buskerud and Vestfold University College.


Damien Wee

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