Abstract

This is a course for bachelor students in their second year of their engineering study. The focus is on architectural reasoning: an agile architecting approach. The students also get a more traditional course in systems engineering following the V-model.
Course Program Architectural Reasoning

**Theory**
- Basic Ideas behind Architectural Reasoning
- Multi-view: CAFCR+
- Fundamentals of Systems Design and Engineering
- Story telling, Key drivers
- Life Cycle
- Business Economics

**Class-work**
- Case Exploration
- Case Elaboration FCR
- Case Elaboration CA
- Case Elaboration Life Cycle

**Homework**
- Consolidation
- Final Consolidation
Make engineering students aware of:

- other disciplines
- “systems” design and engineering
- customers and life cycle as contexts of the system
- the impact of needs on design decisions
Objectives of Module Architectural Reasoning: Experience

Let engineering students apply and experience:

- multiple views
- visualizations
- simplification
- iteration
- quantification
Bachelor Course Systems Engineering: Architectural Reasoning;
Homework

http://www.gaudisite.nl/BachelorSEhomeworkSlides.pdf
Theory Block: The Basic Ideas behind Architectural Reasoning

We are going to stretch you!

from mono engineer
to systems engineer
to architect
Why so chaotic?

Why not follow top-down SE process?
Waterfall model

- identify needs
- specify
- design
- realize
- integrate
- verify & validate

works well:
- in mature product-market combinations
- with long development cycles

works poorly:
- in new product-market combinations
- short development cycles
Concurrent Engineering

- identify needs
- specify
- design
- realize
- integrate
- verify & validate

- total development time is shorter
- technology constraints & opportunities take time to get in the picture
- validation is still late (=feedback on uncertain requirements)

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BSEARconcurrentEngineering
Iterative Approach

- identify needs
- specify
- design
- realize
- integrate
- verify & validate

Learn fast by iterating over needs and technology
- more chaotic
- requires agile mindset

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BSEARiterativeApproach
You study mono-disciplinary engineering

mono-disciplinary engineering

- software engineering
- electrical engineering
- mechanical engineering

specify
design
model, analyse,
partition, interfaces, etc.
coding & CADing
testing
Huge differences in language and way of thinking

- software engineering
- electrical engineering
- mechanical engineering

- embedded systems
- control engineering
- materials and mechanics

**completely different world views**

- virtual world
- intangible
- software and digital hardware

- actuate
- sense

- physical world
- physics laws and constraints
  - e.g. noise, vibrations, turbulence, friction,
Multi-disciplinary design and engineering

**multi-disciplinary design**

**specify** concept and technology selection, allocation, budgetting, etc.  

**design** part specification, design, coding & CADing, testing  

**test & integrate**
Architecting: Fit-For-Purpose

market and customer context
life cycle context

system architecting
multi-disciplinary design

understand context
analyse needs
specify system
explore design options
design, engineer, build, test
validate & verify

mono-disciplinary engineering
software engineering
electrical engineering
mechanical engineering

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BSEARarchitecting
Delivery at the end of this module
More specific deliveries

<table>
<thead>
<tr>
<th>Value Proposition</th>
<th>Business Proposition</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Why does customer want to buy?</em></td>
<td><em>How do we earn money?</em></td>
</tr>
<tr>
<td><em>Why do users like to use the system?</em></td>
<td><em>How do we run a healthy business?</em></td>
</tr>
<tr>
<td>- customer key drivers</td>
<td>- life cycle key drivers</td>
</tr>
<tr>
<td>- cost of ownership</td>
<td>- business model</td>
</tr>
<tr>
<td>- customer business analysis</td>
<td>- cash flow analysis</td>
</tr>
<tr>
<td>- customer stakeholders and concerns</td>
<td>- life cycle stakeholders and concerns</td>
</tr>
<tr>
<td>- story or scenario</td>
<td>- life cycle model</td>
</tr>
<tr>
<td>- context diagram</td>
<td>- supply chain</td>
</tr>
<tr>
<td>- work flow or ConOps</td>
<td>- organization chart</td>
</tr>
<tr>
<td>- plan</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System Specification</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>What does customer get?</em></td>
<td><em>How will we realize this specification?</em></td>
</tr>
<tr>
<td><em>What is the system-of-interest that we deliver?</em></td>
<td><em>How do we ensure performance, safety, robustness, etc.?</em></td>
</tr>
<tr>
<td>- functions</td>
<td>- partitioning and interfaces</td>
</tr>
<tr>
<td>- qualities (e.g. quantified performance)</td>
<td>- dynamic behavior, e.g. functional model</td>
</tr>
<tr>
<td>- interfaces</td>
<td>- performance budgets</td>
</tr>
<tr>
<td>- constraints, standards, regulations</td>
<td>- concept and technology selection</td>
</tr>
<tr>
<td></td>
<td>- make or buy, supplier selection</td>
</tr>
</tbody>
</table>
A time-box is a fixed amount of time allocated to perform one activity.

We iterate many times over different viewpoints. Every viewpoint is addressed multiple times with new insights from other viewpoints.
Rationale behind Time-boxing and Iteration

Learn faster by “sampling” and seeing multiple perspectives

Identify the most relevant issues as early as possible

A time-box is always too short

A specification, design, model, or analysis is never complete or finished

With many uncertainties and unknowns it does not make sense to be perfect

After some time progress slows down; it is more efficient to switch topic

Every view needs feedback from other views

Long time-boxes can waste lot of time

“wasting” a time-box is no problem when it is short and when you learn
Theory Block: CAFCR

You need multiple views on a system
CAFCR defines 5 views
CAFCR+ adds one more view
The “CAFCR” model

- What does Customer need in Product and Why?
  - Customer What
  - Customer How
  - Product What
  - Product How

- Customer objectives
- Application
- Functional
- Conceptual
- Realization

drives, justifies, needs
enables, supports
What does Customer need in Product and Why?

Customer

What

Customer objectives

How

Application

Product

What

Functional

Conceptual

Realization

context

intention

objective
driven

opportunities

constraint

knowledge

awareness

based
CAFCR can be applied recursively

System (producer)

Customer Business

Customer's Business

Customer Drives

Enables

Consumer Drives

Enables

Value Chain

larger scope has smaller influence on architecture

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CAFCR recursion
CAFCR+ model; Life Cycle View

Customer objectives  Application  Functional  Conceptual  Realization

Life cycle operations
maintenance upgrades
development manufacturing installation

sales, service, logistics, production, R&D
Stakeholders and Concerns

- government
  - cost of care

- general practitioner
  - patient

- patient
  - comfort
  - health

- family
  - support

- IT dep.
  - conformance
  - security

- financial dir.
  - cash flow
  - cost of op.

- ref. physician
  - diagnosis
  - treatment

- radiologist
  - diagnosis
  - reimbursement

- nurse
  - patient
  - ease of work

- inspection
  - quality

- facility man.
  - space
  - service supp.

- maintainer
  - accessibility
  - safety

- cleaner
  - accessibility
  - safety

Legend:
- administrative
- clinical
- patient
- support
Case Exploration

Theory
- Basic Ideas behind Architectural Reasoning
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- Final Consolidation
Find an empty classroom and take the following with you:

- ~5 empty flipover sheets
- a set of 4 pens
- a block of yellow note stickers

Return leftovers to my office (D345) at the end of the day.

email Gerrit.Muller and Jamal.Safi the room number at their HBV email address, when you have found a classroom.
Use time-boxes of 15 minutes and perform the following steps:

- Sketch the system-of-interest and its immediate context
  - Annotate the sketch (e.g. main components, interfaces, functions, …)
- Draw an initial design
- Make a specification of the system-of-interest (view it as a blackbox)
  - What functionality, performance, interfaces, standards or regulations
- Identify the main customer stakeholders and their concerns
- Identify the main life cycle stakeholders and their concerns
- Review and make a plan to consolidate in a presentation
## Some recommendations

<table>
<thead>
<tr>
<th><strong>Do</strong></th>
<th><strong>Do not</strong></th>
<th><strong>Because</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• start sketching/drawing as soon as possible</td>
<td>• write long texts .</td>
<td>• sketches stimulate sharing and discussion</td>
</tr>
<tr>
<td>• use shared large sheets of paper (e.g. flip-over)</td>
<td>• immediately capture electronic</td>
<td>• sharing and discussion help to explore faster</td>
</tr>
<tr>
<td>• number the flip-overs and add a title</td>
<td>• have nice but volatile discussions</td>
<td>• remembering the order gets challenging</td>
</tr>
<tr>
<td>• annotate (add notes) during discussions</td>
<td>• write with pen or pencil</td>
<td>• information and insight is quickly lost</td>
</tr>
<tr>
<td>• use yellow note stickers and flip-over markers</td>
<td>• Do not stick to the first solution</td>
<td>• stickers are easily (re)moved</td>
</tr>
<tr>
<td>• be open for ideas and surprises</td>
<td></td>
<td>• you hopefully discover a lot; increased insight will change problem and solution</td>
</tr>
</tbody>
</table>

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BSEARdoAndDont

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1. sketch the system-of-interest and its context
2. draw an initial design
3. make a specification
4. identify customer stakeholders
5. identify life cycle stakeholders
Theory Block: Fundamentals of Systems Design and Engineering

System Designers and Engineers

Partition (decompose)

Model Dynamic Behavior (functions)

Quantify

Allocate and budget

Select concepts
Partitioning is Applied Recursively
Possible Visualizations of Partitioning

Choose a visualization from below

**HW block diagram**

- GPS
- CAN master
- ARM CPU
- 256MB DDR III
- CAN
- gyros
- DL2128V
- 8 12 bit DA

**SW layer diagram**

- view
- PIP
- adjust
- view
- TXT
- browse
- network
- file-system
- audio
- video
- TXT
- etc.
- drivers
- scheduler
- OS
- CPU
- RAM
- etc.

**2D or 3D layout of system**

- primary engine
- transmission
- batteries
- fuel tank

**abstract graph**

- car
  - main engine
  - drive train
  - electric
  - chassis
  - transmission
  - clutch
Partitioning Dominates Many Processes

- engineering
  - parts data base
  - production procedures
  - qualification procedures
  - system documentation
  - procurement
  - production
  - installation
  - quality assurance
  - lifecycle support

- CAD
  - mechanical electrical design database

- SCM
  - source code management

- ERP
  - resource planning, e.g. SAP

- PDM
  - product data management

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BSDCaseOfPartitioning
Theory of Partitioning

- the part is cohesive
- functionality and technology belongs together
- the coupling with other parts is minimal
- minimize interfaces
- the part is selfsustained for production and qualification
- can be in conflict with cost or space requirements
- clear ownership of part
- e.g. one department or supplier
Decoupling via Interfaces

- Part e.g. pipe
- Control interface e.g. CAN
- Power interface e.g. CAN
- Mechanical mounting interface
- Hydrocarbon interface
- Other part with same interfaces can replace original

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SPFInterfaceDecoupling
Simplistic Functional SubSea Example

- **Prevent blow-outs**
- **Regulate flow and pressure**
- **Combine multiple streams**
- **Separate gas, oil, water, sand**
- **Increase well pressure**
- **Sensor signals**
- **Measure pressure, temp, flow**
- **Control pressure, temp, flow**
- **Settings**
- **Transport to top-side**
- **Hydrocarbons**
- **Water sand**
Functional Decomposition

How does the system work and operate?

Functions describe *what* rather than *how*.

Functions are *verbs*.

Input-Process-Output paradigm.

Multiple kinds of flows:
- physical (e.g. hydrocarbons)
- information (e.g. measurements)
- control

At lower level one part \( \sim \) one function
- pump pumps, compressor compresses, controller controls

At higher level functions are complex interplay of physical parts
- e.g. regulating constant flow, pressure and temperature
### Quantification

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>2.4m * 0.7m * 1.3m</td>
</tr>
<tr>
<td>Weight</td>
<td>1450 Kg</td>
</tr>
<tr>
<td>Cost</td>
<td>30000 NoK</td>
</tr>
<tr>
<td>Reliability</td>
<td>MTBF 4000 hr</td>
</tr>
<tr>
<td>Throughput</td>
<td>3000 l/hr</td>
</tr>
<tr>
<td>Response time</td>
<td>0.1 s</td>
</tr>
<tr>
<td>Accuracy</td>
<td>+/- 0.1%</td>
</tr>
</tbody>
</table>

Many characteristics of a system, function or part can be quantified. Note that quantities have unit.
The System-of-interest as Black Box

inputs

functions
quantified characteristics

restrictions, prerequisites
boundaries, exceptions
standards, regulations

interfaces

outputs

system seen as black box
Key Performance Parameters are **SMART** defined in use case: the circumstances where the performance is valid
typical use with relevant (quantified!) context data

- **S**pecific (quantified)
- **M**easurable (verifiable)
- **A**chievable (Attainable, Action oriented, Acceptable, Agreed-upon, Accountable)
- **R**ealistic (Relevant, Result-Oriented)
- **T**ime-bounded (Timely, Tangible, Traceable)
How about the `<characteristic>` of the `<component>` when performing `<function>`?

What is the **accuracy** of the **fuse** when **printing**?

example from a high volume printer
# Concept Selection via Pugh Matrix

## Swivel concept selection

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Weight</th>
<th>CBV</th>
<th>Clamp</th>
<th>Dynamic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maturity</td>
<td>10</td>
<td>5</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>Development level</td>
<td></td>
<td>2</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Cost</td>
<td>20</td>
<td>4</td>
<td>80</td>
<td>2</td>
</tr>
<tr>
<td>Hardware cost</td>
<td></td>
<td>4</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>Development cost</td>
<td></td>
<td>100</td>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>Design robustness</td>
<td>25</td>
<td>5</td>
<td>125</td>
<td>3</td>
</tr>
<tr>
<td>Design life</td>
<td></td>
<td>75</td>
<td>125</td>
<td>3</td>
</tr>
<tr>
<td>Swivel cycles</td>
<td></td>
<td>125</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>Pressure cycles</td>
<td></td>
<td>4</td>
<td>125</td>
<td>100</td>
</tr>
<tr>
<td>Pressure range</td>
<td></td>
<td>4</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Internal</td>
<td></td>
<td>2</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>External</td>
<td></td>
<td>5</td>
<td>125</td>
<td>4</td>
</tr>
<tr>
<td>Temperature range</td>
<td></td>
<td>2</td>
<td>50</td>
<td>4</td>
</tr>
<tr>
<td>Installation</td>
<td>20</td>
<td>2</td>
<td>40</td>
<td>3</td>
</tr>
<tr>
<td>Initial install &amp; retrieval</td>
<td></td>
<td>4</td>
<td>80</td>
<td>3</td>
</tr>
<tr>
<td>Connection/disconnection</td>
<td></td>
<td>4</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>Operation</td>
<td>25</td>
<td>1</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>Swivel resistance</td>
<td></td>
<td>100</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>Spool Length Short</td>
<td></td>
<td>5</td>
<td>125</td>
<td>4</td>
</tr>
<tr>
<td>Spool Length Long</td>
<td></td>
<td>75</td>
<td>125</td>
<td>5</td>
</tr>
<tr>
<td>Hub loads</td>
<td></td>
<td>50</td>
<td>125</td>
<td>4</td>
</tr>
<tr>
<td>Sum points</td>
<td></td>
<td>985</td>
<td>1165</td>
<td>1290</td>
</tr>
</tbody>
</table>

## EDP-LRP connection

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>CBV</th>
<th>Clamp</th>
<th>Dynamic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to connect</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Need for ROV</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Design</td>
<td>-</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Number of parts</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Handle roll-off</td>
<td>+</td>
<td>-</td>
<td>S</td>
</tr>
<tr>
<td>Influence other</td>
<td>+</td>
<td>S</td>
<td>-</td>
</tr>
<tr>
<td>Redundancy</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Design</td>
<td>+</td>
<td>-</td>
<td>S</td>
</tr>
<tr>
<td>Interchangeability</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cost</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HW cost</td>
<td>S</td>
<td>S</td>
<td>-</td>
</tr>
<tr>
<td>Manufacturing cost</td>
<td>+</td>
<td>-</td>
<td>S</td>
</tr>
<tr>
<td>Engineering cost</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Service cost</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Maturity</td>
<td>-</td>
<td>S</td>
<td>+</td>
</tr>
<tr>
<td>Sum</td>
<td>7</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Score</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

## Evaluation

- **CBV swivel**
- **Clamp swivel**
- **Dynamic**

---

*from master paper Halvard Bjørnsen, 2009*

*from master paper Dag Jostein Klever, 2009*
Case Elaboration FCR-views

Theory
- Basic Ideas behind Architectural Reasoning
- Multi-view: CAFCR+
- Fundamentals of Systems Design and Engineering
- Story telling, Key drivers
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Homework
- Consolidation
- Final Consolidation
Start second iteration by elaborating FCR views

Use time-boxes of about 30 minutes

- Decompose the system in subsystems, decompose one subsystem in subsubsystems.
  - Show the subsystems and interfaces in a block diagram
- Make a functional model of the internals of the system-of-interest
  - Use one or more diagrams to show the dynamic behavior
- Define 5..10 Key Performance Parameters of the system-of-interest
  - Define a use case to support the definition of KPPs
- Make a technical budget for one of the key performance parameters
- Review and make a plan to consolidate in a presentation
Class-work Day 2 mapped on CAFCR

1. sketch the system-of-interest and its context
2. draw an initial design
3. make a specification
4. identify customer stakeholders
5. identify life cycle stakeholders
6. partitioning and interfaces
7. make functional design
8. define key performance
9. make performance budget

Customer objectives
Application
Functional
Conceptual
Realization
Life cycle
Story Telling and Key Drivers

Theory
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Theory Block: Understanding Customers

Story telling

Customer Key Driver Graph

Context
Abstract

A story is an easily accessible story or narrative to make an application live. A good story is highly specific and articulated entirely in the problem domain: the native world of the users. An important function of a story is to enable specific (quantified, relevant, explicit) discussions.
From story to design

What does Customer need in Product and Why?

Customer
What

Customer
How

Product
What

Product
How

Customer
objectives

Application

Functional

Conceptual

Realization

market
vision

story

analyze
design

case

analyze
design

design

a priori solution knowledge

version: 1.1
January 26, 2015
SHTfromStoryToDesign
A day in the life of Bob

This brilliant invention will change the world forever because it is so unique and valuable that nobody believes the feasibility. It is great and WOW at the same time, highly exciting.

Vtables are seen as the solution for an indirection problem. The invention of Bob will obsolete all of this in one incredible move, which will make him famous forever.

He opens his PDA, logs in and enters his private secure unique non trivial password, followed by a thorough authentication. The PDA asks for the fingerprint of this little left toe and to pronounce the word shit. After passing this test Bob can continue.
Points of attention

- purpose
- scope
- viewpoint, stakeholders
- visualization
- size (max 1 A4)
- recursive decomposition, refinement
Criteria for a good story

- accessible, understandable
  "Do you see it in front of you?"
- valuable, appealing
  attractive, important
  "Are customers queuing up for this?"
- critical, challenging
  "What is difficult in the realization?"
  "What do you learn w.r.t. the design?"
- frequent, no exceptional niche
  "Does it add significantly to the bottom line?"
- specific
  names, ages, amounts, durations, titles, ...
Betty is a 70-year-old woman who lives in Eindhoven. Three years ago her husband passed away and since then she lives in a home for the elderly. Her 2 children, Angela and Robert, come and visit her every weekend, often with Betty's grandchildren Ashley and Christopher. As so many women of her age, Betty is reluctant to touch anything that has a technical appearance. She knows how to operate her television, but a VCR or even a DVD player is way to complex.

When Betty turned 60, she stopped working in a sewing studio. Her work in this noisy environment made her hard-of-hearing with a hearing-loss of 70dB around 2kHz. The rest of the frequency spectrum shows a loss of about 45dB. This is why she had problems understanding her grandchildren and why her children urged her to apply for hearing aids two years ago. Her technophobia (and her first hints or arthritis) inhibit her to change her hearing aids' batteries. Fortunately her children can do this every weekend.

This Wednesday Betty visits the weekly Bingo afternoon in the meetingplace of the old-folk's home. It's summer now and the tables are outside. With all those people there it's a lot of chatter and babble. Two years ago Betty would never go to the bingo: “I cannot hear a thing when everyone babbles and clatters with the coffee cups. How can I hear the winning numbers?!”. Now that she has her new digital hearing instruments, even in the bingo cacophony, she can understand everyone she looks at. Her social life has improved a lot and she even won the bingo a few times.

That same night, together with her friend Janet, she attends Mozart's opera The Magic Flute. Two years earlier this would have been one big low rumbly mess, but now she even hears the sparkling high piccolos. Her other friend Carol never joins their visits to the theaters. Carol also has hearing aids, however hers only “work well” in normal conversations. “When I hear music it’s as if a butcher’s knife cuts through my head. It’s way too sharp!”. So Carol prefers to take her hearing aids out, missing most of the fun. Betty is so happy that her hearing instruments simply know where they are and adapt to their environment.
Value and Challenges in this story

Value proposition in this story:
quality of life:
  active participation in different social settings
usability for nontechnical elderly people:
  "intelligent" system is simple to use
  loading of batteries

Challenges in this story:
Intelligent hearing instrument
Battery life — at least 1 week
No buttons or other fancy user interface on the hearing instrument, other than a robust On/Off method
The user does not want a technical device but a solution for a problem
Instrument can be adapted to the hearing loss of the user
Directional sensitivity (to prevent the so-called cocktail party effect)
Recognition of sound environments and automatic adaptation (adaptive filtering)

source: Roland Mathijssen, Embedded Systems Institute, Eindhoven
Abstract

This presentation provides an example of modeling in the subsea domain.
The examples in this presentation are based on the work of SEMA participants: Martin Moberg\textsuperscript{a}, Tormod Strand\textsuperscript{a}, Vazgen Karlsen\textsuperscript{f}, and Damien Wee\textsuperscript{f}, and the master project paper by Dag Jostein Klever\textsuperscript{f}. Sensitive and confidential information is removed or obfuscated.

All mistakes are to be blamed to the author.

Gunnar Berge stimulated the creation of a subsea example.

\textsuperscript{a}Aker Solutions
\textsuperscript{f}FMC Technologies
On September 4, Captain Frode Johansen was discussing the plans for the upcoming workover of South Gulfaks (see http://www.npd.no/en/Publications/Facts/Facts-2011/Chapter-10/Gullfaks-Sor/) with his crew. Their vessel had been out of operation for recertification of the equipment much longer than anticipated, so there was a lot of pressure from Statoil on their schedule. Statoil sees diminishing production in several of the wells, so workover operations are urgent.

With the upcoming fall and winter storms, Frode hopes to finish the next three workover operations in a new record time. The equipment supplier had not only recertified all equipment, but also renovated parts of the riser system allowing for faster deployment and retrieval. The supplier tested and installed equipment in Horten. Tomorrow they will arrive in Sotra, their company support station. Here they will stock their fuel, food, coiled tubing, and other material.

The weather forecast shows a depression close to Iceland that moves slowly in Norway’s direction. If they can start deployment of the riser on September 7, then they probably finish the workover before the storm associated with the depression is too severe.

Since the schedule is so tight, the captain proposes to preassemble the riser system as far as possible while traveling. In addition, the accumulators can already be charged. The captain asks the foreman to make a schedule and to allocate tasks to the crew. Safety will be a key attention point, since working with such equipment with sea state 3 provides risks.
Annotated Physical Diagram of WorkOver System

- **tension frame** connects **riser to rig tension system**
- **surface flow tree** provides **well control**
- **wireline** coil tubing **BOP** provides **well control**
- **work over control system** monitoring and control of **subsea installation**
- **emergency disconnect package** provides **disconnect function**
- **lower riser package** provides **well control function**
- **Xmas tree** provides **well control**
- **well head**
- **well**

**SubSea Modeling Example**

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SSMEworkoverPhysicalAnnotated
Typical Workover Operation

1. assembly, functional test
2. run EDP/LRP
3. run risers
4. hook up SFT and TF
5. move above well
6. ROV assisted connect
7. hook up coil tubing and wireline BOP
8. system function and connection seal test
9. run coil tubing and wireline

7. perform workover operations
8. retrieve coil tubing and wireline BOP
9. unhook coil tubing and wireline BOP
10. ROV assisted disconnect
11. move away from well
12. retrieve SFT and TF
13. retrieve risers
14. retrieve EDP/LRP
15. disassembly

12. retrieve WITH
11. retrieve SFT and TF
10. retrieve risers
9. retrieve EDP/LRP
8. ROV assisted disconnect
7. move away from well
6. ROV assisted connect
5. move above well
4. hook up coil tubing and wireline BOP
3. hook up SFT and TF
2. run risers
1. run EDP/LRP

rig
vessel or platform
assembly, functional test
run EDP/LRP
run risers
hook up SFT and TF
move above well
ROV assisted connect
hook up coil tubing and wireline BOP
system function and connection seal test
run coil tubing and wireline
perform workover operations
retrieve coil tubing and wireline BOP
unhook coil tubing and wireline BOP
ROV assisted disconnect
move away from well
retrieve SFT and TF
retrieve risers
retrieve EDP/LRP
disassembly
vessel or platform
well
ROV assisted connect
ROV assisted disconnect
move above well
move away from well
disassembly
12. retrieve WITH
11. retrieve SFT and TF
10. retrieve risers
9. retrieve EDP/LRP
8. ROV assisted disconnect
7. move away from well
6. ROV assisted connect
5. move above well
4. hook up coil tubing and wireline BOP
3. hook up SFT and TF
2. run risers
1. run EDP/LRP

SubSea Modeling Example
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Typical Workover Operation as Cartoon

1. EDP
2. LRP
3. vessel or platform
4. rig
5. EDP
6. LRP
7. vessel or platform
8. rig
9. vessel or platform
10. rig
11. vessel or platform
12. rig

SubSea Modeling Example
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Typical Workover Operation on Timeline

**Assumptions:**
- Running and retrieving risers: 50 m/hr
- Running and retrieving coiled tubing/wireline: 100 m/hr
- Depth: 300 m
Typical Workover Operation Context

Zero order model

\[ t_{\text{workover}} = t_{\text{transportation}} + t_{\text{preparation}} + t_{\text{workover}} + t_{\text{finishing}} \]

First order model

\[ t_{\text{workover}} = t_{\text{transportation}} + t_{\text{preparation}} + t_{\text{workover}} + t_{\text{disruption}} + t_{\text{finishing}} \]

SubSea Modeling Example

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SSMTypicalWorkoverOperationContext
## 0-order Cost Model Workover Operation

<table>
<thead>
<tr>
<th>workover cost per day</th>
<th>assumed cost (MNoK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>platform, rig equipment crew</td>
<td>2 0.2 0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>deferred operation per day</th>
<th>assumed cost (MNoK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>production delay ongoing cost operation</td>
<td>0.1 0.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>workover duration</th>
<th>estimated duration (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>transportation preparation workover finishing total</td>
<td>24 36 48 27 135 (5.6 days) 62 (2.6 days)</td>
</tr>
</tbody>
</table>

\[
\text{cost} = \text{cost}_{\text{workover/day}} \times t_{\text{workover}} + \text{cost}_{\text{deferred op./day}} \times t_{\text{deferred op.}} \\
\approx 2.3 \times 5.6 + 0.3 \times 2.6 \approx 14 \text{ MNoK / workover}
\]
Disruption Workover Operation

Disruption, e.g. storm

perform workover operations

retract wireline
shut down valves
control t&p well
disconnect EDP
move away
wait
move above well
reconnect EDP
control t&p well
open valves
run wireline

wait for resolution of disruption

workover disruption
move away
wait for resolution of disruption
move above well
reconnect
continue workover

vessel or platform
EDP
LRP
riser
XT
well
TF
SFT
wellhead
WOCS
rig
3
a
7
7a
7b
7c
7
24
48 hours

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SSMEdisruptionWorkoverOperation

SubSea Modeling Example
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### 1st Order Cost Model Workover Operation

#### Workover Cost per Day

<table>
<thead>
<tr>
<th>Component</th>
<th>Assumed Cost (MNoK)</th>
<th>Production Loss (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Workover Cost per Day</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Platform, Rig</td>
<td>2</td>
<td>135 (5.6)</td>
</tr>
<tr>
<td>Equipment</td>
<td>0.2</td>
<td>72</td>
</tr>
<tr>
<td>Crew</td>
<td>0.1</td>
<td>11</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2.3 MNoK/day</td>
<td>83 * 0.3 = 27</td>
</tr>
</tbody>
</table>

#### Deferred Operation per Day

<table>
<thead>
<tr>
<th>Component</th>
<th>Assumed Cost (MNoK)</th>
<th>Production Loss (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Deferred Operation per Day</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production Delay</td>
<td>0.1</td>
<td>27</td>
</tr>
<tr>
<td>Ongoing Cost Operation</td>
<td>0.2</td>
<td>162 (6.7)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>0.3 MNoK/day</td>
<td>27</td>
</tr>
</tbody>
</table>

#### Workover Duration

- Workover 0-order average disruption duration
- Overhead: 1st order disruption correction
- Total: estimated duration (hours)

- Production loss:
  - 62 (2.6 days)

#### 1st Order Cost

\[
1^{st} \text{ order cost} = \text{cost}_{\text{workover/day}} \times t_{\text{workover}} + \text{cost}_{\text{deferred op./day}} \times t_{\text{deferred op.}} \\
\sim = 2.3 \times 6.7 + 0.3 \times 3.7 \sim = 16.5 \text{ MNoK / workover} \\
0^{th} \text{ order cost} \sim = 14 \text{ MNoK} ; \text{ disruption cost} \sim = 2.5 \text{ MNoK}
\]
Workover operation; architecture overview

This A3 based on the work of SEMA participants: Martin Moberg, Tormed Strand, Vazgen Karlson, and Damien Wee, and the master project paper by Dag Jostein Kleveland. "Aker Solutions, FMC Technologies"

version 2.2 Gerrit Muller

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SSMEoverviewA3
Levels of A3s

contextual A3AO

workover operations

workover robustness

A3AO topic of interest

workover duration and cost

workover health safety environment

A3AOs aspect elaboration

ROV handling

navigation and positioning

connect and disconnect

barrier and containment

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SSMElevelsOfA3s
Example Graph for Motorway Management System

Key-drivers

Safety
- Reduce accident rates
- Enforce law
- Improve emergency response

Effective Flow
- Reduce delay due to accident
- Improve average speed
- Improve total network throughput
- Optimize road surface
- Speed up target groups
- Anticipate on future traffic condition

Smooth Operation
- Ensure traceability
- Ensure proper alarm handling
- Ensure system health and fault indication

Environment
- Reduce emissions

Derived application drivers

Early hazard detection with warning and signaling

Maintain safe road condition
- Classify and track dangerous goods vehicles
- Detect and warn noncompliant vehicles

Improve average speed
- Enforce speed compliance

Improve total network throughput
- Enforce red light compliance

Optimize road surface
- Enforce weight compliance

Smooth Operation
- Anticipate on future traffic condition

Requirements

Automatic upstream accident detection
- Deicing

Weather condition dependent control
- Traffic condition dependent speed control

Traffic speed and density measurement
- Cameras

Note: the graph is only partially elaborated for application drivers and requirements
Example Context of Motorway Management System

- Maintenance contractors
- Fleet management
- Urban traffic control
- Advanced vehicle control
- Environmental monitoring
- Other concerns
- Special applications
- Bus lanes
- Lorry lanes
- Restaurants
- Gas stations
- Car repair
- Towing service
- Toll tunnel
- Specialized segments
- Contingencies
- "Add-ons"
- Administrative
- Special destinations
- Competing or cooperating?
- Government
- Car administration
- Taxes
- Airports
- Railways
- Third party

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AVcontextMotorwayManagement
Case Elaboration CA-views

- Theory
  - Basic Ideas behind Architectural Reasoning
  - Multi-view: CAFCR+
  - Fundamentals of Systems Design and Engineering
  - Story telling, Key drivers
  - Life Cycle
  - Business Economics

- Class-work
  - Case Exploration
  - Case Elaboration FCR
  - Case Elaboration CA
  - Case Elaboration Life Cycle

- Homework
  - Consolidation
  - Final Consolidation
Continue second iteration by elaborating CA views

Use time-boxes of about 40 minutes

- Develop a story that helps you to understand the customer better and that facilitates analysis of specification and design
  - Verify your story against the story criteria
- Develop a customer key driver graph
  - Start with Key Performance Parameters and ask “why (is this needed)” repeatedly.

Use time-box of about 20 minutes for the remaining task

- Make a context diagram
Customer objectives | Application | Functional | Conceptual | Realization | Life cycle

1. sketch the system-of-interest and its context
2. draw an initial design
3. make a specification
4. identify customer stakeholders
5. identify life cycle stakeholders
6. partitioning and interfaces
7. make functional design
8. define key performance
9. make performance budget
10. develop 3 alternate solutions
11. determine 5..10 criteria for comparison
12. rank 3 alternate solutions against criteria
13. Make a Story
14. Customer Key Driver Graph
15. Context diagram
Theory Block: Life Cycle

Life Cycle

Conception and Development

From Deployment to Decommissioning and Disposal
Product Life Cycle

create
system
sell
produce
options
service
systems
dispose
systems
after sales
create
options
sell
produce
options

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System Development

0. feasibility
1. definition
2. system design
3. engineering
4. integration & test
5. field monitoring

sales
logistics
production
service
development & engineering: marketing, project management, design

product documentation
supply chain
production and qualification procedures
service procedures
Individual System Life Cycle

system order
ordering components manufacturing shipping installation using local changes, e.g. accounts procedures
add option maintenance upgrade
using
sales shipping refurbishing shipping installation using secondary use
maintenance dispose
Theory Block: Business Economics

Simple Cash flow model

Business models

Cost of Ownership
Expenses and Income

investment: development cost

expenses: purchase materials labour

income: system sales

create system

sell produce systems
**Example Cash Flow calculation**

<table>
<thead>
<tr>
<th></th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
</tr>
</thead>
<tbody>
<tr>
<td>investments</td>
<td>100k$</td>
<td>400k$</td>
<td>500k$</td>
<td>100k$</td>
<td>100k$</td>
<td>60k$</td>
<td>20k$</td>
</tr>
<tr>
<td>sales volume (units)</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>material &amp; labour costs</td>
<td>-</td>
<td>-</td>
<td>40k$</td>
<td>200k$</td>
<td>400k$</td>
<td>600k$</td>
<td>600k$</td>
</tr>
<tr>
<td>income</td>
<td>-</td>
<td>-</td>
<td>100k$</td>
<td>500k$</td>
<td>1000k$</td>
<td>1500k$</td>
<td>1500k$</td>
</tr>
<tr>
<td>quarter profit (loss)</td>
<td>(100k$)</td>
<td>(400k$)</td>
<td>(440k$)</td>
<td>200k$</td>
<td>500k$</td>
<td>840k$</td>
<td>880k$</td>
</tr>
<tr>
<td>cumulative profit</td>
<td>(100k$)</td>
<td>(500k$)</td>
<td>(940k$)</td>
<td>(740k$)</td>
<td>(240k$)</td>
<td>600k$</td>
<td>1480k$</td>
</tr>
</tbody>
</table>

**cost price / unit = 20k$**

**sales price / unit = 50k$**

variable cost = sales volume * cost price / unit

income = sales volume * sales price / unit

quarter profit = income - (investments + variable costs)
Cash Flow as Function of Time

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SFChockeyStick
What If...?

SubSea Modeling Example

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SFChockeyStickWhatIf
Cost of Ownership Model

Cost Of Ownership model

- radiologist
- nurse
- security
- administration
- operator

- personnel
- consumables
- service
- facilities
- financing

k$
Business Models

create system
sell system
produce systems
service systems
dispose systems
create options
sell options
sell capability (e.g. racing)
increase other business (e.g. food and drink)
run other business (e.g. advertisements)

after sales
create options
sell options

initial sales
sell spare parts
sell consumables
maintenance services

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Case Elaboration Life Cycle-view

Theory
- Basic Ideas behind Architectural Reasoning
- Multi-view: CAFCR+
- Fundamentals of Systems Design and Engineering
- Story telling, Key drivers
- Life Cycle
- Business Economics

Class-work
- Case Exploration
- Case Elaboration FCR
- Case Elaboration CA
- Case Elaboration Life Cycle

Homework
- Consolidation
- Final Consolidation
Continue second iteration by elaborating life cycle view

Use time-boxes of about 30 minutes

- Develop a business plan for your company
  - determine your role in the value chain
  - determine income, expenses, and investments
  - estimate cash flow as function of time
- Identify needs and concerns from life cycle stakeholders
  - determine life cycle key drivers and key performance parameters
- Make a Cost of ownership estimate for customers
  Use time-box of about 20 minutes for the remaining task
- Make a schedule for development and start of deployment
Class-work Day 4 mapped on CAFCR

Customer objectives

1. sketch the system-of-interest and its context
2. draw an initial design
3. make a specification
4. identify customer stakeholders

Application

5. identify life cycle stakeholders
6. partitioning and interfaces
7. make functional design
8. define key performance

Functional Conceptual Realization

9. make performance budget
10. develop 3 alternate solutions
11. determine 5..10 criteria for comparison
12. rank 3 alternate solutions against criteria
13. develop a story
14. Customer Key Driver Graph
15. Context diagram

Life cycle

16. Make business plan
17. needs and concerns
18. Cost of Ownership model
19. Schedule
20. check specification and design for major gaps or improvements

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BSEARelaborationLCmappedOnCAFCR
Homework after Day 4

Check specification and design for major gaps or improvements

Transform your results in electronic form (e.g., PowerPoint or Visio)

Make a T-shape presentation for your management; main purpose go/no-go decision

Write an individual reflection report, max 2 A4s:

What are your main learning points?

What aspects deserve most attention in next phase? Explain why.
Summary Architectural Reasoning

Objective: Awareness

Make engineering students aware of:

- other disciplines
- “systems” design and engineering
- customers and life cycle as contexts of the system
- the impact of needs on design decisions

Objective: Experience

Let engineering students apply and experience:

- multiple views
- visualizations
- simplification
- iteration
- quantification

Stretch, Stretch, Stretch

- system architecting
- multi-disciplinary design
- market and customer context
- life cycle context
- mono-disciplinary engineering
- software engineering
- electrical engineering
- mechanical engineering
- design, engineer, build, test
- understand context
- analyse needs
- specify system
- explore design options
- validate & verify

Main Deliveries

- value proposition
- business proposition
- system specification
- design
- system architecting
- multi-disciplinary design
- market and customer context
**Time-boxing and Iteration**

A **time-box** is a fixed amount of time allocated to perform one activity. We **iterate** many times over different viewpoints. Every viewpoint is addressed multiple times with new insights from other viewpoints.

---

**CAFCR views**

- **What** does **Customer** need in **Product** and **Why**?
- **Customer** **How**
- **Product** **What**
- **C**ustomer objectives
- **A**pplication
- **F**unctional
- **C**onceptual
- **R**ealization

---

**Stakeholders and Concerns**

- government
  - cost of care
  
- financial dir.
  - cash flow
  - cost of op.

- insurance
  - cost of care

- administration
  - patient id
  - invoice

- general practitioner
  - patient comfort
  - health

- ref. physician
  - diagnosis
  - treatment

- radiologist
  - diagnosis
  - reimbursement

- nurse
  - patient
  - ease of work

- inspection
  - quality

- operator
  - ease of use

- IT dep.
  - conformance
  - security

- facility man.
  - space
  - service supp.

- maintainer
  - accessibility
  - safety

- cleaner
  - accessibility
  - safety

---

**SubSea Modeling Example**

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Partitioning

Interfaces

Key Performance Parameters

Functional Model

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Combining 3 Dimensions

How about the **characteristic** of the **component** when performing **function**?

What is the **accuracy** of the **fuse** when **printing**?

---

Concept Selection

**Swivel concept selection**

<table>
<thead>
<tr>
<th>CBV sensor</th>
<th>clamp sensor</th>
<th>dynamic</th>
</tr>
</thead>
<tbody>
<tr>
<td>evaluation criteria</td>
<td>weight</td>
<td>CBV</td>
</tr>
<tr>
<td>Stability</td>
<td>Development level</td>
<td>15</td>
</tr>
<tr>
<td>Cost</td>
<td>Installation cost</td>
<td>Development cost</td>
</tr>
<tr>
<td>Design robustness</td>
<td>Design life</td>
<td>20</td>
</tr>
<tr>
<td>Temperature</td>
<td>Temperature range</td>
<td>20</td>
</tr>
<tr>
<td>Operation</td>
<td>Initial install/relocation</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Connection/disconnection</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CBV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
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<td>7</td>
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<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>985</td>
</tr>
</tbody>
</table>

**EDP-LRP connection**

| From master paper Håvard Bjørmen, 2009 | From master paper Dag Jostein Klever, 2009 |

---

Technical Budget

---

Intentionally left blank
Summary Customer Understanding

Story Telling

Customer What
Customer How
Product What
Product How

Customer objectives
Application
Functional
Conceptual
Realization

What does Customer need in Product and Why?

a priori solution knowledge
market vision

analyze design
analyze design
design

case

Key Driver Graph

Key-drivers
Safety
Reduce accident rates
Enforce law
Maintain safe road condition
Reduce delay due to accident
Improve emergency response
Classify and track dangerous goods vehicles
Improve average speed
Enforce speed compliance
Improve total network throughput
Optimize road surface
Ensure proper alarm handling
Enforce red light compliance
Smooth Operation
Anticipate on future traffic condition
Enforce weight compliance
Ensure system health and fault indication
Reduce emissions

Derived application drivers
Early hazard detection with warning and signaling
Traffic speed and density measurement
Automatic upstream accident detection
Weather condition dependent control
Cameras

Requirements
Desing
Traffic condition dependent speed control

System Context

motorway management system
radiologist
nurse
security
administration
operator

maintenance contractors
fleat management
urban traffic control
advanced vehicle control
administrative
toll tunnel
car repair
towing service
gas stations
restaurants
bus lanes
lorry lanes
environmental monitoring

environmental monitoring

Cost of Ownership Model

Cost Of Ownership model

radiologist
nurse
security
administration
operator

personnel
consumables
service
facilities
financing

SubSea Modeling Example
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January 26, 2015

Gerrit Muller
Summary Life Cycle and Business Economics

Product Life Cycle

- after sales
  - create options
  - sell produce options
- create system
  - sell produce systems
  - service systems
  - dispose systems

Cash Flow

<table>
<thead>
<tr>
<th></th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
</tr>
</thead>
<tbody>
<tr>
<td>investments</td>
<td>100k$</td>
<td>400k$</td>
<td>500k$</td>
<td>100k$</td>
<td>100k$</td>
<td>60k$</td>
<td>20k$</td>
</tr>
<tr>
<td>sales volume (units)</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>material &amp; labour costs</td>
<td>-</td>
<td>-</td>
<td>40k$</td>
<td>200k$</td>
<td>400k$</td>
<td>600k$</td>
<td>600k$</td>
</tr>
<tr>
<td>income</td>
<td>-</td>
<td>-</td>
<td>100k$</td>
<td>500k$</td>
<td>1000k$</td>
<td>1500k$</td>
<td>1500k$</td>
</tr>
<tr>
<td>quarter profit (loss)</td>
<td>(100k$)</td>
<td>(400k$)</td>
<td>(440k$)</td>
<td>200k$</td>
<td>500k$</td>
<td>840k$</td>
<td>880k$</td>
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<tr>
<td>cumulative profit</td>
<td>(100k$)</td>
<td>(500k$)</td>
<td>(940k$)</td>
<td>(740k$)</td>
<td>(240k$)</td>
<td>600k$</td>
<td>1480k$</td>
</tr>
</tbody>
</table>

Cost price / unit = 20k$
Sales price / unit = 50k$

Hockey Stick

System Life Cycle

- system order
  - printing components
  - manufacturing
  - shipping
  - installation
  - add option
  - maintenance
  - upgrade
  - using
  - sales
  - refurbishing
  - shipping
  - installation
  - secondary use
  - dispose

Local changes, e.g.
accounts procedures

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