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

# Managing Installation Tolerances through System Modeling and Tolerance Budgeting

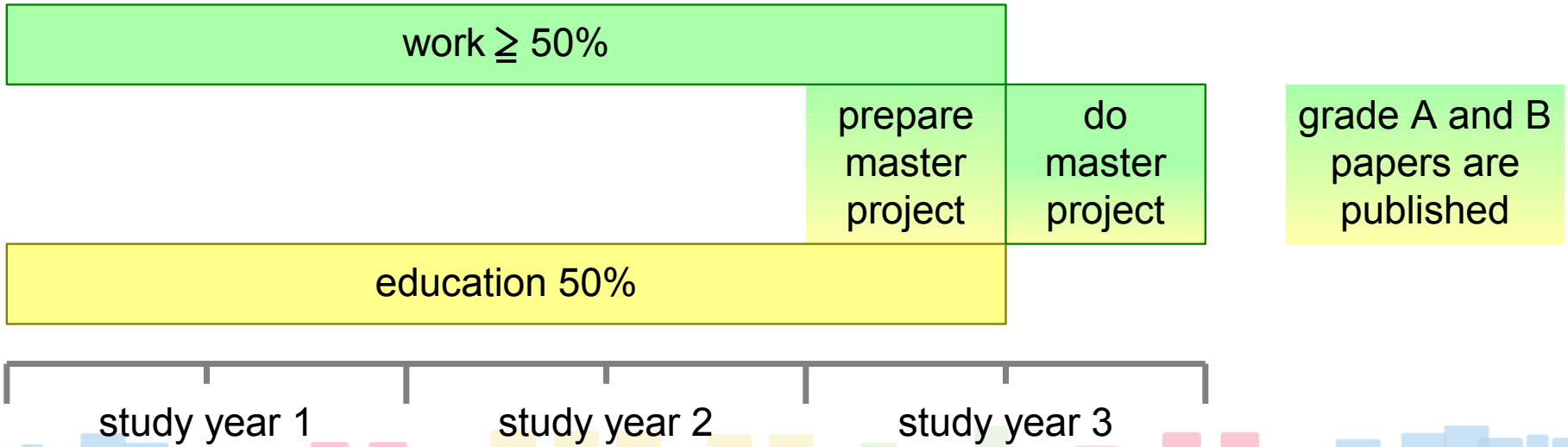
*Thomas Henanger – Aker Solutions*
*Gerrit Muller – HSN-NISE*
*Luca Piciaccia- Aker Solutions*

# Research Model Master Students Systems Engineering in Kongsberg, Norway

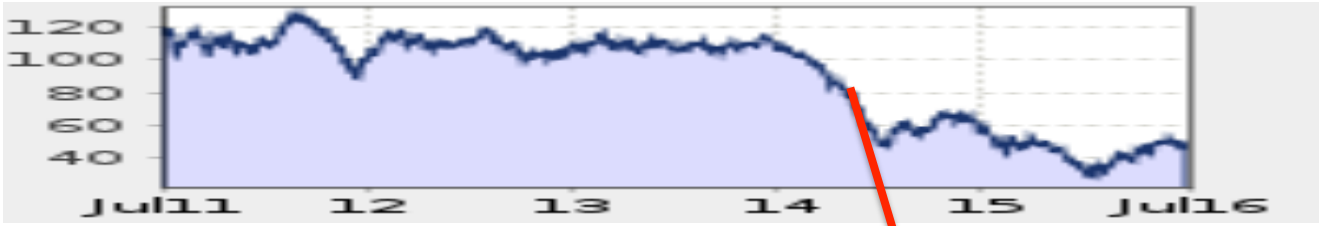
26th annual INCOSE international symposium
Edinburgh, UK
July 18 - 21, 2016

students know:
+ domain
+ SE methods and techniques

students:
+ apply
+ reflect
+ evaluate



# Context: Low oil prices hit Norway hard.

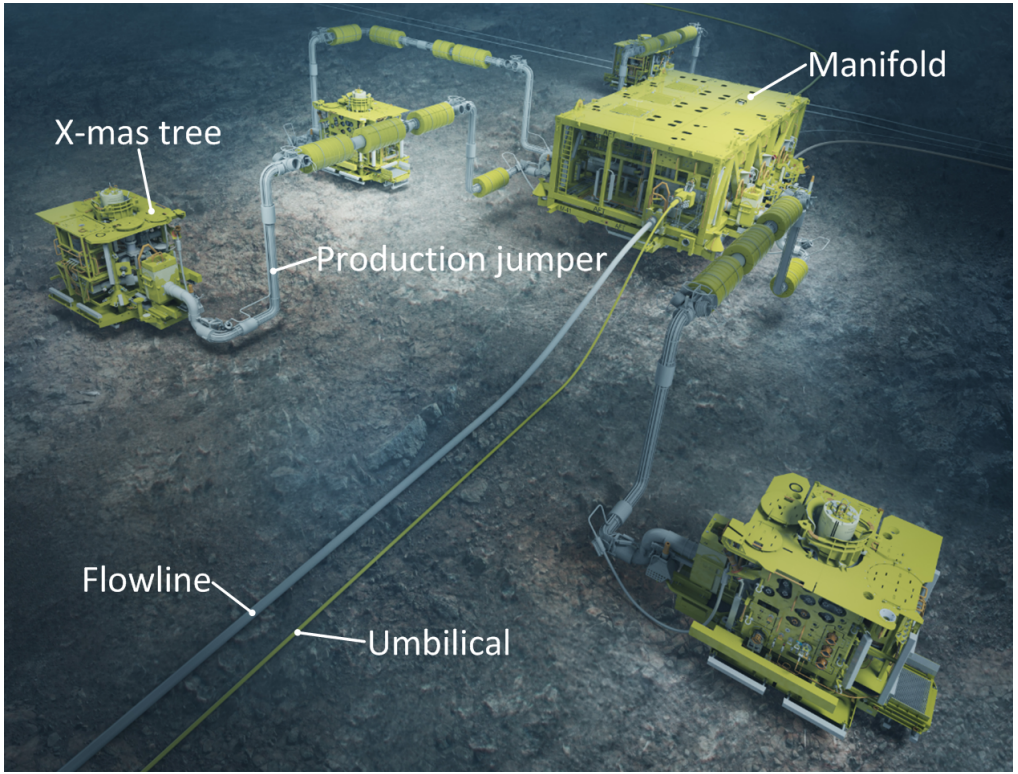



oil price

From oil-price.net


Norwegian Unemployment rate

# Subsea production system overview



# The Company Aker Solutions



- Aker Solutions (AKSO) is a Norwegian supplier of products and systems to the international offshore oil and gas industry.
- AKSO has approximately 17 000 employees
- in about 20 countries,
- and had a revenue of 33 billion NOK in 2014

# Problem statement

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

Late discovery of design errors -> increased cost.

The worst-case scenario is identifying an error during the installation phase that endangers safe installation.

The installation of the system on the seabed normally requires multiple vessels and rigs, which are often on a tight schedule. This is an expensive phase for the operators.

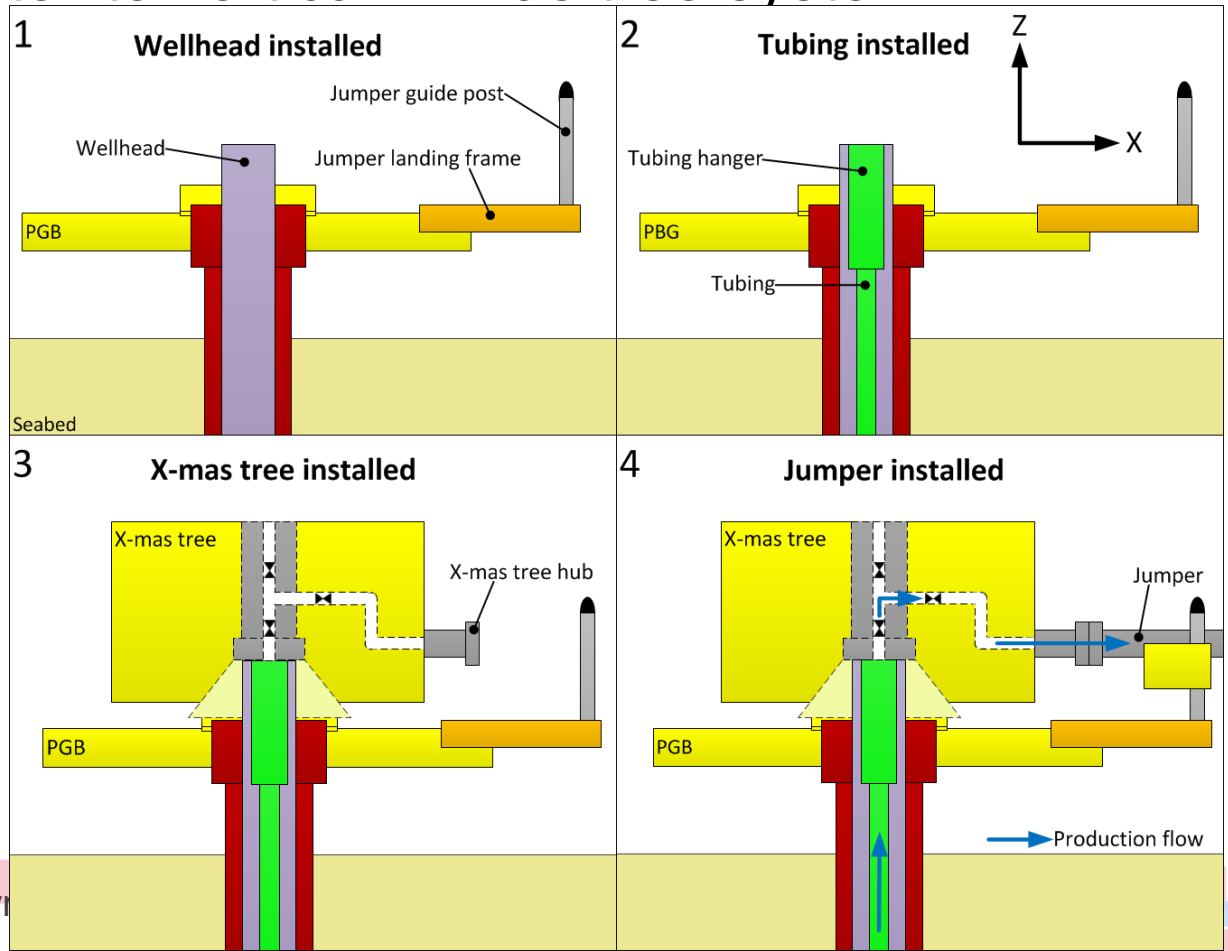
An error in installation tolerances, which stops the installation, would cause delay in schedules and serious cost impacts.

The potential consequences of errors in **installation tolerances**, demands a thorough process of **managing and verifying** them during **early engineering** phases.

# Research questions

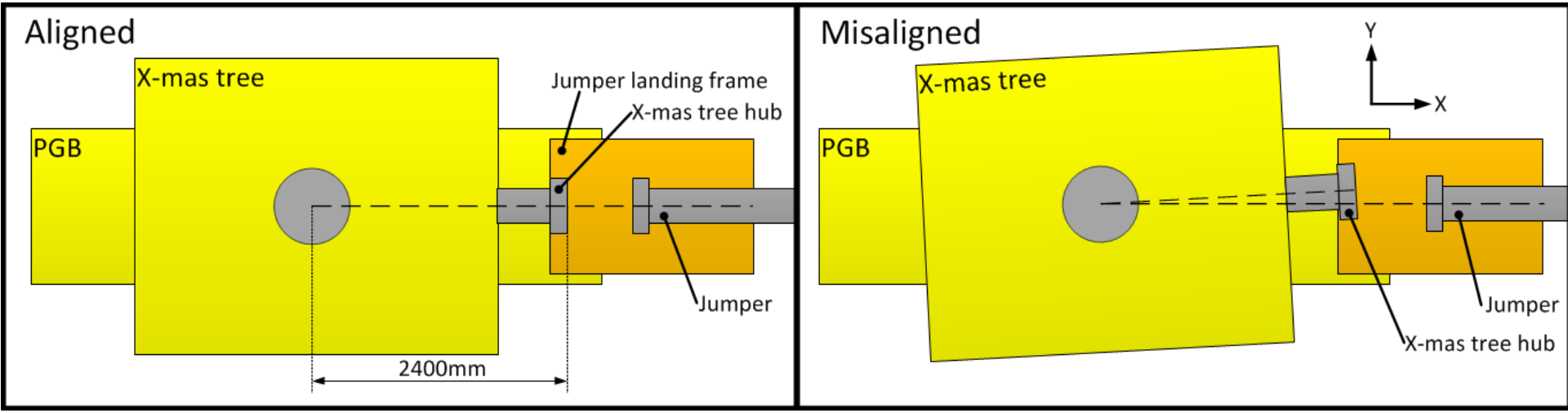
- Will experienced personnel accept models and tolerance budget as credible verification?
- Do models and tolerance budgets provide the required knowledge for an engineer familiar with the system of interest to understand the tolerance view?

# Simplified installation sequence of satellite vertical X-mas tree system



# Top view of vertical X-mas tree aligned and misaligned



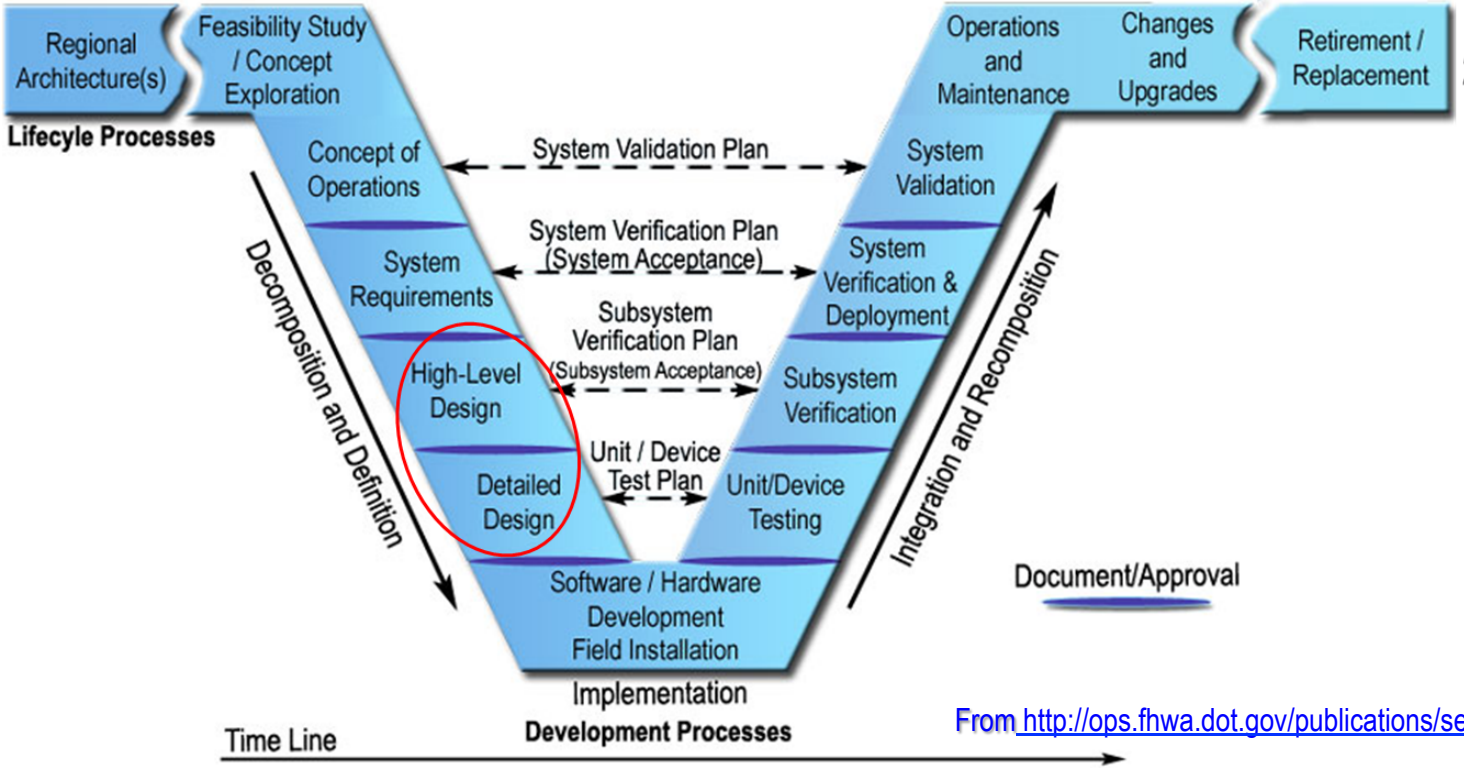


# Current way of managing tolerances

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

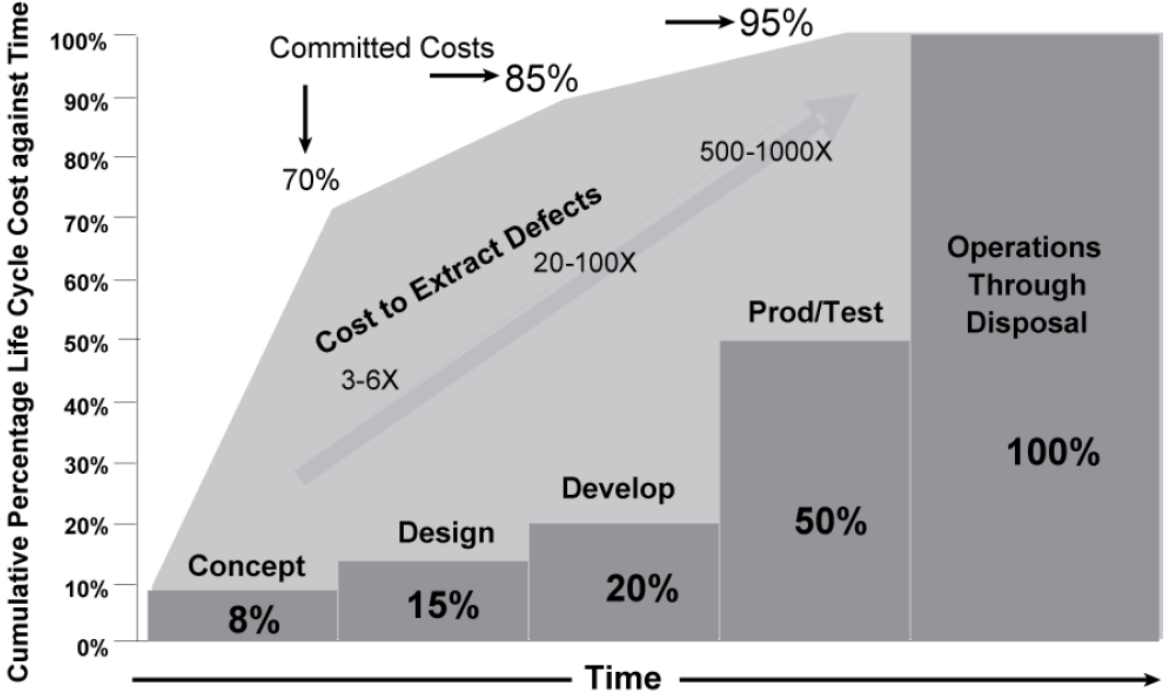
- machining and fabrication tolerances
  - when developing drawings
  - These drawings normally come from calculations and experience on what is possible and required to manufacture,
  - as well as industry standards. The machining and fabrication tolerances are largely standardized
- installation tolerances
  - shared responsibility between the product groups through the interface management
- Use of **tolerance budgets** as a tool to verify tolerances exist to some extent in various approaches in AKSO, but not under a governing procedural umbrella.

# V-model




From http://ops.fhwa.dot.gov/publications/seitsguide/section3.htm

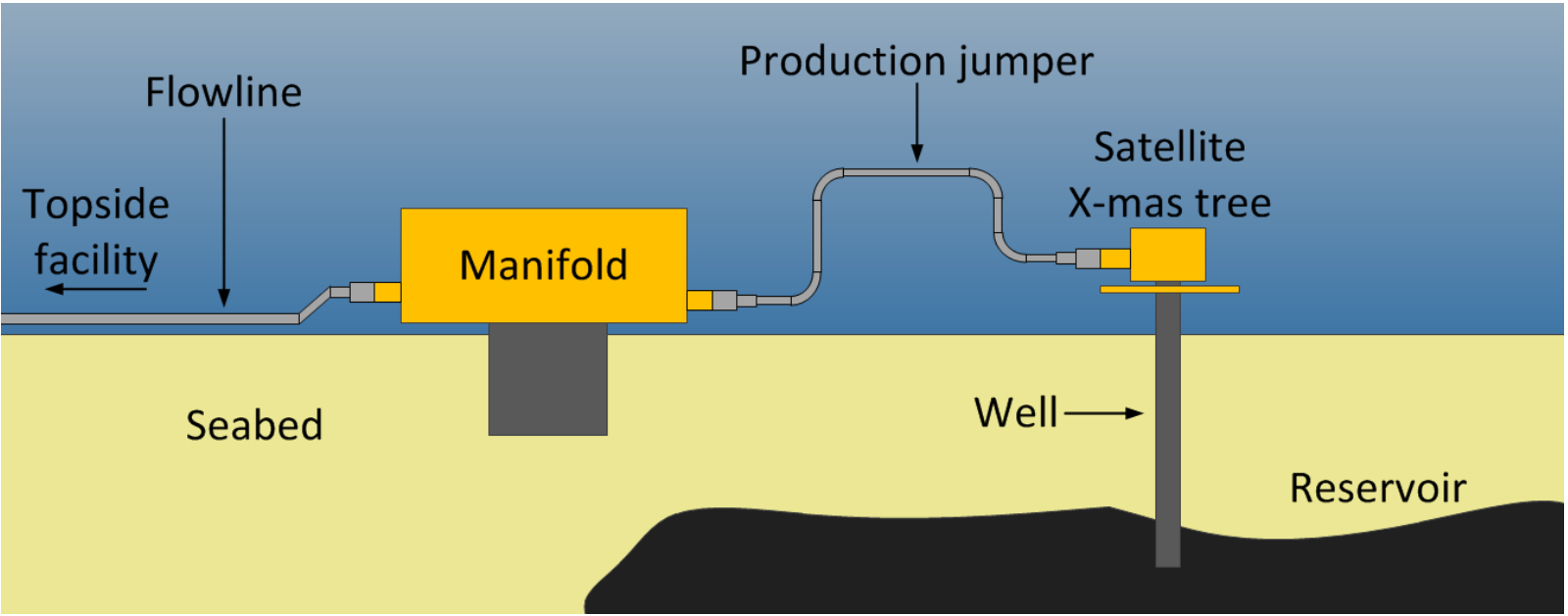
# Committed Life-cycle Cost against Time




From: Systems Engineering Handbook

# System Modeling

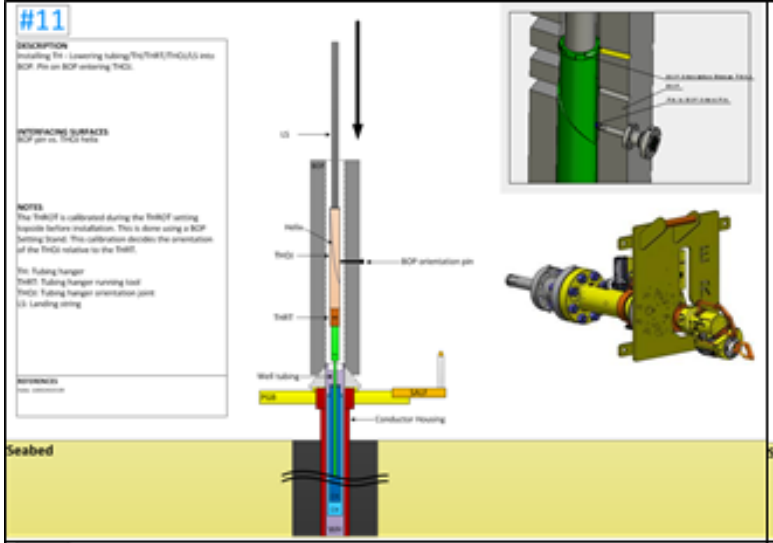


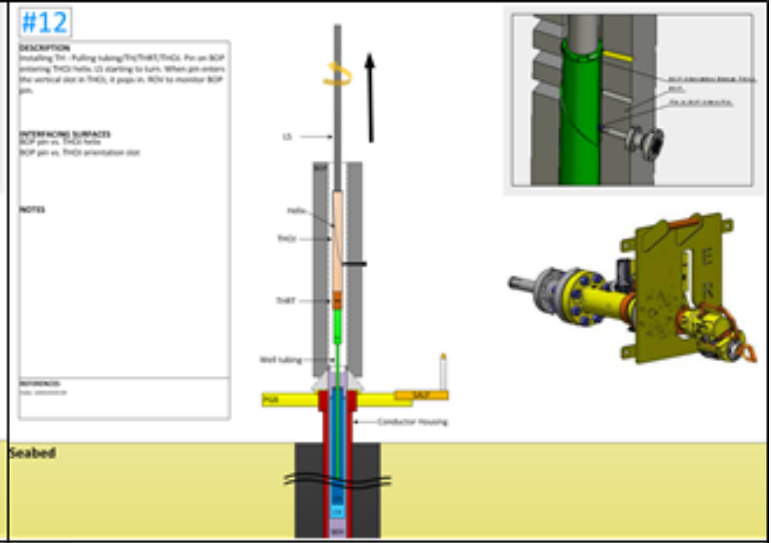


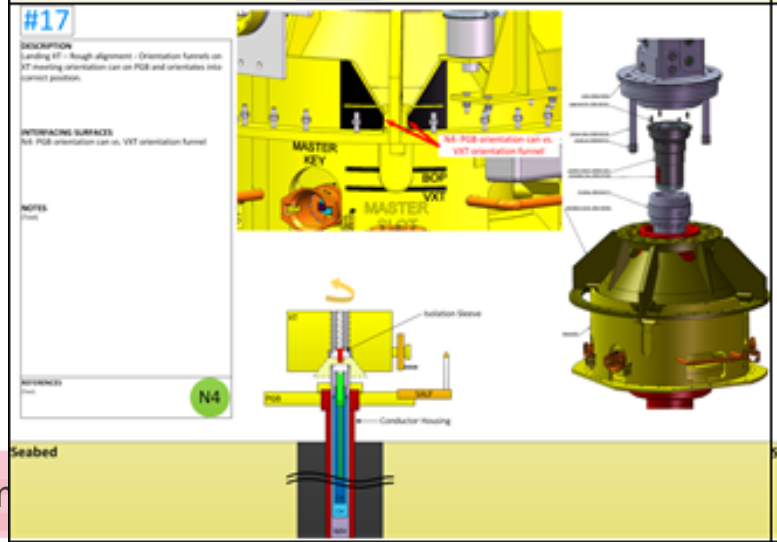
# Technical Budgeting

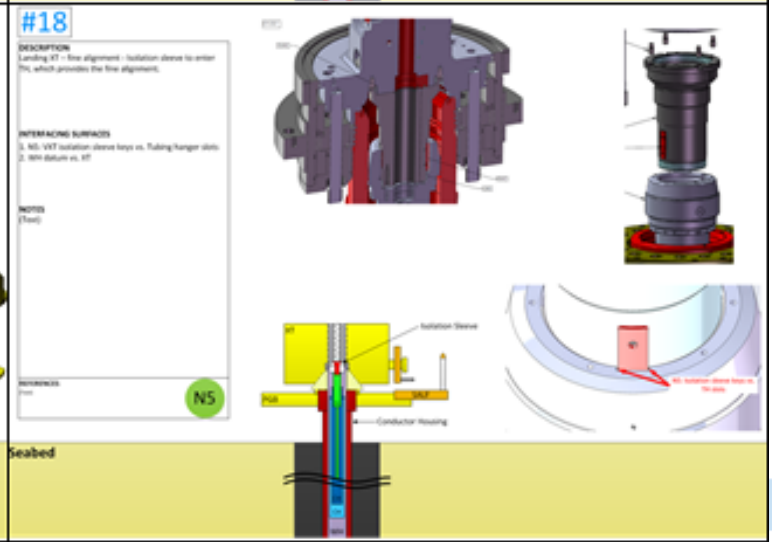
- To make the design more explicit.
- To provide a baseline for taking design decisions.
- To specify the requirements for the detailed design of the components.
- To have guidance during integration.
- To be a baseline for verification.
- To manage the design margins explicitly.

# Extract from system model of installation sequences

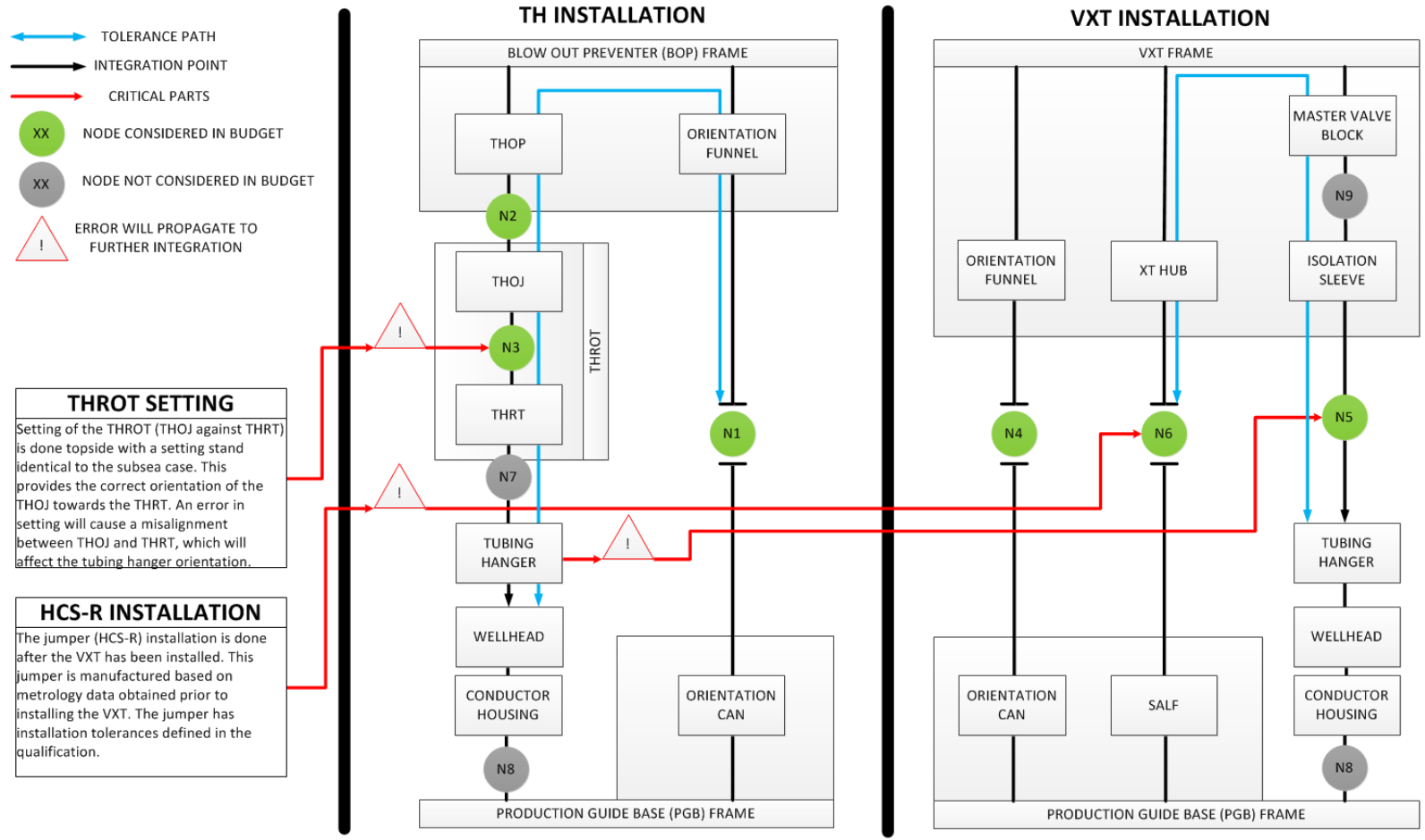


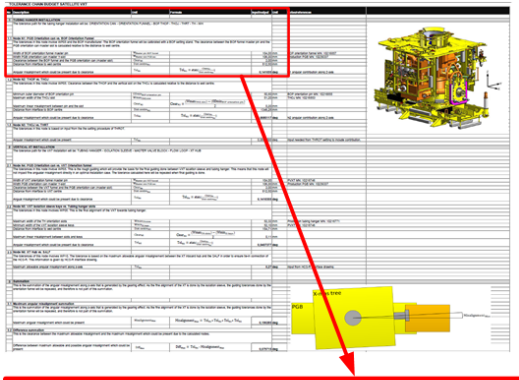



# Tolerance chain block diagram



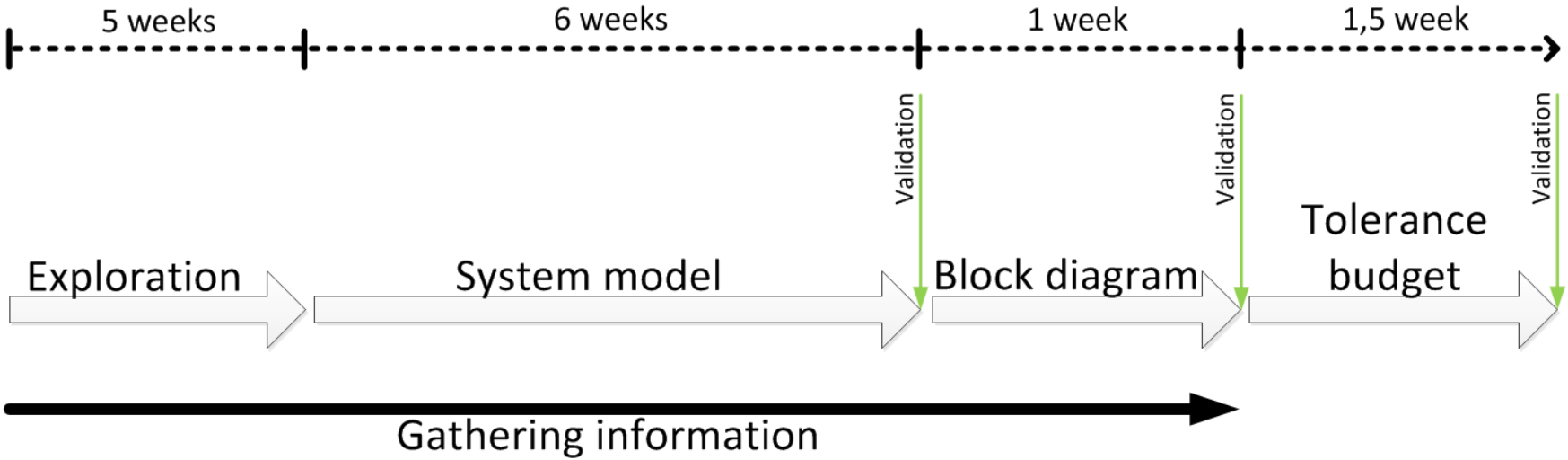
# Layout and extract of the tolerance budget



| No | Description | Unit | Formula | Input/output | Unit |
|---|---|---|---|---|---|
| 1 | **TUBING HANGER INSTALLATION** | | | | |
| | The tolerance path for the tubing hanger installation will be: ORIENTATION CAN - ORIENTATION FUNNEL - BOP THOP - THOJ - THRT - TH - WH | | | | |
| 1.1 | **Node N1: PGB Orientation can vs. BOP Orientation Funnel** | | | | |
| | The tolerances in this node involve WP05 and the BOP manufacturer. The BOP orientation funnel will be calibrated with a BOP setting stand. The clearance between the BOP funnel master pin and the PGB orientation can master slot is calculated relative to the distrance to well centre. | | | | |
| | Width of BOP orientation funnel master pin | $W_{\text{Master pin BOP funnel}}$ | | | mm |
| | Width PGB orientation can master Y-slot | $W_{\text{Master slot PGB can}}$ | | | mm |
| | Clearance between the BOP funnel and the PGB orientation can (master slot) | $\text{Clear}_{N5}$ | | | mm |
| | Distance from interface to well centre | $\text{Dist centre}_{N1}$ | | | mm |
| | Angular misalignment which could be present due to clearance | $\text{Tol}_{N1}$ | $\text{Tol}_{N1} = \text{atan}(\frac{\text{Clear}_{N1}}{\text{Dist centre}_{N1}})$ | | deg |

# Time line for the systems engineering effort





# Interviews with stakeholders

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

- We discovered that the personnel from the different product groups had significant **differences in opinions** on the subject
- In addition, differences in **experience** within tolerance management and the system of interest among stakeholders caused challenges in differentiating the value of their opinions
- The interviews also identified **different views** among the personnel regarding the **value of** our **systems engineering** effort
- as well as the general **methodology** of **tolerance management**
- it was sometimes difficult to speak the same tolerance **language** with the interviewed personnel
- The definition of tolerances has **different meanings** in the different product groups.

# Financial Cost and Potential Risk Benefit

| Estimated time | Cost per engineering hour for operator | Estimated cost of effort for one engineer | Estimated cost of effort including involvement of additional resources |
|---|---|---|---|
| ~2 months = 315 h | ~1 000 NOK | ~315.000 NOK | ~350.000 NOK |

| Estimated minimum time before error is fixed | Day rate for one installation vessel | Estimated cost per week delay |
|---|---|---|
| ~1 week = 7 days | ~2.0 MNOK/day | ~14.0 MNOK |

# Conclusions



- The systems engineering effort had a positive impact on the process of managing installation tolerances.
- Value in preventing late verification of tolerances and possible late changes and errors during installation.
- The cost of such an effort is, in AKSO's case, insignificant relative to the cost accumulated by the preventable scenarios.
- Clear benefit in developing understanding and identifying critical integration steps of a system
  - An example is, that by using this technique as a screening-method at an early stage (before contract award), would help identify critical aspects where there is need for further investigation, and which possibly could trigger necessary design changes.
- Limited knowledge about the system tolerance view among respective product groups increases the risk not meeting tolerance requirements.
- Having one systems engineer coordinating the tolerance management from the start, with support from dedicated engineers in the product groups, may aid the process of developing a well-integrated system at the end.