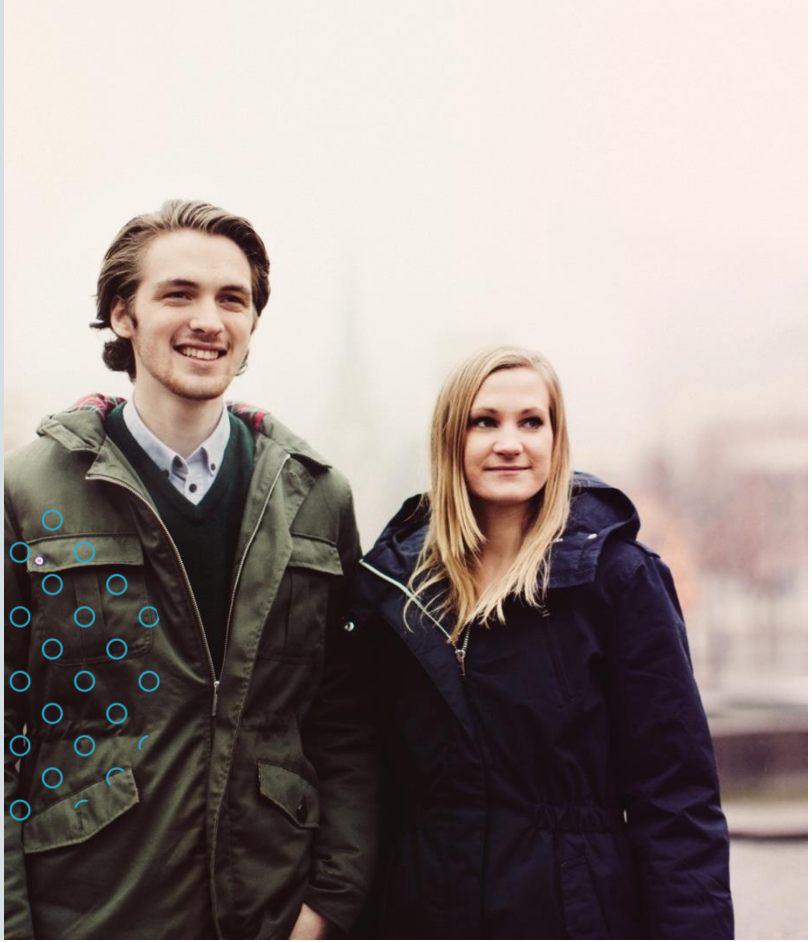
University College of Southeast Norway

"What can Systems Engineering contribute to Oil and Gas? Illustrated with case studies from subsea"

June 15, KSEE 2017



Gerrit Muller
Professor Systems Engineering
USN-NISE

July 2016; INCOSE Edinburgh

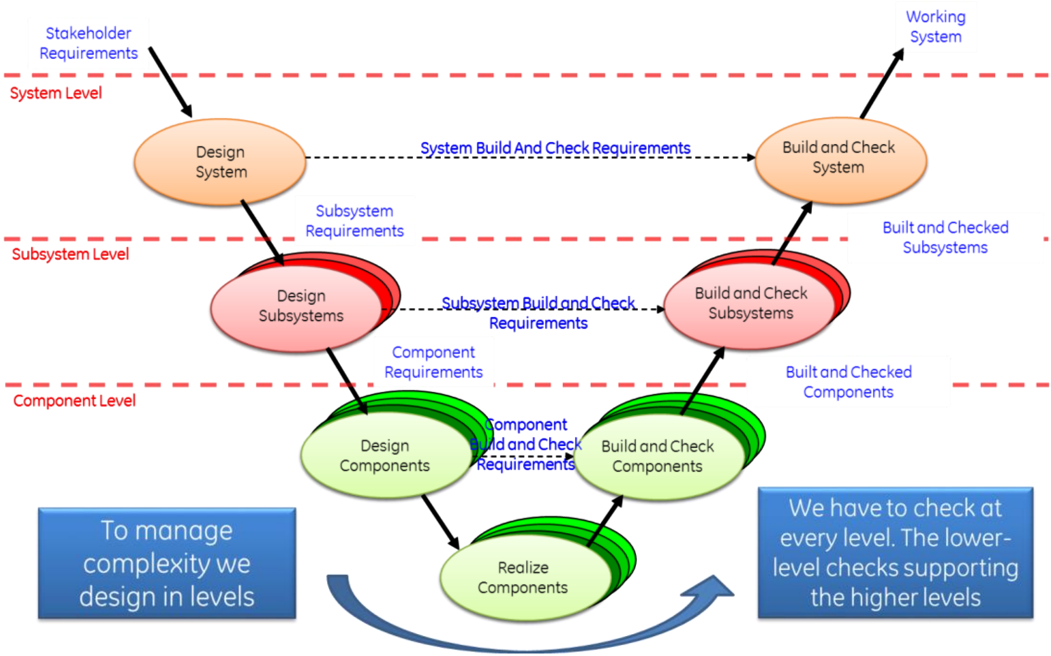
Shell and GE kick off an INCOSE working group Oil&Gas

The Working Group prepared a number of slides on the value of systems engineering.

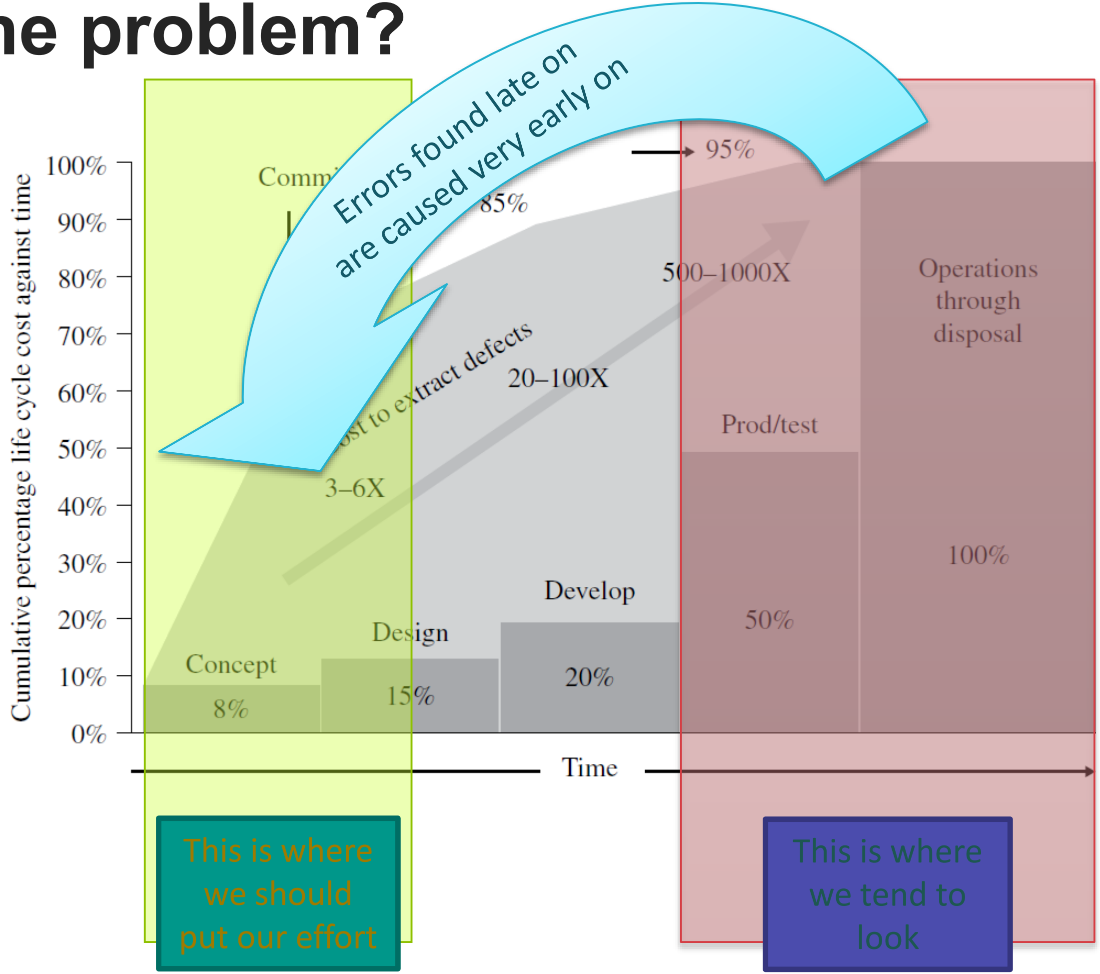
This presentation proudly re-uses some of WG slides

What is Systems Engineering (SE)?

- **Interdisciplinary** field of engineering that focuses on how to design and manage complex engineering projects over their life cycles.
- Ensures that all likely aspects of a project or system are considered, and **integrated** into a whole.
- Both an **approach** and a **discipline** in engineering



What's the problem?



Graph produced by Defense Acquisition University

SE in other Industries

- SE methodology is not new to other industries
- Significant opportunity in O&G to create a "step change" by tailoring SE methodology to the O&G industry

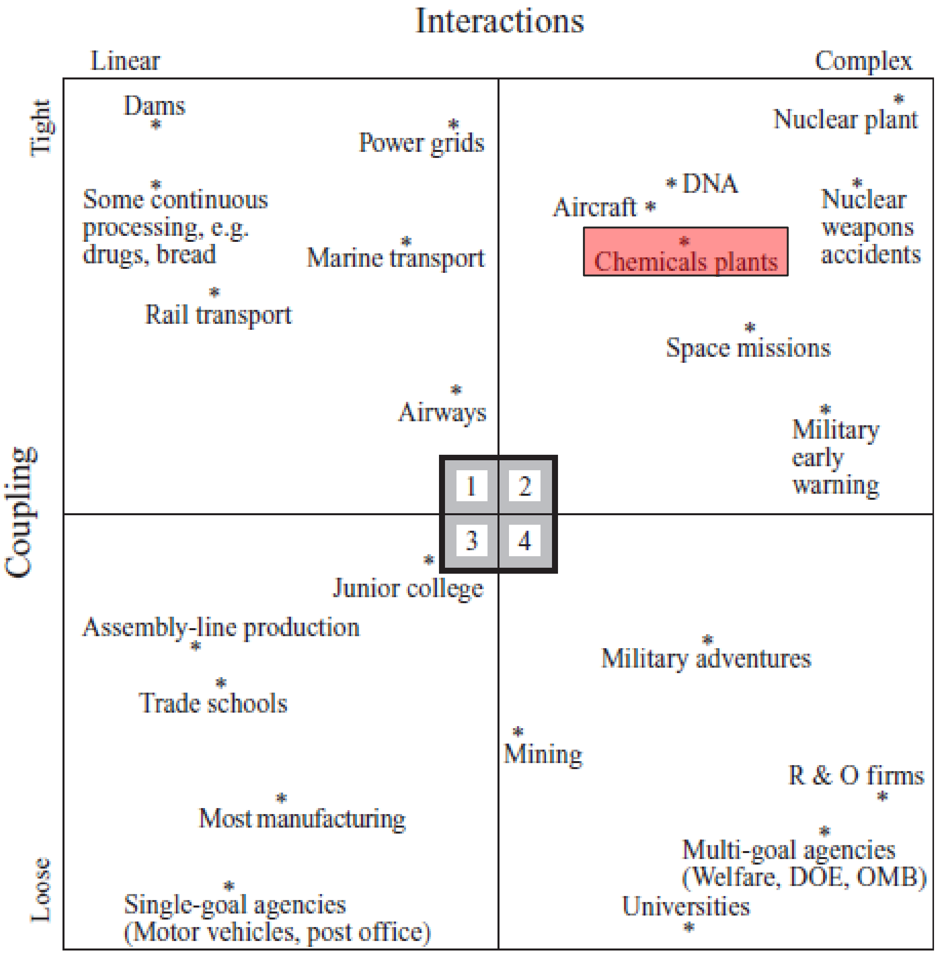


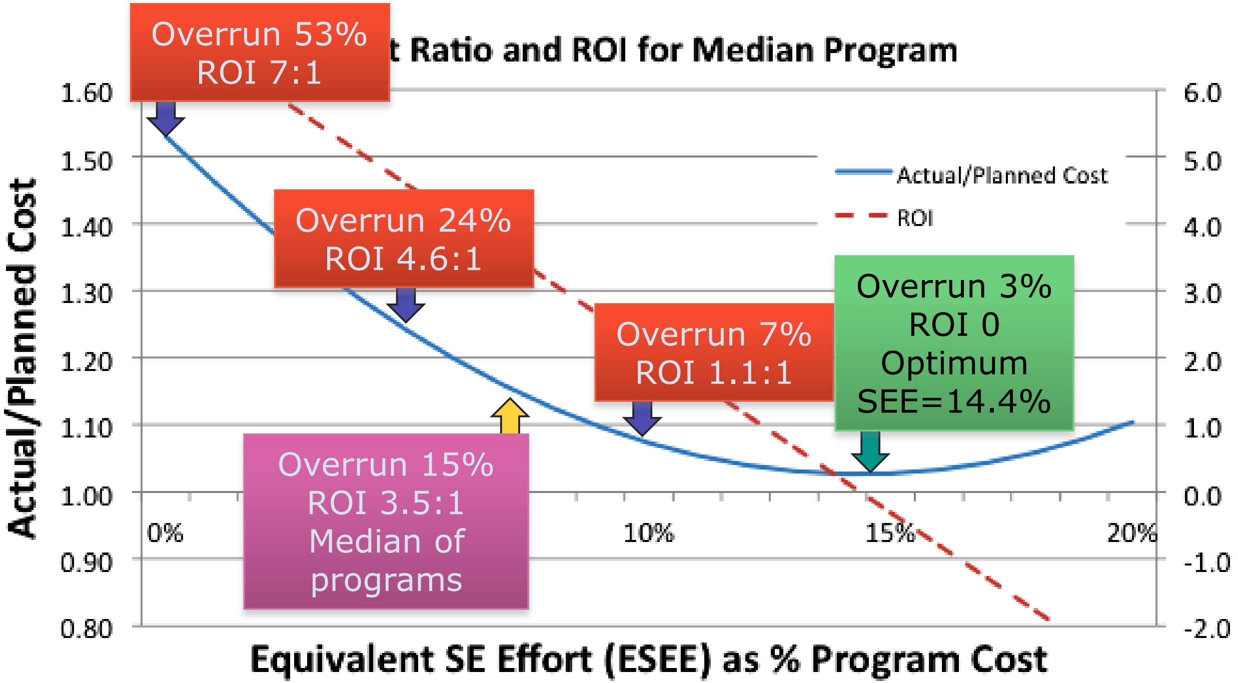
*Figure from Perrow: Normal Accidents

Why SE Now in O&G; Call for Change

- O&G currently builds large systems and has done so for many years with success; however…
  - Cost has increased significantly
  - Quality escapes still persist across the industry
  - Schedule for delivery has increased significantly
- O&G currently practices several SE methodologies; however…
  - Subsea developments have gotten increasingly more complex due to higher pressure and temperatures
  - Lack of traceability from requirements to the product installed
  - Reliance on people with decades of experience to design, build, install, and operate their equipment, leading to inconsistent, incompatible designs that frequently do not meet the requirements or stakeholder needs without significant and extraordinary efforts by all parties

- O&G is missing a methodology to consistently produce an output from project to project with differing staff….So, how much SE is needed?

Return on Investment



SE activities include:

- Mission/Purpose Definition
- Requirements Engineering
- System Architecting
- System Integration
- Verification & Validation
- Technical Analysis
- Scope Management
- Technical Leadership/ Management

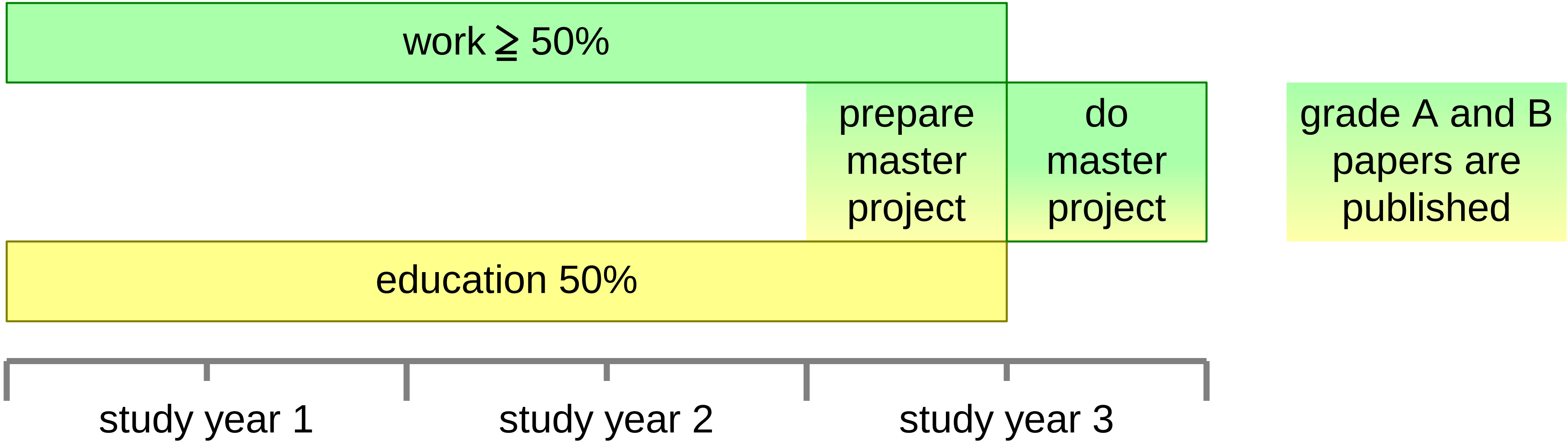
A Systems Engineer's job is to deliver the system behavior stakeholders pay money for and profit lines are dependent on

Honour, EC, Systems Engineering Return on Investment, PhD thesis, Univ South Australia 2013

Research Model Master Students Systems Engineering in Kongsberg, Norway

students know:
+ domain
+ SE methods
and techniques

students:
+ apply
+ reflect
+ evaluate



Master Projects in Oil and Gas 2009..2017

- 80 students finished their master project
- 15 of their papers have been published
- Key word distribution publications

Concept Selection	4
Conceptual Modeling	2
Tolerance Management	2
Late Design Changes	2
Requirements	1
Systems Integration	1
A3	1
Knowledge management	1
Needs Analysis	1
autonomous	1
Enterprise Resource Management (ERP)	1
Lifecycle Management	1
Qualification	1
Trade study	1
ConOps	1

Key word distribution all projects

Concept Selection	13
Conceptual Modeling	9
Requirements	9
Systems Integration	8
A3	6
Knowledge management	4
Systems Design	4
MBSE	4
Interface Management	4
Needs Analysis	3
Risk Management	3
Functional Design	2
Project Management	2
Taguchi	2
Documentation	2
Decision Making	2
Tolerance Management	2
Late Design Changes	2

26th annual INCOSE international symposium
Edinburgh, UK
July 18 - 21, 2016

Evaluating the effectiveness and effort in applying a Requirements Management Tool on a Subsea Oil and Gas Workover System

Damien Wee – FMC Technologies

Gerrit Muller – HSN-NISE

[2]

Overview of requirements for a typical workover system project

26th annual INCOSE international symposium
Edinburgh, UK
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Order of Precedence

112 documents!

1) ALARM Principles (25 pages – HSE)
2) Reliable sourcing
3) Cad standards
4) SIS instruments (15 pages – TS&R/Systems)
5) Qualify technology for first use
6) Qualify technology for first use
7) Qualify technology for first use
8) Qualify technolgoy for first use
9) Engineering number system
10) Engineering Number system
11) LCI requirements (56 pages – Documents – General)
12) Preparation of technical hierachies (15 pages – General)
13) Working environment (37 pages – General)
14) SPIR registration (10 pages – General)
15) Quality requirements (16 pages – Quality)
16) Performance standards for safety barriers
17) SAS operator station HMI (55 pages – Controls)
18) Subsea Intervention Systems (34 pages – Systems/Products)
19) Subsea umbilicals and cables (28 pages – Controls)
20) Subsea production control system (50 pages – Controls)
21) Subsea valves (27 pages – Well Integrity products)
22) Alarm systems (28 pages – Controls)
23) Technical network and security (11 pages – Controls)
23) SIS
25) Infomation management system (38 pages – Controls)
26) Subsea electrical high voltage connector assembly (33 pages – Controls)
27) Mechanical completion requirements
28) Preservation requirements
29) LCI requirements (123 pages – General)
30) Materials requirements (32 pages – Materials / Risers / Well control products)
31) Electrical/Optical connectors (70 pages – Controls)
32) Mechanical, technical requirements and standards
33) Electrical standards (6 pages – Controls)
34) Electrical system design (74 pages – Controls)
35) Electrical, instrumentation and telecommunication (65 pages – Controls)
36) Automation (6 pages – Controls)
37) Automation technology (22 pages – Controls)
38) Field instrumentation (102 pages – Controls)
39) Safety and automation system (38 pages – Controls/TS&R)
40) SAS application functions and structure (45 pages – Controls)
41) SAS integration of subsea control (25 pages – Controls)
42) Subsea Technology (6 pages – Systems)
43) Fasteners (13 pages – Well Control products)
44) LCI requirements (61 pages – General)
45) Electrical equipment (36 pages – Controls)
46) Automation technology (35 pages – Controls)
47) Testing and inspection of SIS (21 pages – Quality)
48) Subsea XT and CWO activities
49) Recertification of well control equipment
50) Subsea XT and CWO systems (137 pages – Systems/Materials/All products)
51) Well intervention equipment and services
52) Mechanical completion manual

1 Norwegian Petroleum Directorate(1)

2 Client specifications (53)

Project Design Requirements

3

Project specific requirements (2)

Project exception lists

1) Safety Requirement Specification
2) Technical and operational guidelines

4 Norsk standards (22)

1) Well integrity in drilling and well operations
2) Subsea production system
3) Material selection
4) Surface preparation and coating
5) Cathodic protection
6) Welding and inspection of piping
7) Qualification of manufacturers of special materials
8) Non metallic sealing materials
9) Electrical system
10) Mechanical equipment
11) Safe use of lifting equipment
12) Technical safety
13) Working environment
14) Environmental care
15) Machinery working environment
16) HS
17) Safety equipment data sheet
18) HSE
19) Criticality analysis for maintenance purposes
20) Risk and emergency prepardness
21) Temporary equipment
22) Suppliers' documentation of equipment

5 ISO standards (21)

1) Guidelines for quality plan
2) Drilling and production equipment
3) Subsea production system
4) Production control system
5) Completion and workover riser system
6) ROV interface
7) Material use in H2S environment
8) Hydraulic fluid power
9) Material selection
10) Hydraulic fluid power system
11) Quality requirements for welding
12) Contamination
13) Quality management system
14) Quality management system requirements
15) Systems and software engineering – Software lifecycle
16) Hydraulic fluid power
17) Hydraulic fluid power – Assembled systems
18) Reliability and maintenance data
19) Production assurance and reliablity management
20) Risk management
21) Software engineering

6 Others (12)

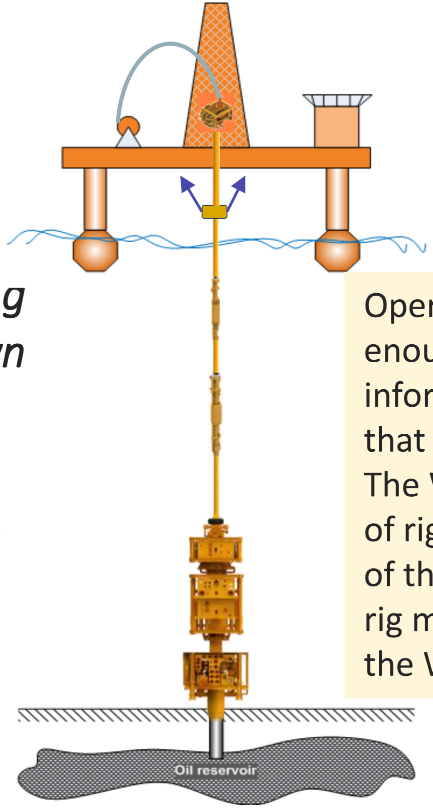
1) Planning and execution of marine operations
2) Recertification of well control equipment
3) Risk management
4) Modelling and analysis
5) Cathodic protection design
6) Duplex stainless steel
7) Qualification procedure for new technology
8) Safety electronics system
9) Functional safety – SIS
10) Optical fibre cable
11)Application of IEC61508 and IEC61511
12) Cleanliness of hydraulic fluid

WOS requirements key challenges – Unknown operating conditions

Requirement

Two rigs may be used for drilling and completions, with unknown requirements for future rigs

- Lack of information regarding type of rigs to be used



Operator typically expects the WOS to be flexible enough to be used on different rigs, however information about the rig is usually not available as that is part of another contract.
The WOS interfaces with the rig and the different type of rigs used will affect the design of the WOS. Motion of the rig will cause stresses on the WOS, using a larger rig may imply that we have stiffer motion at the top of the WOS, causing more fatigue stresses.

Architecting builds on Engineering & Management

Systems Architecting, Design, and Integration

Systems **Partitioning** (Work Breakdown Structure, Bill of Material)

Dynamic Behavior (functionality, interaction)

Quantified **Quality Attributes** (performance, safety, reliability, …)

in **relation** to each other and in the **context**

prerequisite for ↑   content for ↓

Systems Engineering Management

Project Management

Requirements Engineering

Interface Management

Product Life Cycle Management

and much more…

AkerSolutions™

Preferred partner

Early Phase Need Analysis

-Can We Ease Systems Integration? [3]

INCOSE 2014 Best Student Paper Award

Kongsberg 14.06.2013

Eldar Tranøy | Systems Engineer

University College of Southeast Norway

Motivation For Research

- Large cost overruns on EPC projects on the Norwegian continental shelf
  - ➢ Skarv
  - ➢ Snøhvit LNG
  - ➢ Yme
- 10 large EPC projects totaled a 96 Bn NoK cost overrun
- Large media exposure and highlighted in the Norwegian national budget

Main Cost Drivers

- Scope changes and late design changes are considered to be the main drivers
  - ➢ Has potential to add schedule delay
- Imposes a project risk
  - ➢ Oil companies need means to mitigate these risks
- The risk is transferred to the contractors
- Methods and tools to reduce the amount of late design changes might yield a competitive advantage

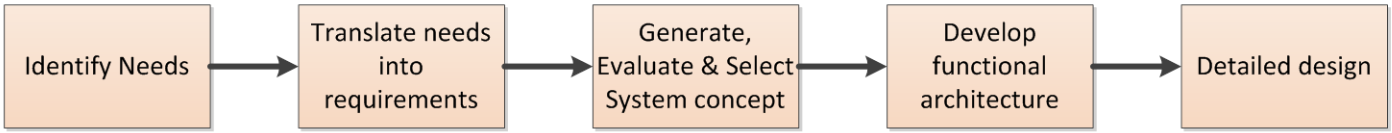
Project	Estimated cost	Actual / New estimate	Change	Change in %
Balder	5	8,08	3,08	62
Gullfaks Sat 1	6,86	9	2,14	31
Jotun	6,2	7,2	1	16
Njord	6,31	7,76	1,45	23
Norne	8,62	9,27	0,65	8
Oseberg Sør	8,05	8,75	0,7	9
Oseberg Øst	3,49	4,3	0,81	23
Troll Gass	18,25	20,77	2,52	14
Varg	2,94	3,64	0,7	24
Visund	7,85	11,4	3,55	45
Åsgard	28,52	37	8,48	30
Kårstø	2,94	7,08	4,14	141
Åsgard Transport	7,36	7,96	0,6	8
Snøhvit LNG	43,8	64,5	20,7	47
Ormen Lange	72,5	107,1	34,6	48
Alvheim	8,7	17,2	8,5	98
Statfjord Seinfase	14,5	18,5	4	28
Blane	1,8	3,5	1,7	94
Valhall Re-dev	23,7	39,9	16,2	68
Gjøa (ink gaspipe)	30,2	34,7	4,5	15
Yme	4,7	8	3,3	70
Skarv	34,3	35,8	1,5	4
Vega + Vega Sør	6,4	7,5	1,1	17

Numbers from the investment committee's report are all calculated as value pr. 1998

Systems Engineering - Benchmarking

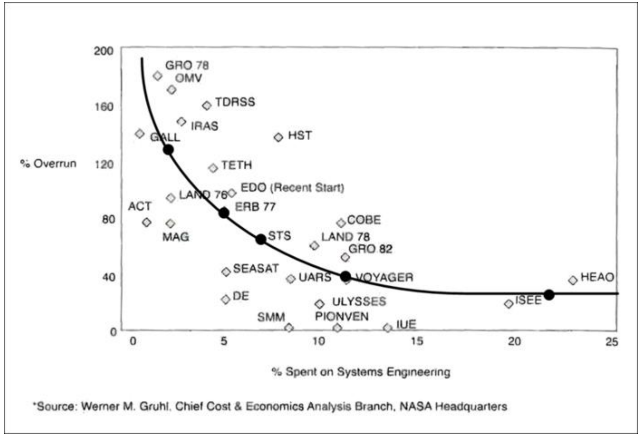
- Systems Engineering Body of Knowledge (SEBoK)

- Fundamental SE process:



Systems Engineering – Benchmarking

- Eric Honour (2004) – Value of Systems engineering
- Gruhl (1992) – NASA research
  - Less cost overruns with early phase effort
- Barker (2003) – IBM research
  - Productivity improvement, cost savings and increased quality of design



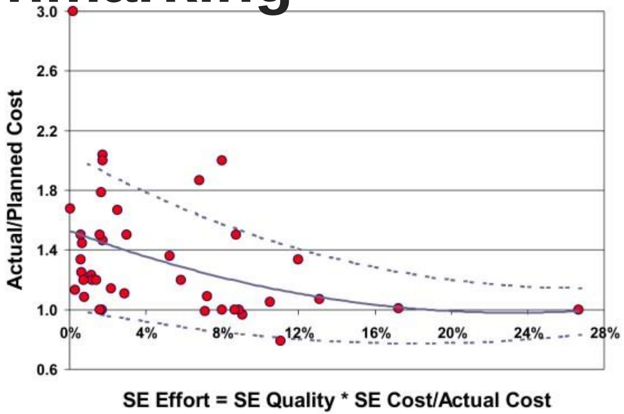
Systems Engineering - Benchmarking

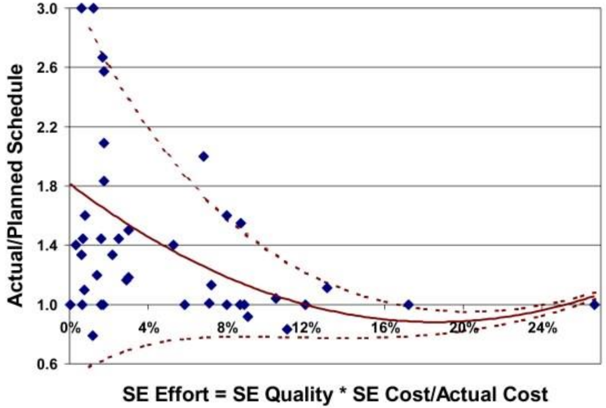
- Honour defines a metric to measure Systems Engineering
- Systems Engineering Effort (SEE)

$$SEE = SE\ Quality\ * \frac{SE\ Cost}{Project\ Cost}$$

- Optimum SEE at 15-20 %

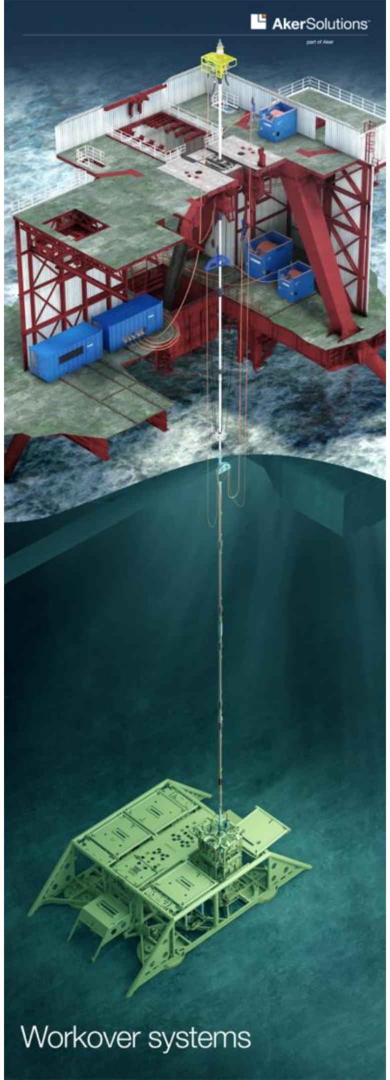
- This implies that contractors are either doing too little SE or performing SE with too low quality





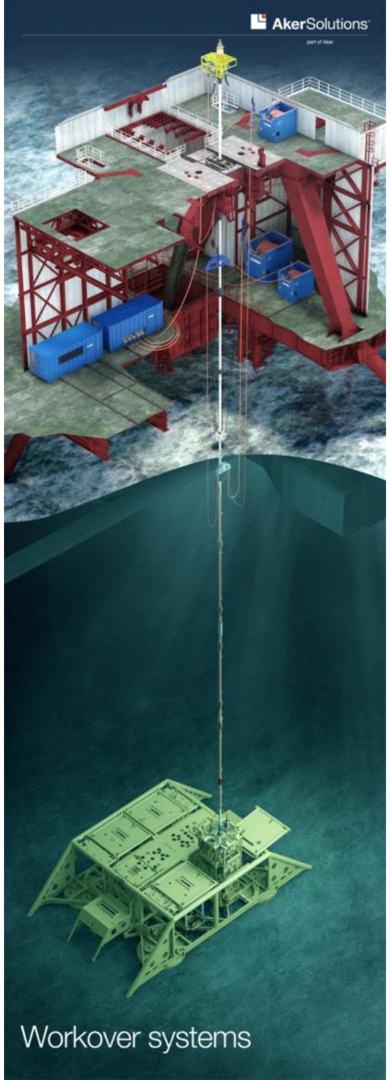
Example Project – Vigdis NE WOS

- Workover Systems / Light Well Intervention Equipment
- System delivery comprise of:
  - EDP/LRP
  - Riser System
  - multiWOCS
- Interfaces XMTs/Wells from multiple vendors
- Interfaces multiple offshore vessels / rigs
- Follows the “FastTrack” delivery scheme



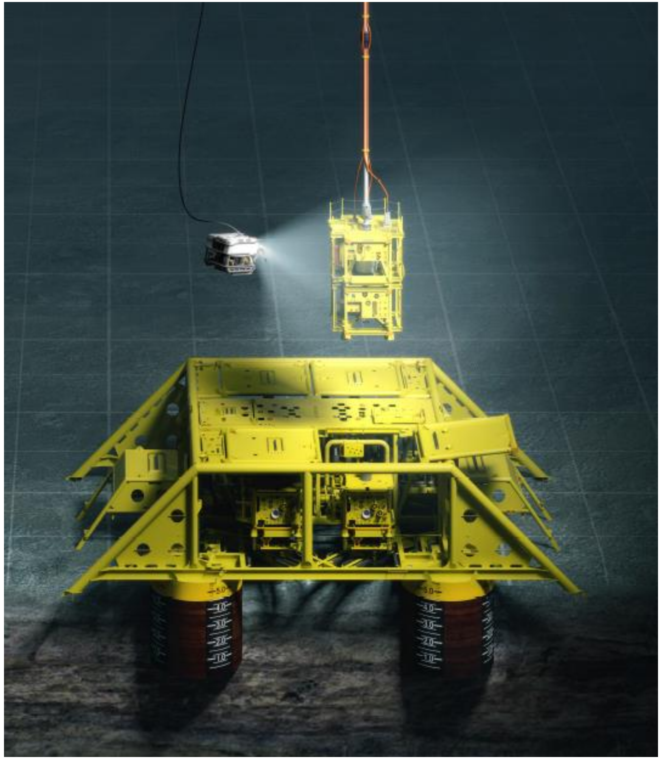
Identifying Root Causes

- We needed to benchmark SE performance in Vigdis NE WOS
- Amount of SE:
  - **8,5% of total project cost**
  - **Too low for optimum SEE**
  - **High enough to expect good results**
- Startup of SE activities:
  - Initiated at project startup
  - Confirmed by project timeline
- Performed a comparison of internal SE activities compared to SE fundamental processes



Capturing the Customer Perspective

- Assess if the initial system design covered the operational need of the customer
- Establish a basis to evaluate the initial need analysis done in the project
- Performed through in-depth interview with customers' technical lead
- Three main root causes were identified



Capturing the Customer Perspective

- Cross vendor interfaces
  - Not evaluated in the research

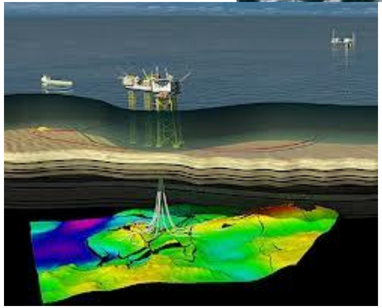
- **Mismatch** between tendered design and **operational needs**
  - Requirements derived from the tender phase were generic, not application specific
  - Leads to over-dimensioning of subsystems

- **Mismatch** between requirements in governing documents and **operational needs** and physical limitations of interfacing systems and stakeholders
  - The needs of the operational vessels not covered by governing documents
  - This will in turn affect how the requirements interact
  - Governing documents define the system and impose weight restrictions
  - These restrictions exceed the lifting capacity of the operational vessels

Capturing the Customer Perspective

- This effectively means that the design that won the tender is **not suitable for the actual operational needs** of the customer

Aker Solutions – Tender Phase



- When contractors enter into a tender, it is not unusual that **essential operational data is missing**.
- This finding also correlates with the investment committee’s report
- Examples of **typical missing data**:
  - Meteorological and oceanographic data
  - Field data
  - Soil data
  - Fluid data
  - Installation vessel data

Analysis of Cost and Potential Impact

- Analysis of VO registry
  - Changes to design or scope normally results in a variation order (VO)
  - Cost of change is normally carried by customer
  - Review of 23 VO's

- Findings
  - 74% of the VO's were preventable by need analysis
  - 92% of the cost incurred by late design changes, were preventable

- Root cause analysis of the preventable VO's
  - Changes to product design
  - Mismatches between project requirements and operational needs

25th anniversary
annual INCOSE
international symposium
Seattle, WA
July 13 - 16, 2015

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

Martin Moberg

Gerrit Muller, HBV-NISE Martin Moberg, Aker Solutions

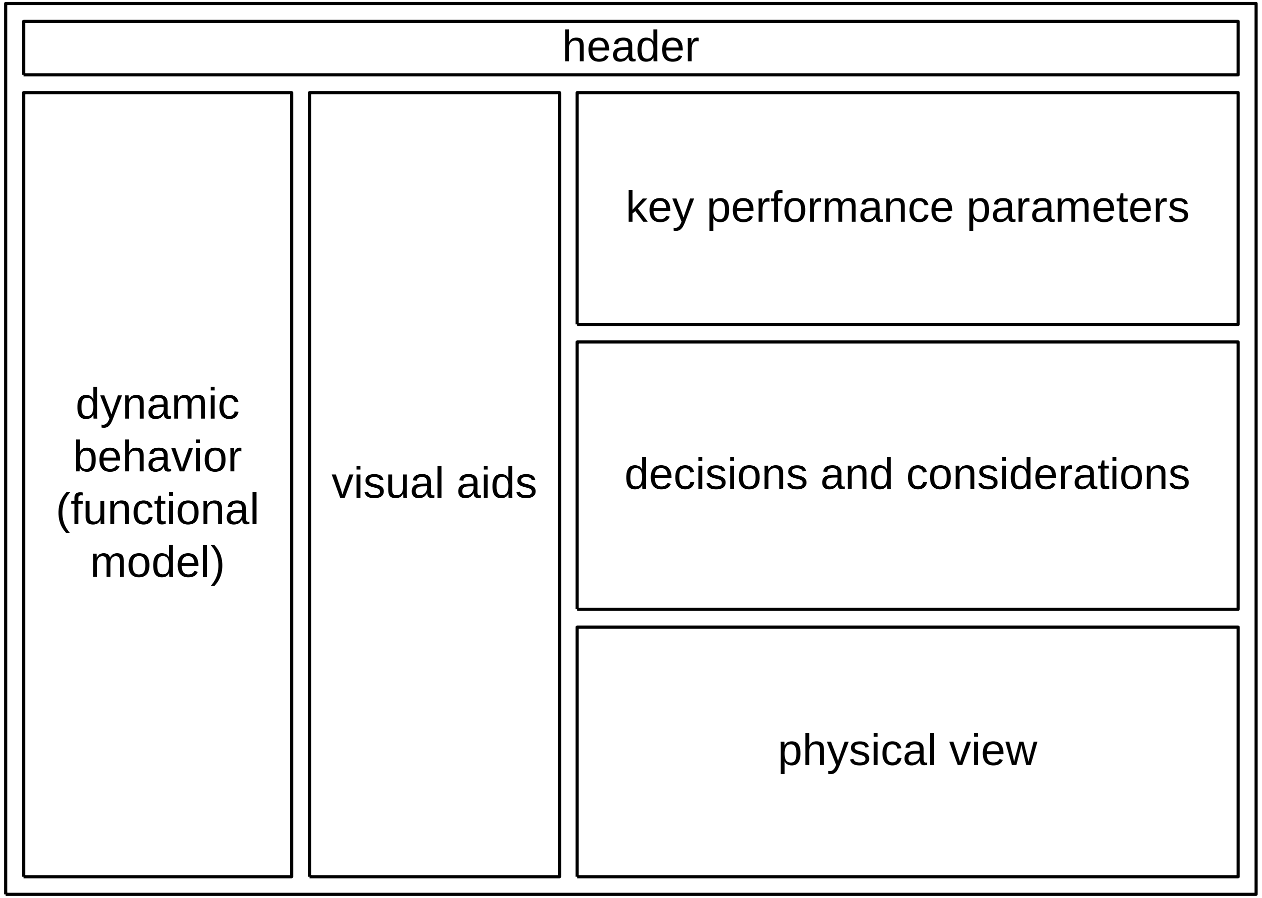
Damien Wee, FMC Technologies

Kongsberg, Norway

[4]

Damien Wee

Borches: A3 architecture overview, example layout



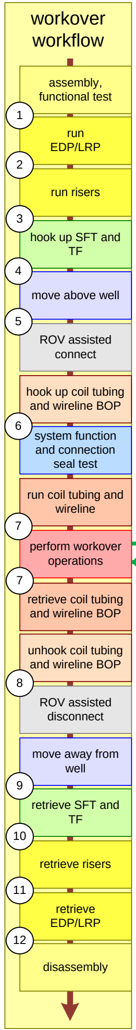
simplified from http://www.gaudisite.nl/BorchesCookbookA3architectureOverview.pdf

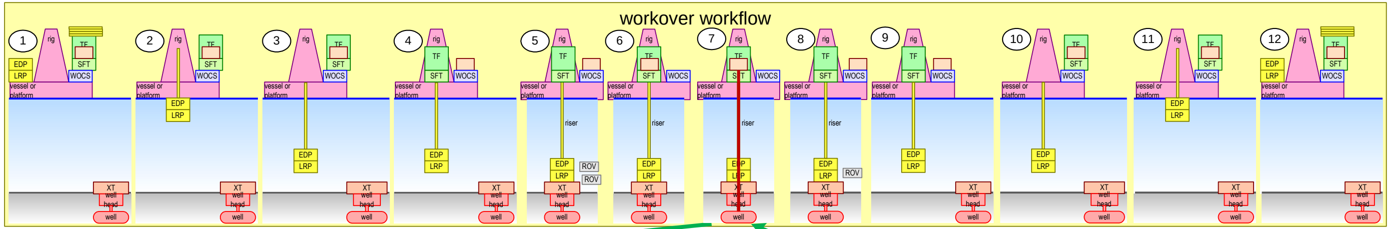
A3 Architecture Overview

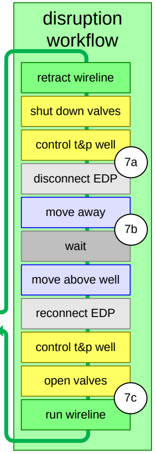
Workover operation; architecture overview

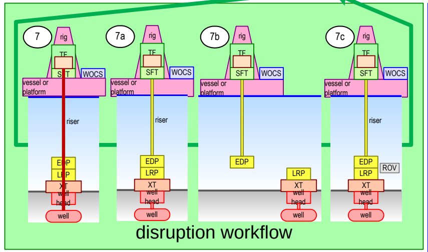
This A3 based on the work of SEMA participants: Martin Moberg[a], Tormod Strand[a], Vazgen Karlsen[f], and Damien Wee[f], and the master project paper by Dag Jostein Klever[f]. [a]Aker Solutions, [f]FMC Technologies

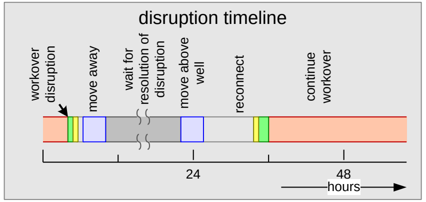
version 2.2 Gerrit Muller

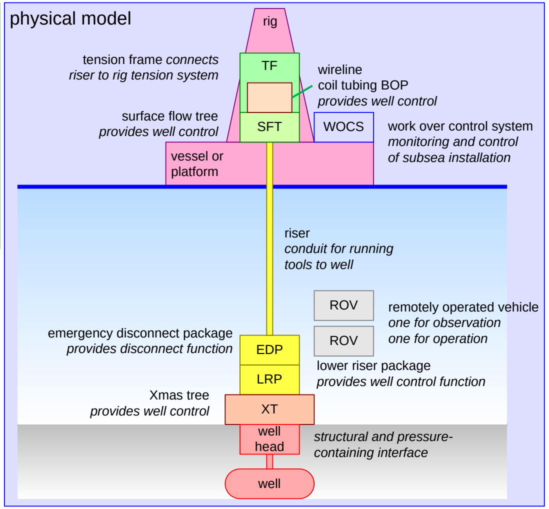


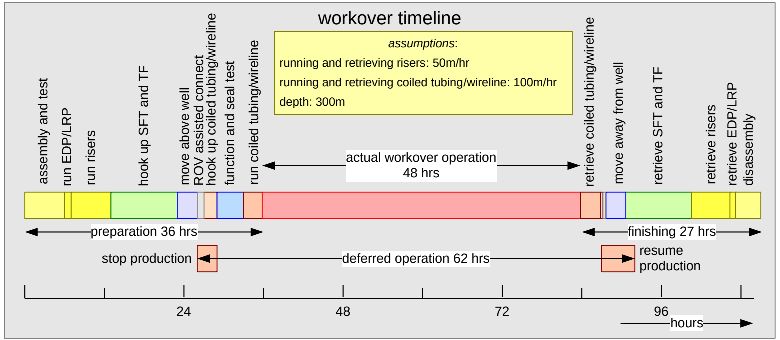












0-order workover cost estimate

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)

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

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

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Concept selection through illustrative ConOps – A Holistic Decision

Herman Solli – Aker Solutions

Gerrit Muller – HSN-NISE

[5]

Late design changes

- **Late identification of operational needs**
  - Main focus on fulfilling requirements, operational needs “discovered along the way”
- **Lack of knowledge transfer**
  - Repeated mistakes. Previous lessons and experience not utilized efficiently

From INCOSE System Engineering Handbook: A Guide for System Life Cycle version 3.2.2

Methods of interest

Concept of Operation:

- Method for analysis and understanding of system needs throughout the system life cycle.

[Kossiakoff, System Engineering Principles and Practice]

- Describes the way the system works from the operators perspective.

[INCOSE System Engineering Handbook: A Guide for System Life Cycle version 3.2.2]

- A “meeting of the minds” between user, developer, and other stakeholders.

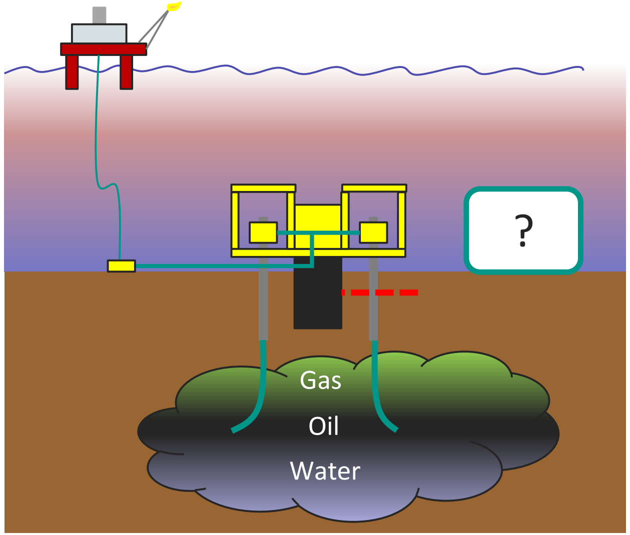
[Investigation of a Graphical CONOPS Development for Agile Systems Engineering. SERC 2009]

Pugh Matrix

- Multi criteria decision making method in matrix format.
- Allows for comparison of multiple design candidates towards a set of criteria.
- Communicates the main characteristics of the proposed system.

Case – Subsea contingency well

- We used a Contingency satellite subsea well as case for the research.
- Based on a report on the case.
- Idea is to have a back-up system ready to reduce production downtime in the case of a damaged well. By connecting a new well to an existing system.

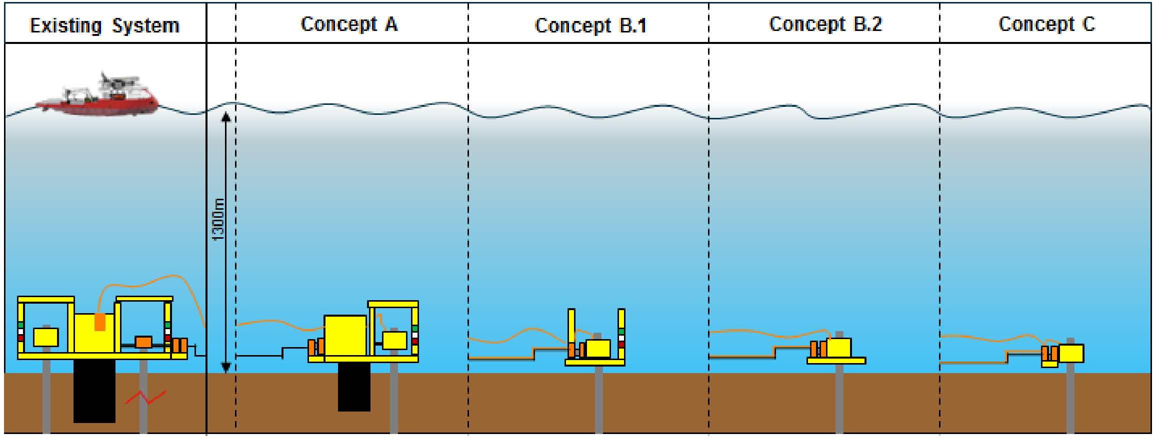


1. a fully spec compliant solution
2. a minimal low-cost solution

Application of the Tools

Illustrative ConOps:

- Create a common understanding of the concepts amongst project personnel and stakeholders.
- Gather and display known vital information in an comprehensible way.
- Act as an early validation of the concepts.
- Reveal operational needs.



Illustrative ConOps

1. Operation sequence/step

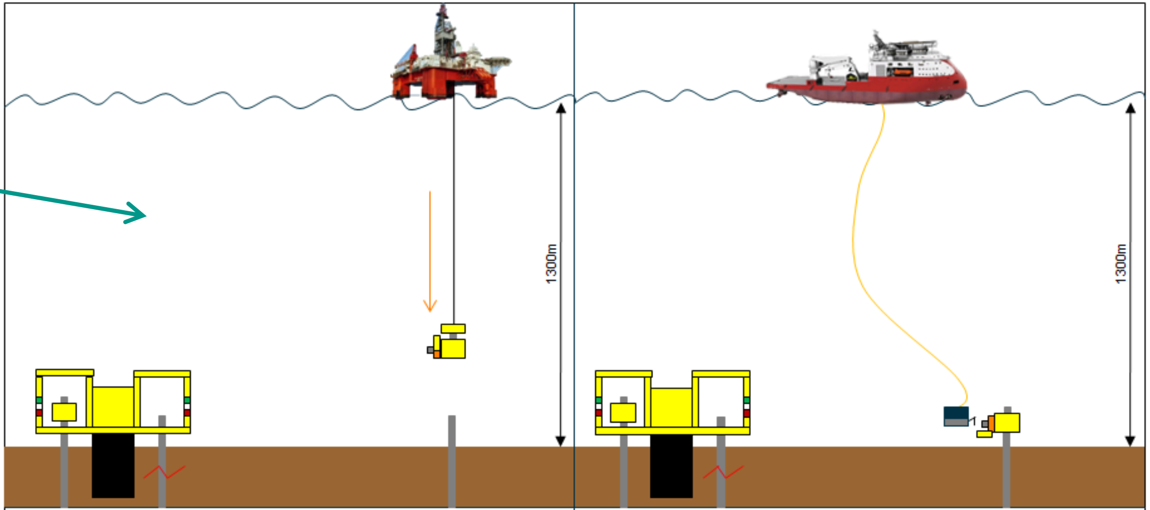
2. Simple illustration of the operation step

3. Short summary of operation step

4. Key information:
- Stakeholders
- Operation platform
- Constraints/opportunities
- Trigger words for discussion

3. Installation of XT on wellhead

4. Lower the foldable porch



Installation of modified XT. The XT is equipped with a foldable porch to accommodate the HCS connection. ROV may be required for guiding onto WH.

Operation platform: Drilling Rig or Vessel
Estimated operation Time: 12-19 Hours (TRT)
Stakeholders: Statoil, AKSO (WP04, SLS), Installation Contractor.
Keywords: Guiding onto WH. Orientation on WH. Installation tolerances.

The foldable landing porch for the HCS connection is lowered by ROV when the XT is connected and aligned.

Operation platform: Drilling Rig or Vessel
Estimated operation Time: 1 Hour
Stakeholders: Statoil, AKSO (WP02, WP03, WP08, WP10, SLS), Installation contractor.
Keywords: HCM/HCS modification. Guiding onto wellhead. Dropped object protection. Alignment.

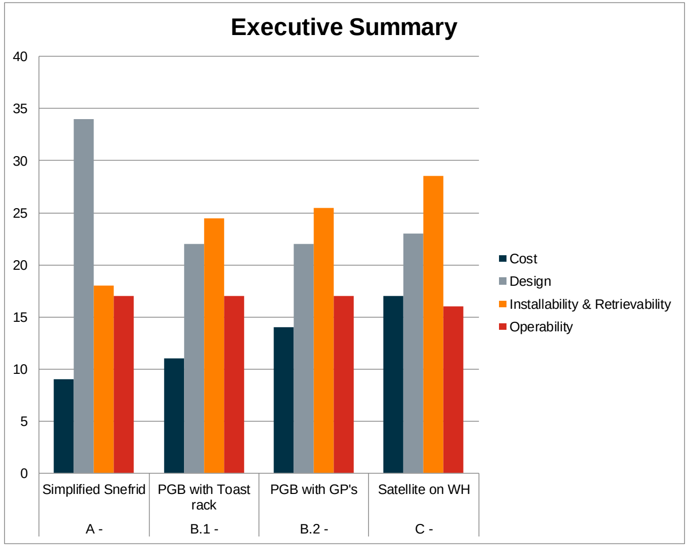
Pugh Matrix

User input

	Criteria	Priority setting	A Simplified Snefrid	B.1 PGB with Toast rack	B.2 PGB with GP's	C Satellite XT on WH
			Concepts			
Cost	Hardware Cost	High	2	3	4	5
Cost	Installation Cost	Standard	2	2	3	4
Cost	Operational Cost	Standard	3	3	3	3
Design	Engineering hours (Amount of new engineering, re-use, analysis)	Standard	5	3	3	2
Design	Design familiarity (Is the design known in AkSo? Previously delivered?)	Standard	4	2	3	3
Design	Requirement compliance	Standard	5	4	3	2
Design	Deliverytime from call-off (Long lead items, fabrication time)	High	3	3	3	4
Design	Amount of new qualifications (TQP's)	High	5	2	2	2
Design	On-shoreTestability (Availability of necessary equipment and procedures)	Standard	4	3	3	4
Installability & Retrievability	Number of installation runs required	Standard	1	2	2	5
Installability & Retrievability	Installation time	Standard	1	2	3	4
Installability & Retrievability	Weather vulnerability (Metocean constraints, Hs)	Low	2	4	4	4
Installability & Retrievability	Need for special tools	Low	4	3	3	3
Installability & Retrievability	Guide system robustness	High	4	4	3	2
Installability & Retrievability	Size of vessel required (Rig, heavy lift vessel, installation vessel)	Standard	1	2	3	5
Installability & Retrievability	Weight & Size	Standard	1	3	4	5
Installability & Retrievability	Retrieval flexibility of equipment	Standard	3	4	4	2
Operability	ROV access	Standard	3	4	4	4
Operability	Flow assurance (Hydrate/Scale, pipeline friction, pressure bleed-off)	Standard	3	3	3	3
Operability	Dewatering & start-up (Service access, injection points, etc.)	Standard	3	4	4	4
Operability	Reliability	Standard	3	4	4	4
Operability	Interchangeability	Standard	5	2	2	1
	Indicating summary:		**78**	**74,5**	**78,5**	**84,5**

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

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



Conclusions

- **USN-NISE students** in Oil & Gas performed a significant amount of **research in systems engineering**
- **Systems Engineering Management** is **"hot"** in Oil & Gas
- **Systems Architecting, Design, and Integration** requires attention from Oil & Gas
- **Simple means** (e.g. low effort), such as SMART requirements, Pugh Matrix, ConOps, A3s, and Conceptual Modeling **are effective** (most excuses are invalid)
- However, **introduction** is still **challenging**

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- ~80 IM students in Oil&Gas doing their master project at USN

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And 8 more master projects in Oil and gas at http://gaudisite.nl/MasterProjectPapers.html