

Bachelor Course Systems Engineering: Architectural Reasoning

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`www.gaudisite.nl`

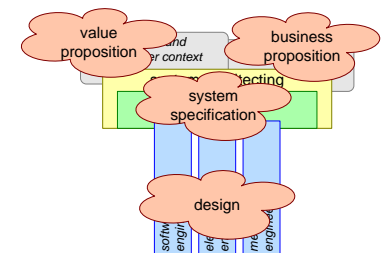
Abstract

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.

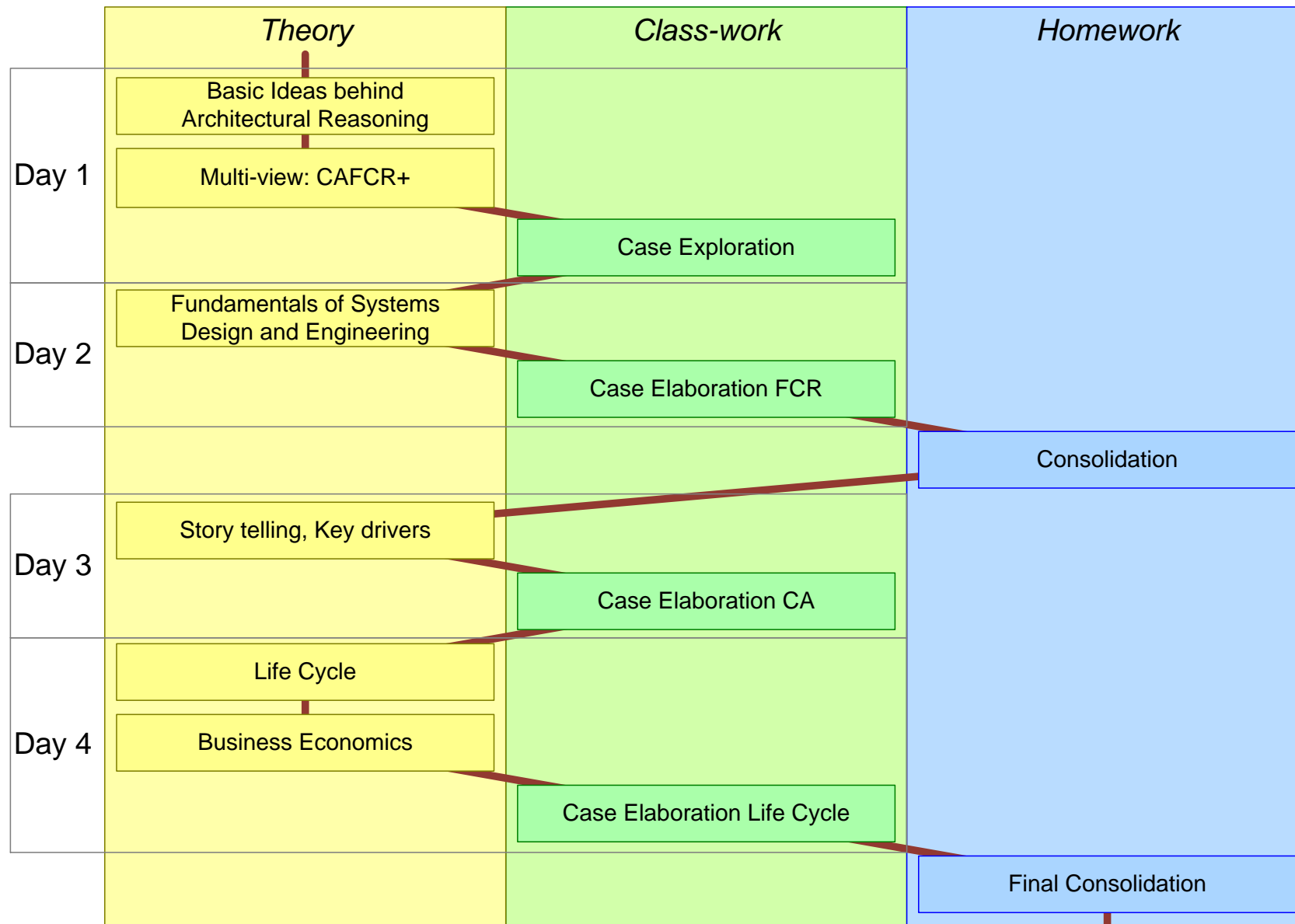
Distribution

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status: draft
version: 1.0



Course Program Architectural Reasoning



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

Let engineering students apply and experience:

- multiple views
- visualizations
- simplification
- iteration
- quantification

See Homework Presentation

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

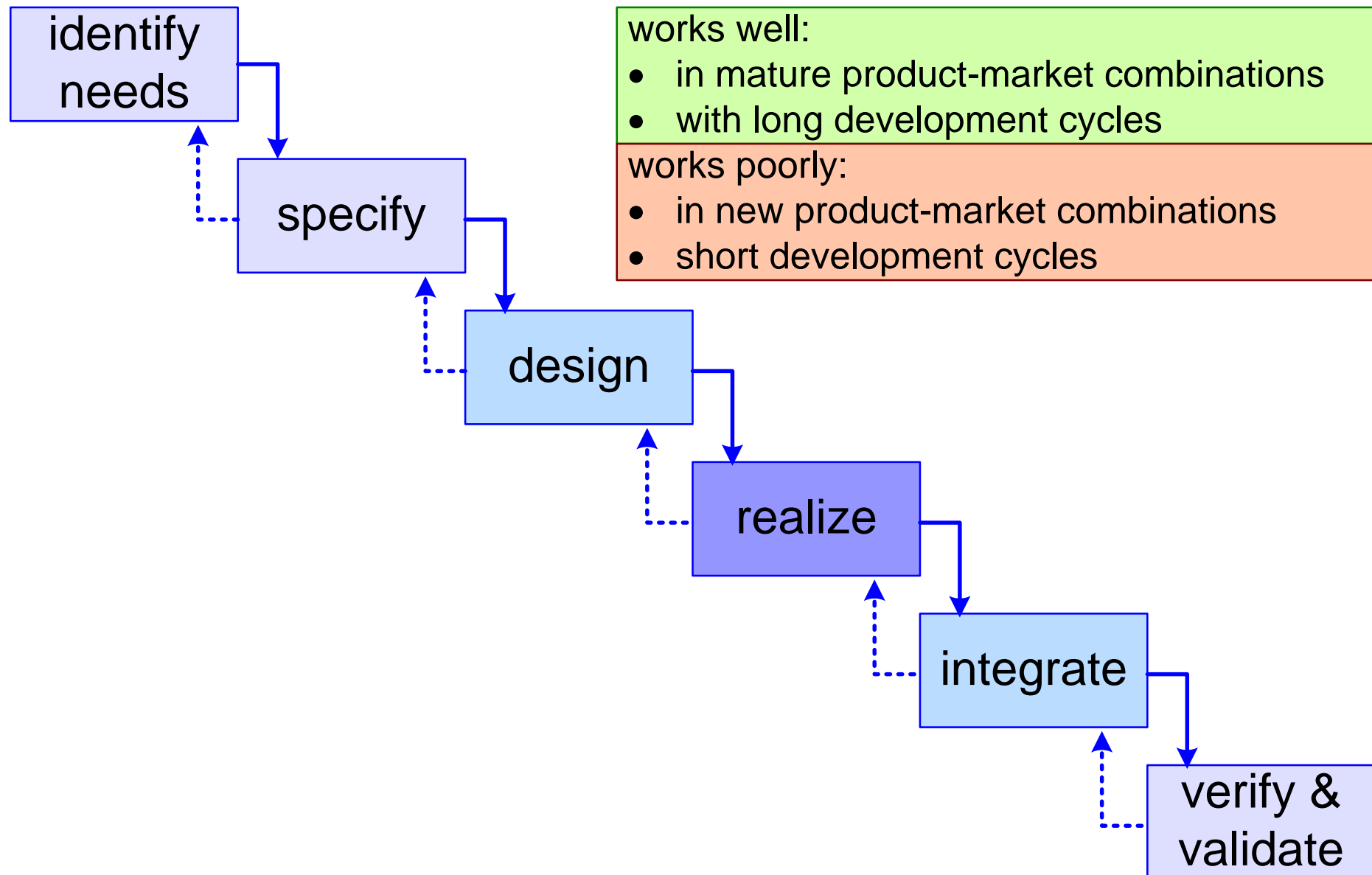
to systems engineer

to architect

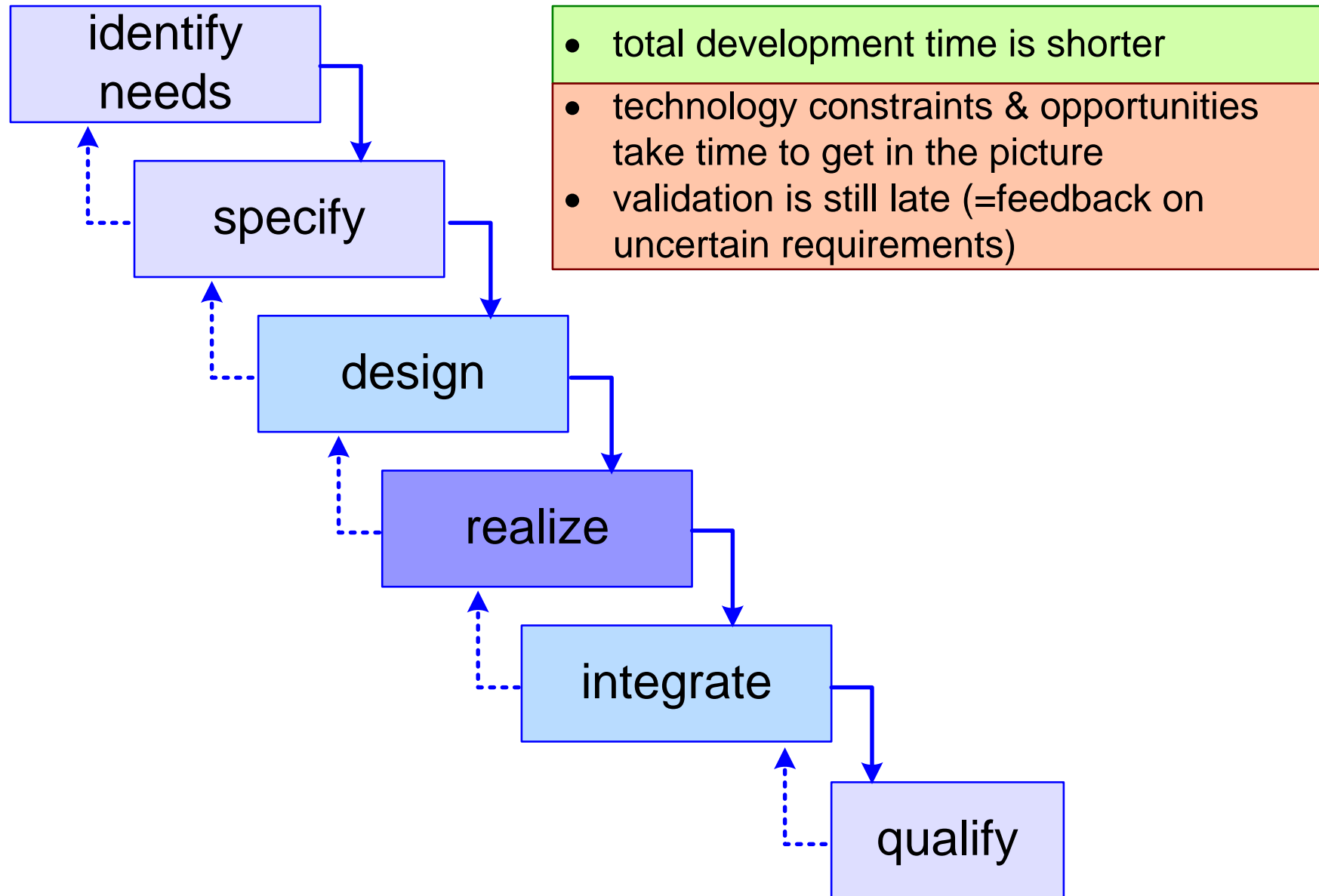
Why so chaotic?

Why not follow
top-down SE process?

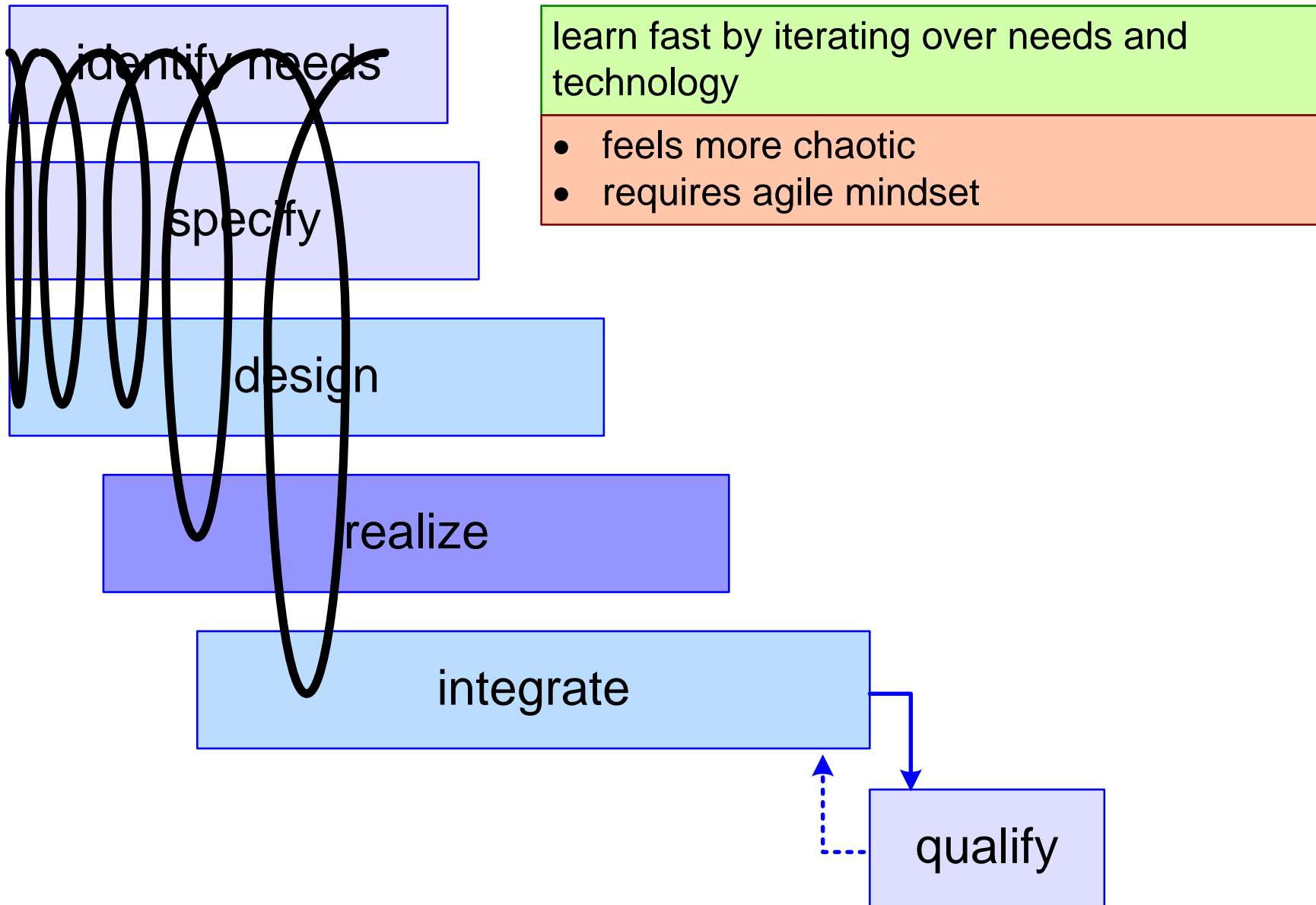
Waterfall model



Concurrent Engineering



Iterative Approach



You study mono-disciplinary engineering

mono-disciplinary
engineering

*software
engineering*

*electrical
engineering*

*mechanical
engineering*

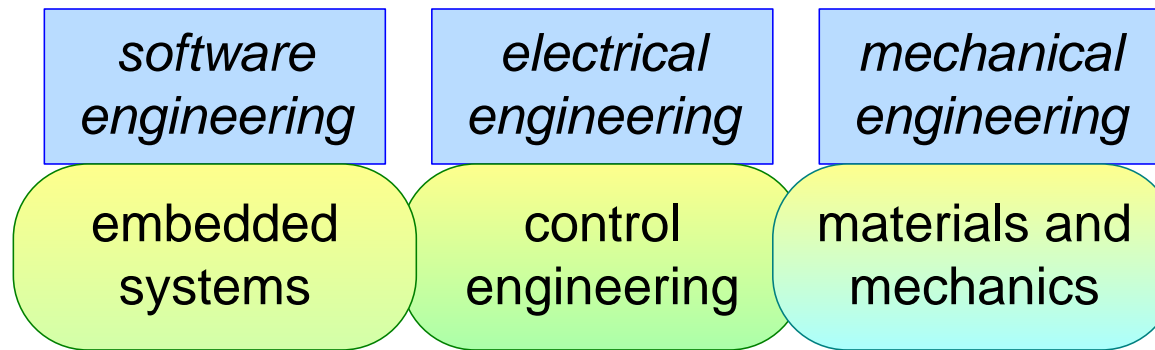
specify

design
model, analyse,
partition, interfaces, etc.

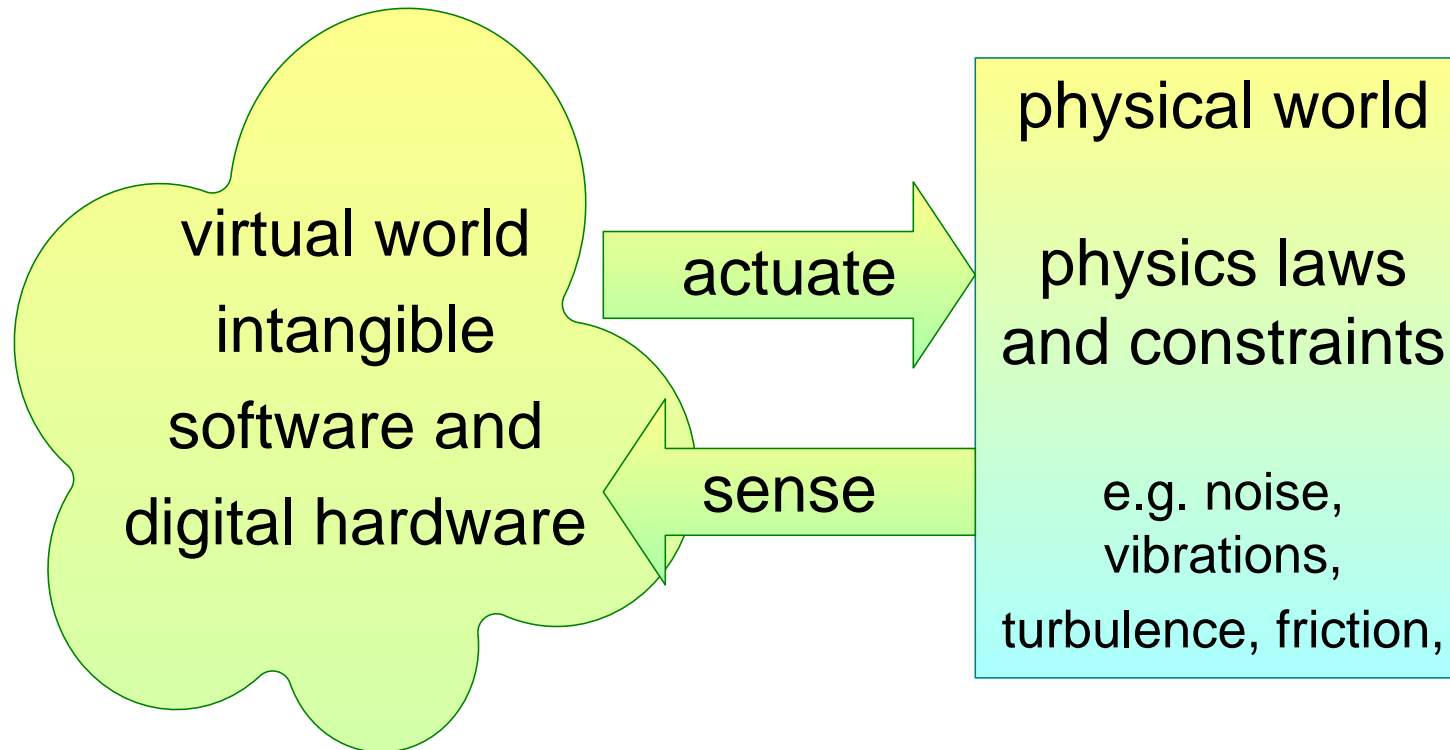
coding & CADing

testing

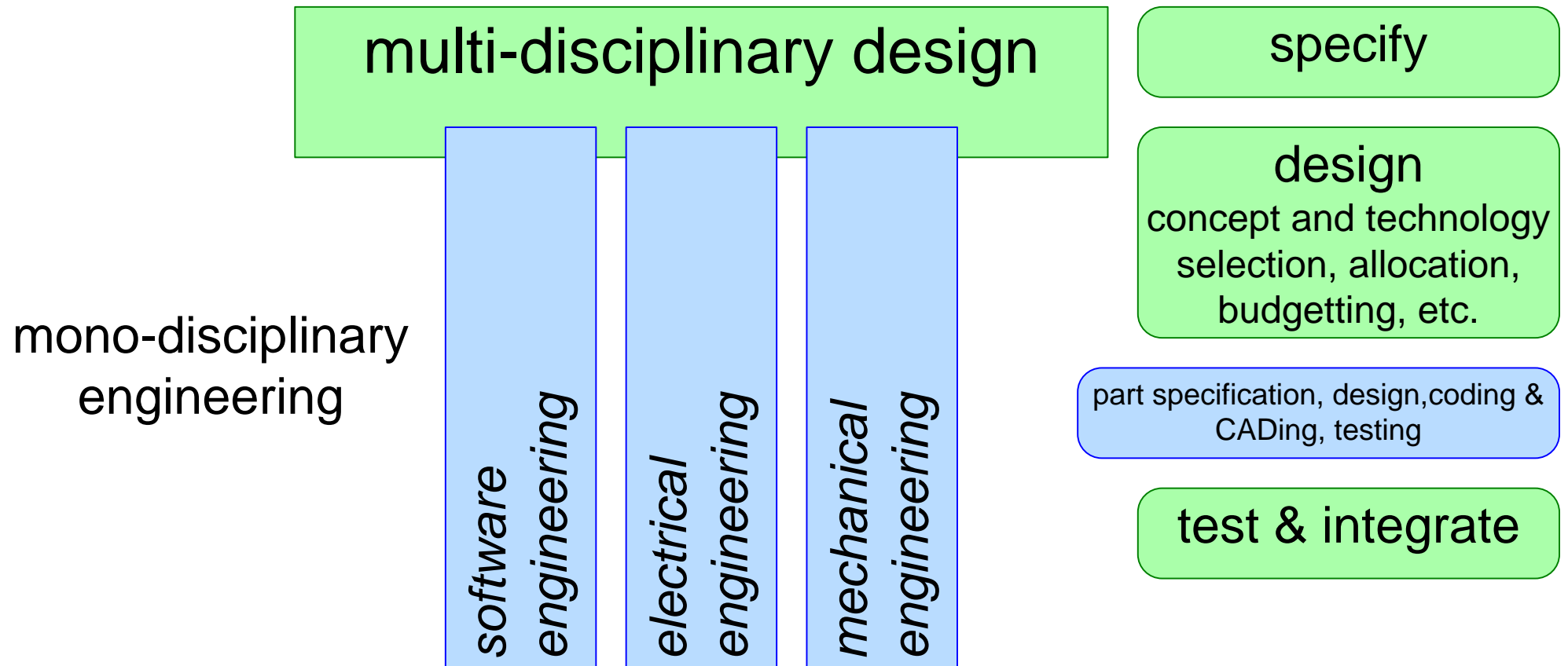
Huge differences in language and way of thinking



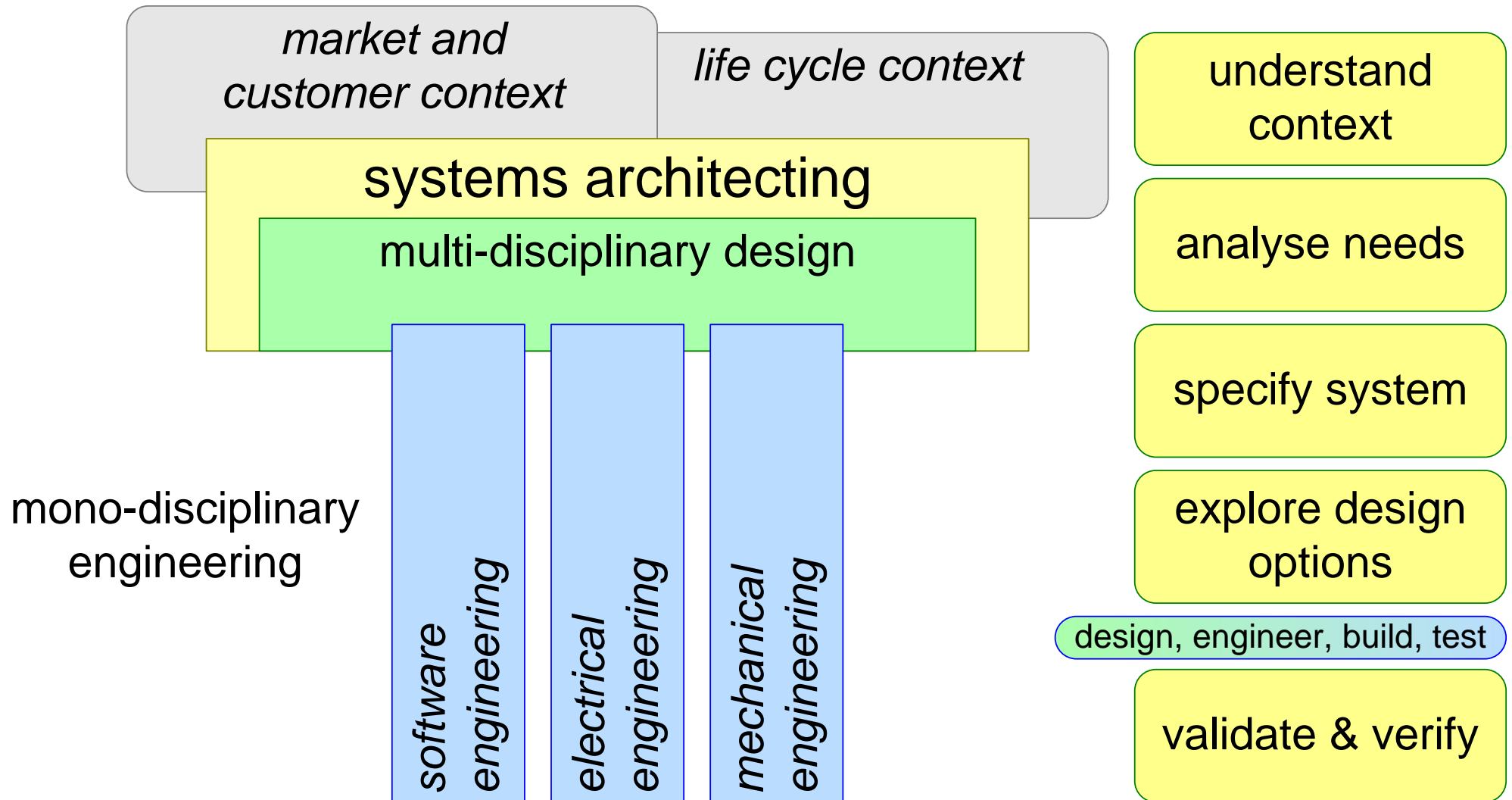
completely different world views



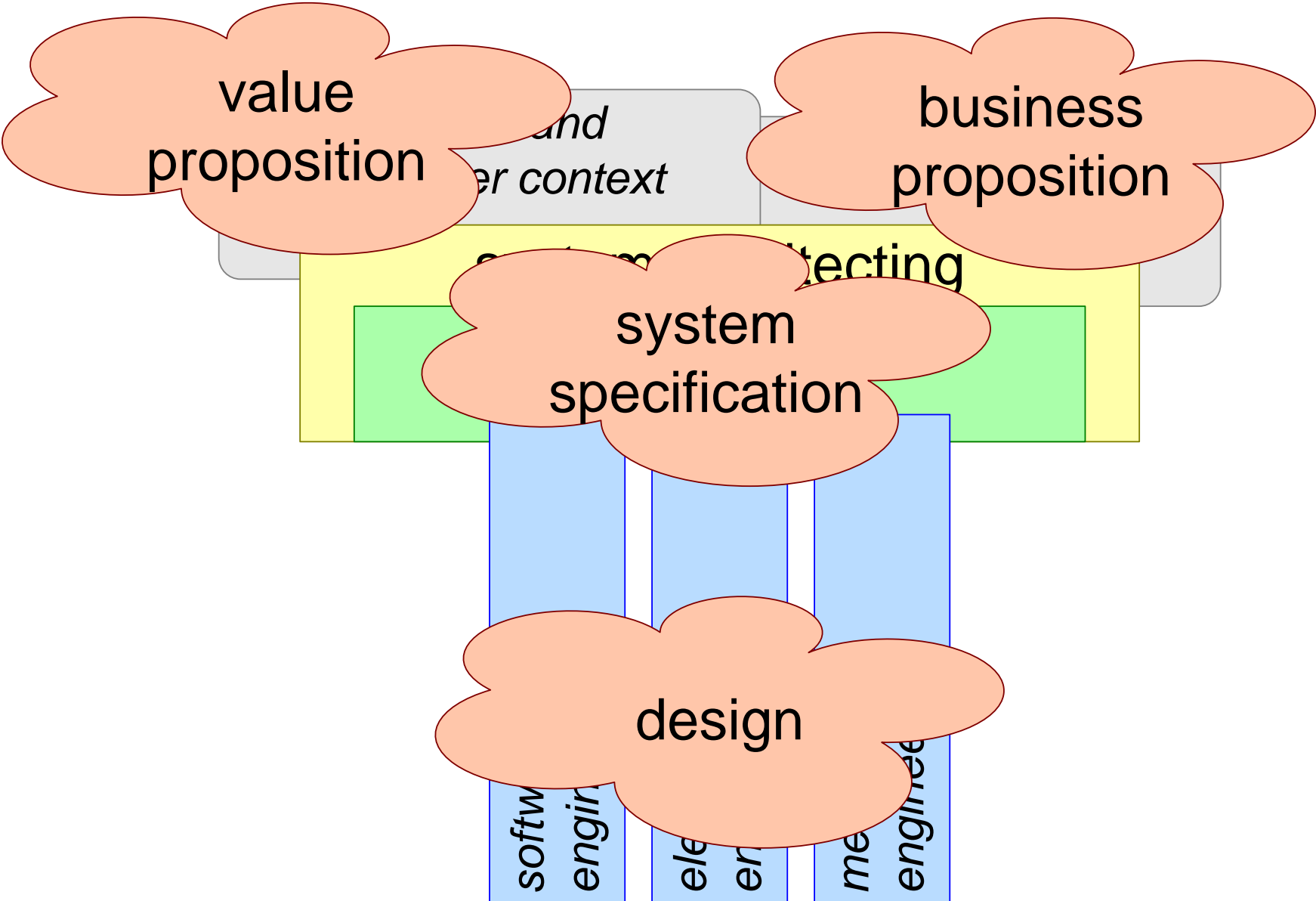
Multi-disciplinary design and engineering



Architecting: Fit-For-Purpose



Delivery at the end of this module



More specific deliveries

Value Proposition

Why does customer want to buy?

Why do users like to use the system?

- customer key drivers
- cost of ownership
- customer business analysis
- customer stakeholders and concerns
- story or scenario
- context diagram
- work flow or ConOps

Business Proposition

How do we earn money?

How do we run a healthy business?

- life cycle key drivers
- business model
- cash flow analysis
- life cycle stakeholders and concerns
- life cycle model
- supply chain
- organization chart
- plan

System Specification

What does customer get?

What is the system-of-interest that we deliver?

- functions
- qualities (e.g. quantified performance)
- interfaces
- constraints, standards, regulations

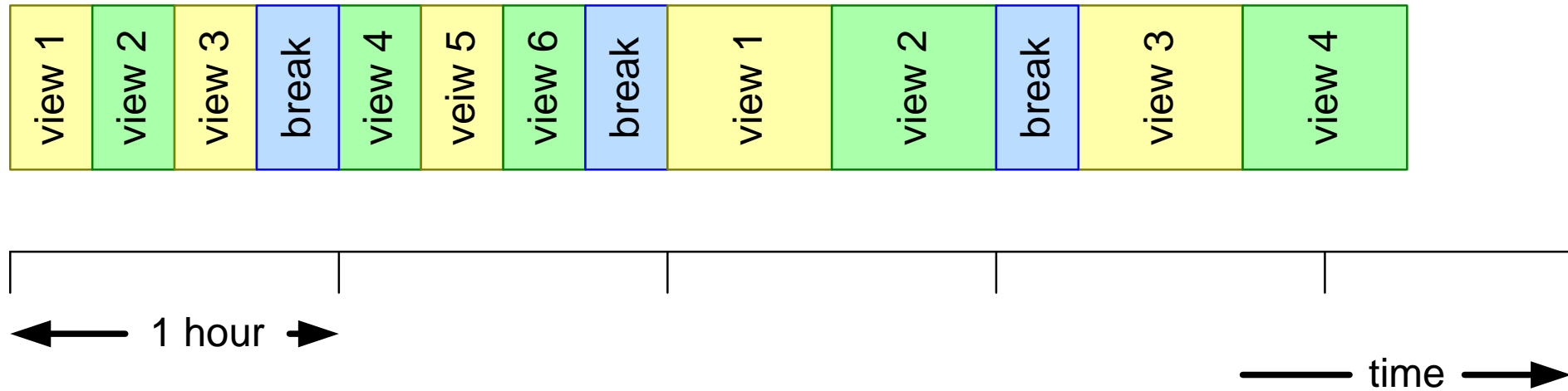
Design

How will we realize this specification?

How do we ensure performance, safety, robustness, etc.?

- partitioning and interfaces
- dynamic behavior, e.g. functional model
- performance budgets
- concept and technology selection
- make or buy, supplier selection

Time-boxing and Iteration



time-box

A time-box is a fixed amount of time allocated to perform one activity.

iteration

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

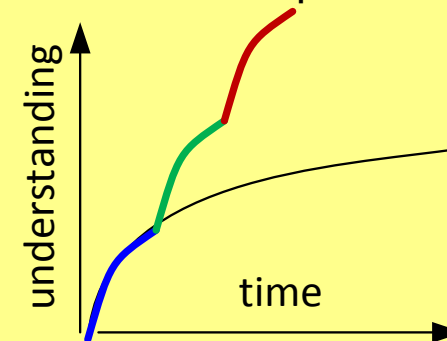
With many uncertainties and unknowns it does not make sense to be perfect

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



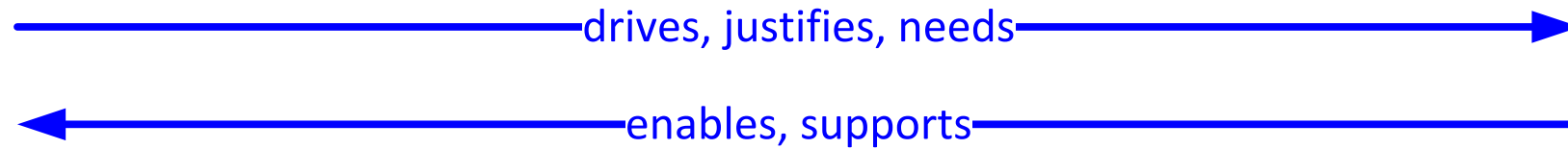
Theory Block: CAFCR

You need multiple views on a system

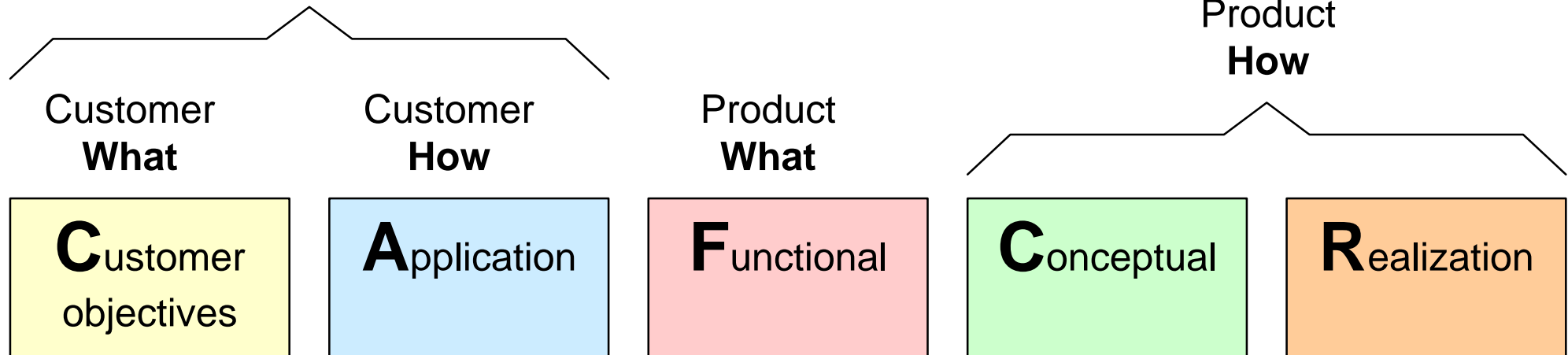
CAFCR defines 5 views

CAFCR+ adds one more view

The “CAFCR” model

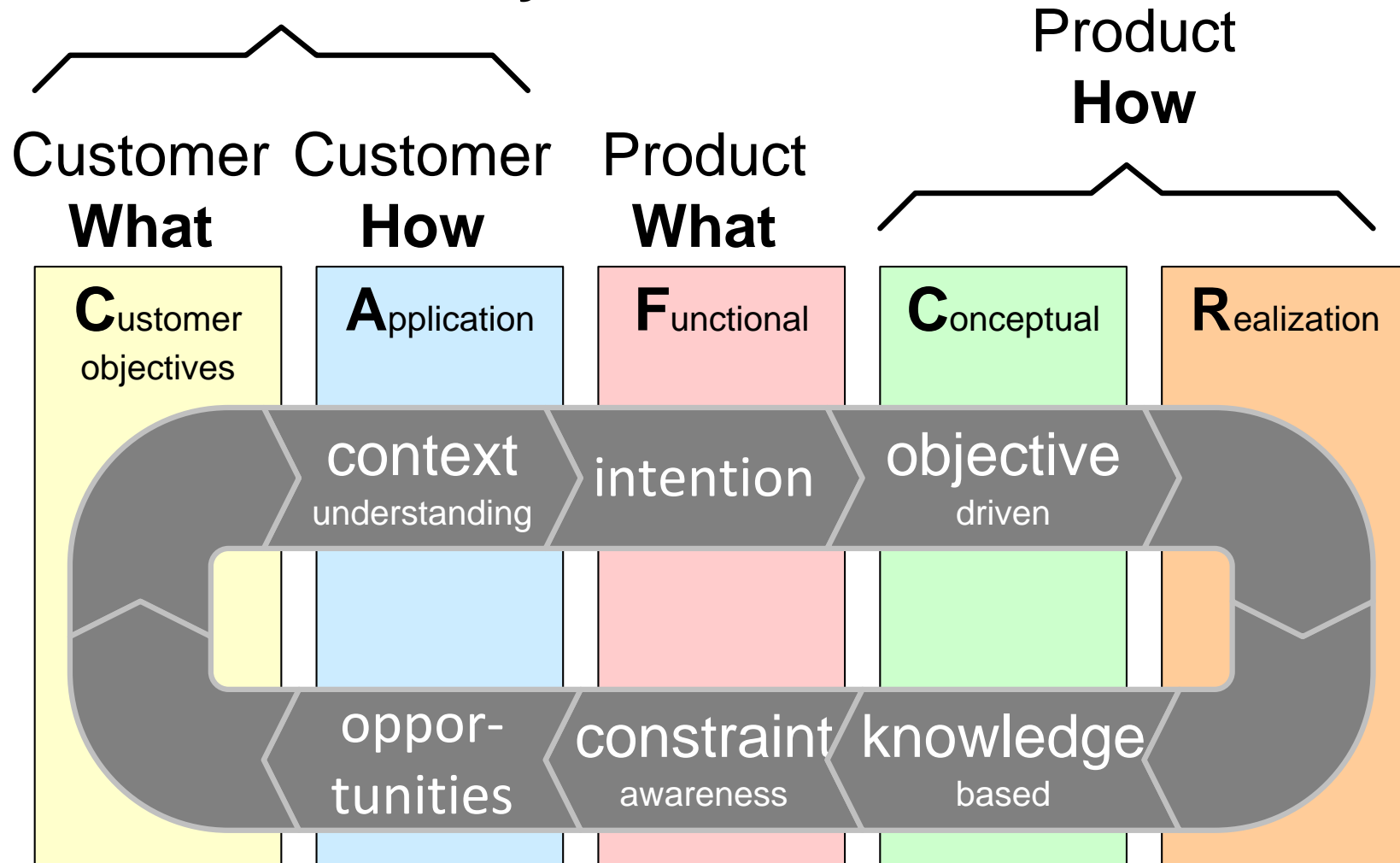


What does Customer need
in Product and **Why?**

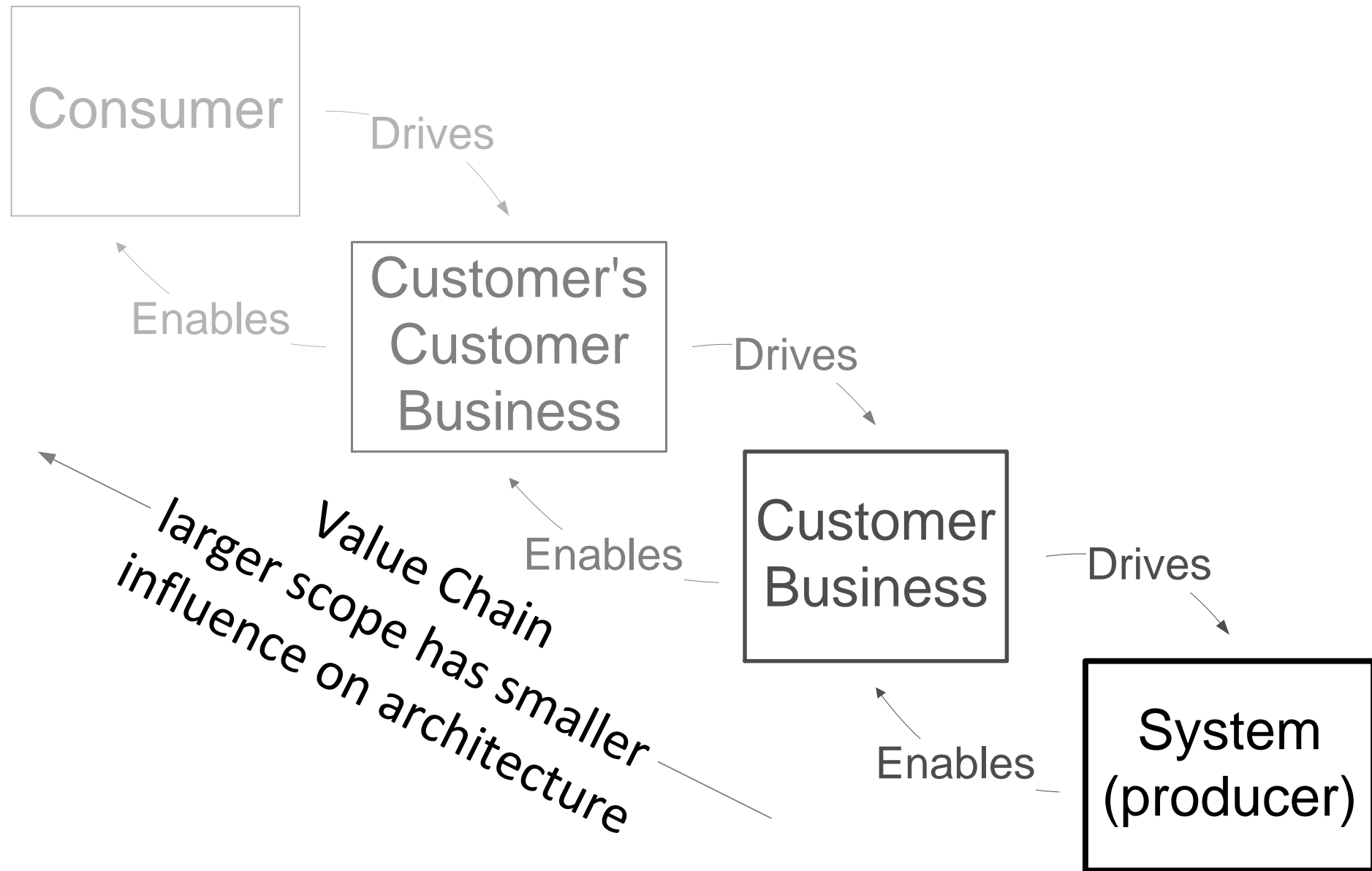


Integrating CAFCR

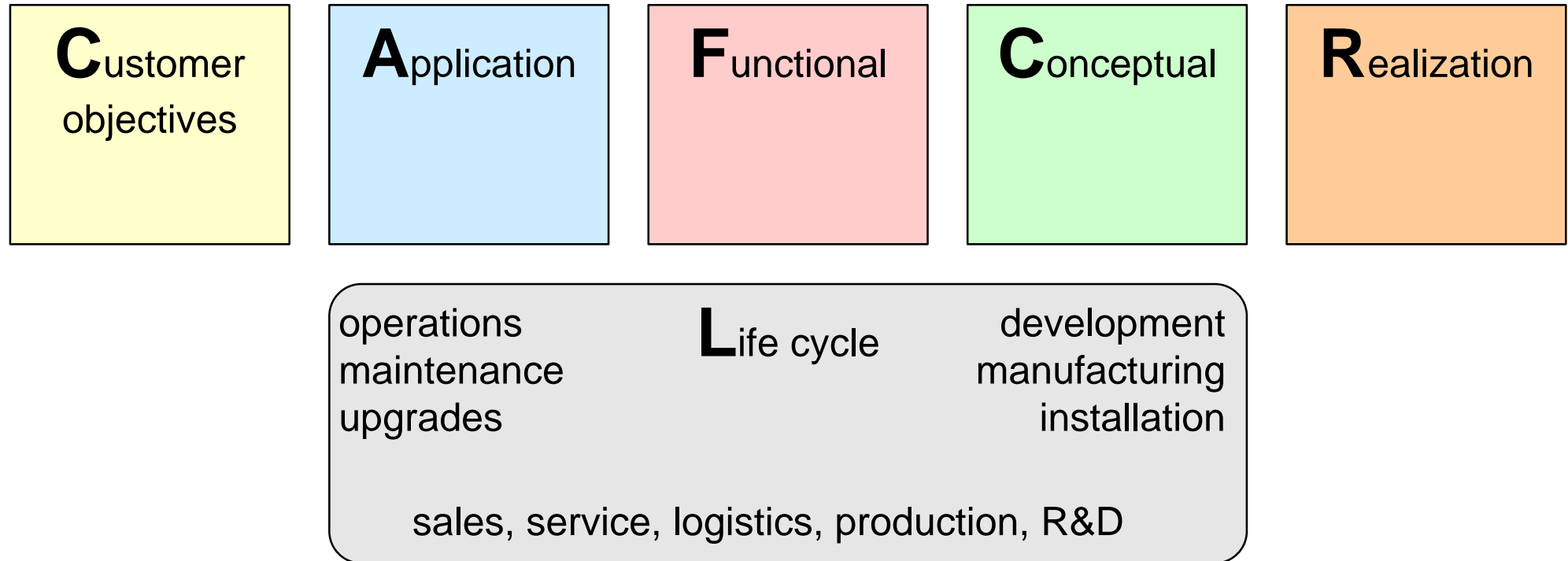
What does Customer need
in Product and **Why?**



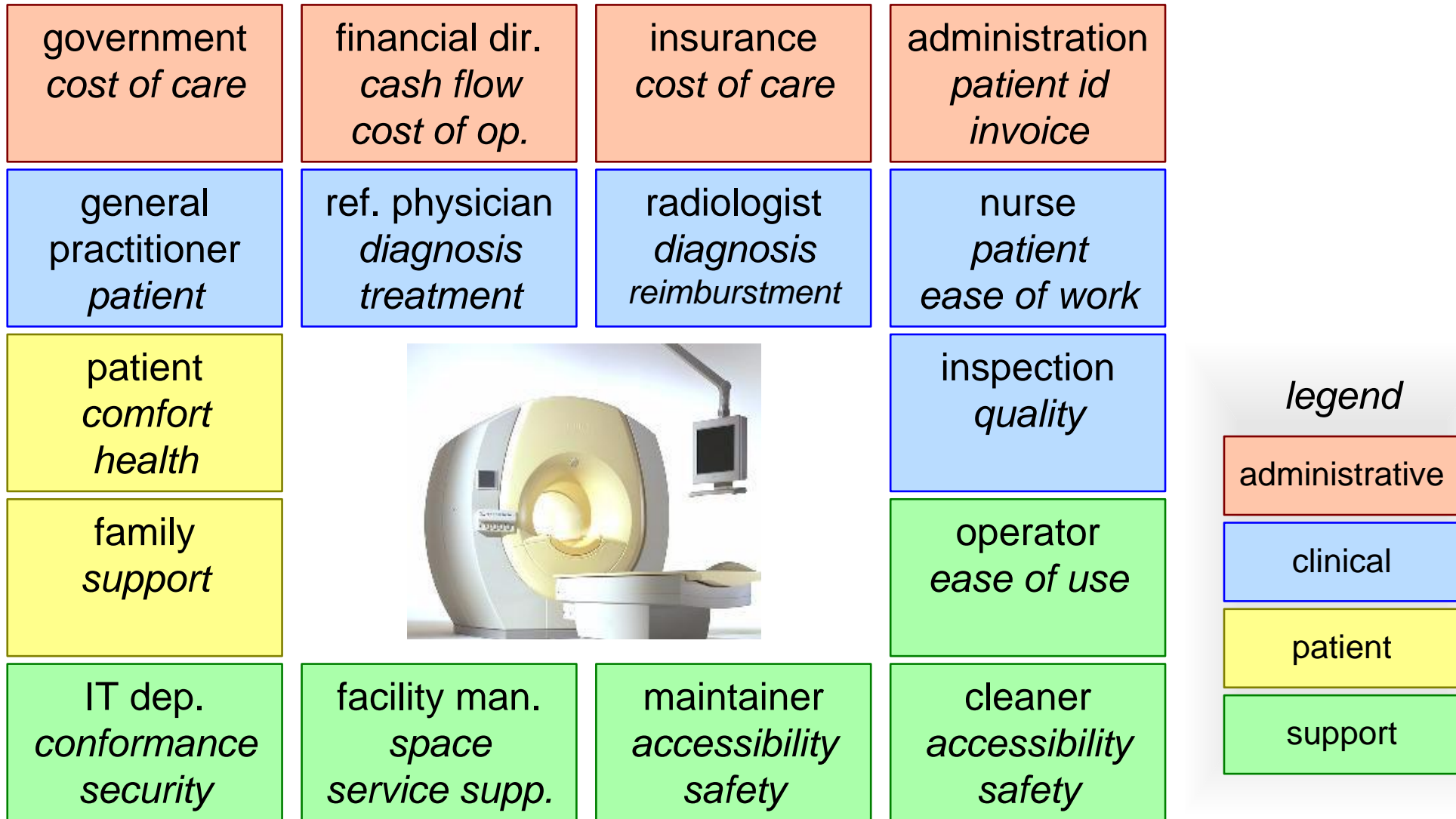
CAFCR can be applied recursively



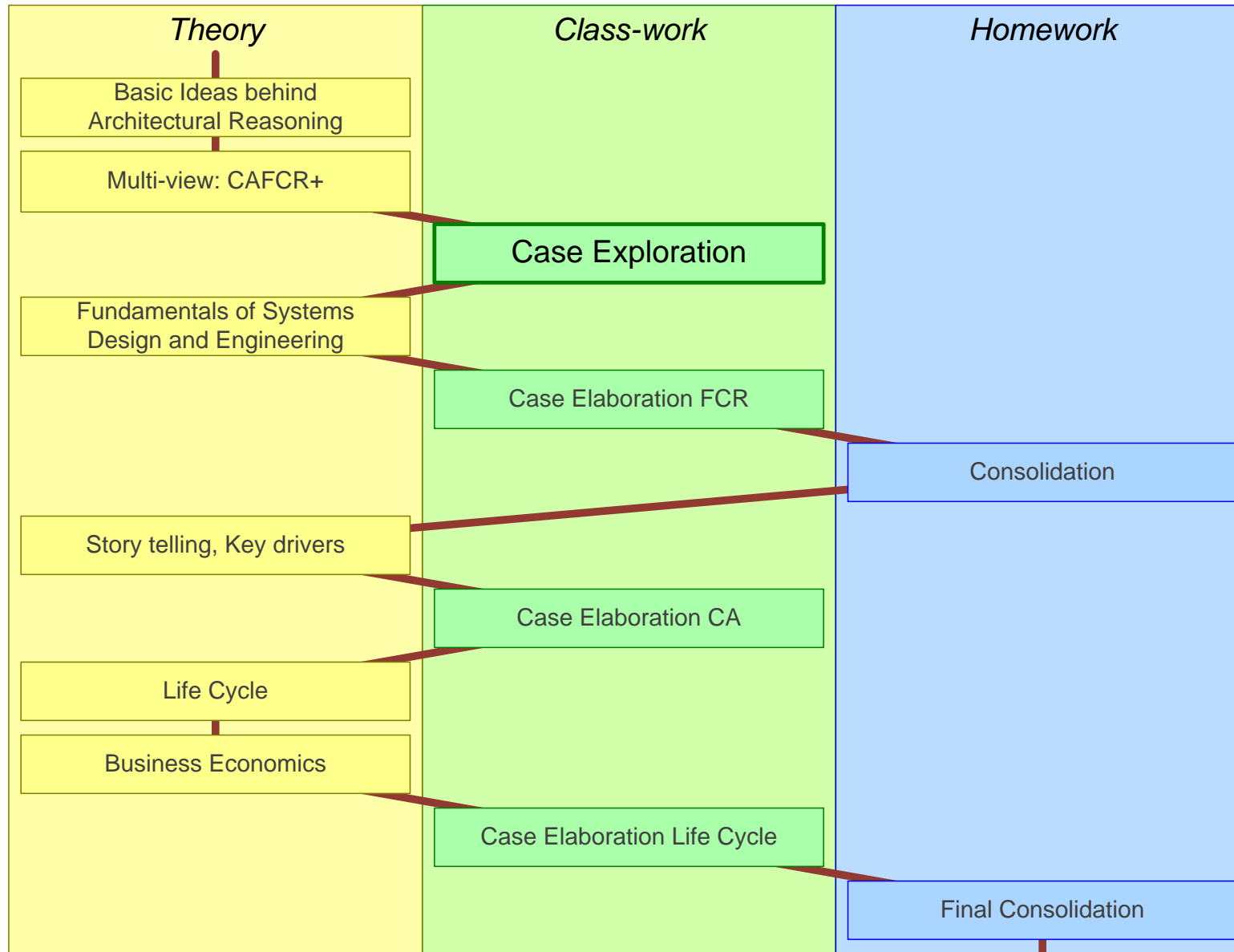
CAFCR+ model; Life Cycle View



Stakeholders and Concerns



Case Exploration



Classroom Work Instructions

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 Gerrit's office (Krona 5370) or Jamal at the end of the 4 sessions.

email Gerrit.Muller and Jamal.Safi the room number at their USN email address, when you have found a (class)room.

Some recommendations

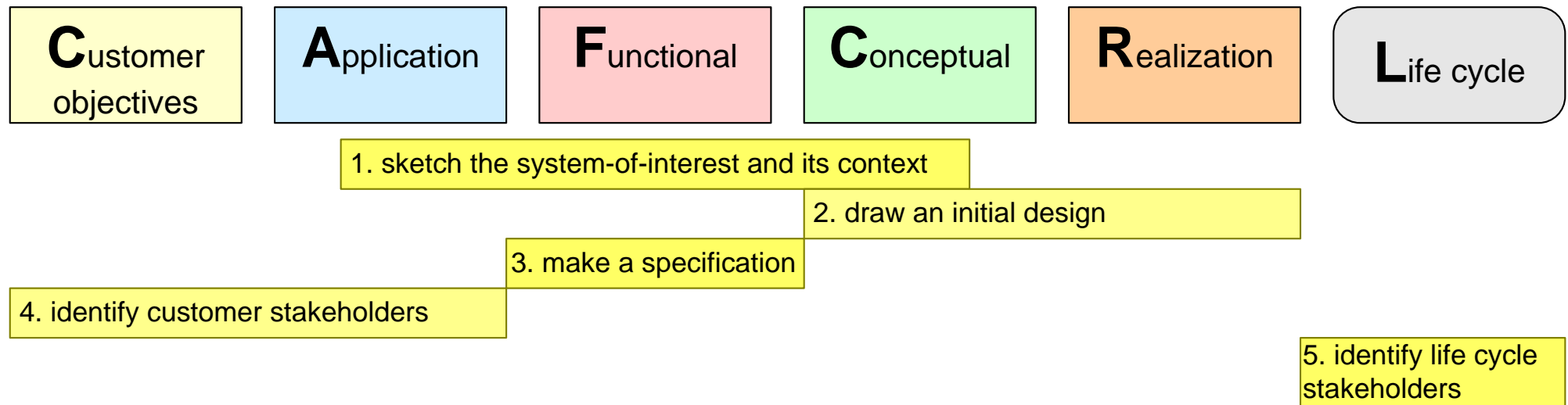
Do	Do not	Because
<ul style="list-style-type: none">• start sketching/drawing as soon as possible• use shared large sheets of paper (e.g. flip-over)• number the flip-overs and add a title• annotate (add notes) during discussions• use yellow note stickers and flip-over markers• be open for ideas and surprises	<ul style="list-style-type: none">• write long texts• immediately capture electronic• have nice but volatile discussions• write with pen or pencil• Do not stick to the first solution	<ul style="list-style-type: none">• sketches stimulate sharing and discussion• sharing and discussion help to explore faster• remembering the order gets challenging• information and insight is quickly lost• stickers are easily (re)moved• you hopefully discover a lot; increased insight will change problem and solution

Class-work Day 1: Exploration

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

Class-work Day 1 mapped on CAFCR



Theory Block: Fundamentals Systems Design and Engineering

System Designers and Engineers

Partition (decompose)

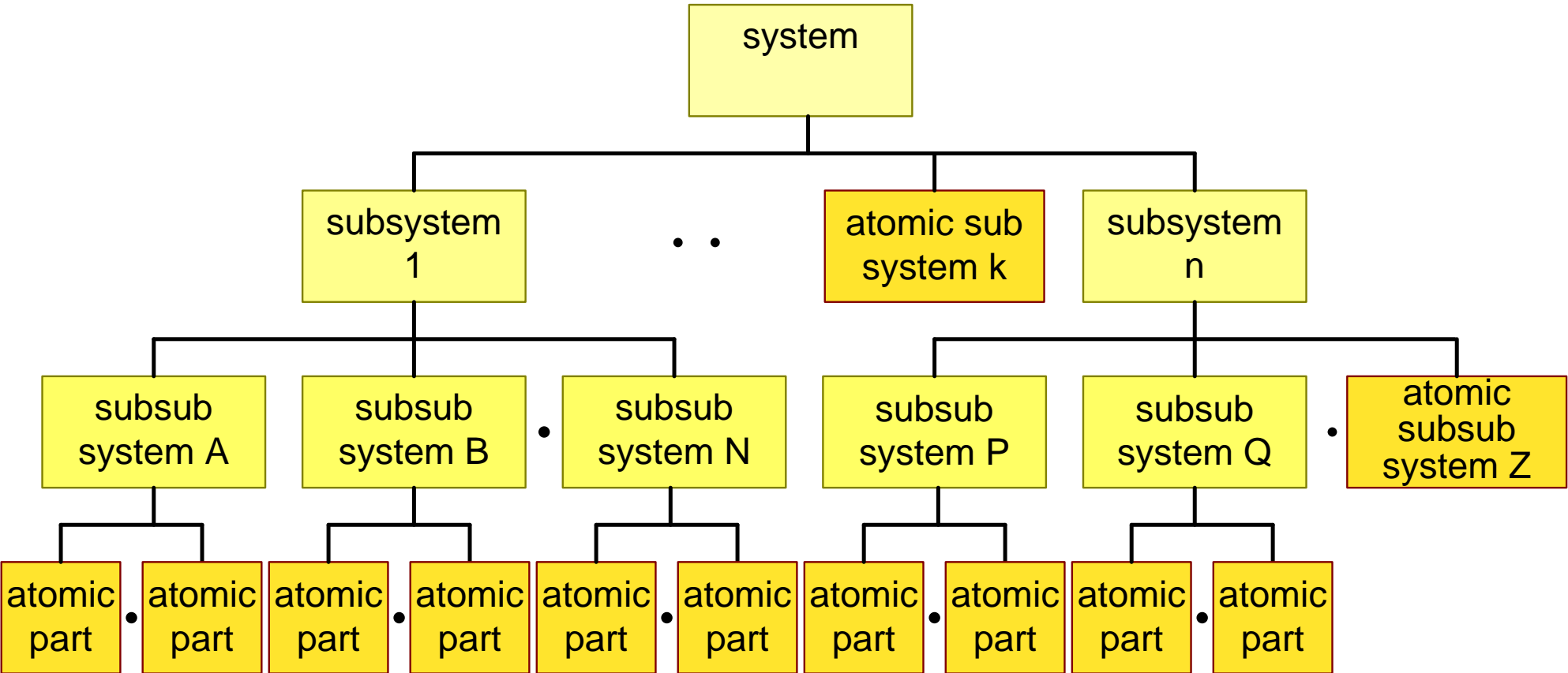
Model Dynamic Behavior (functions)

Quantify

Allocate and budget

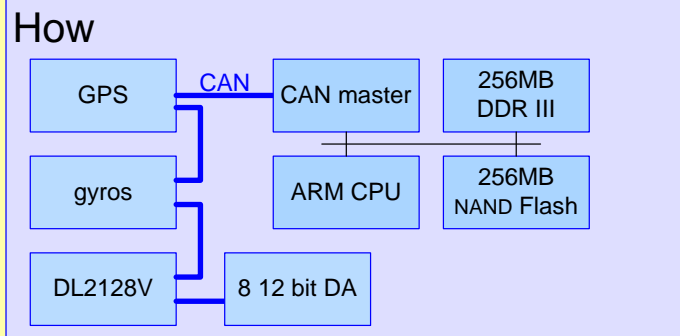
Select concepts

Partitioning is Applied Recursively

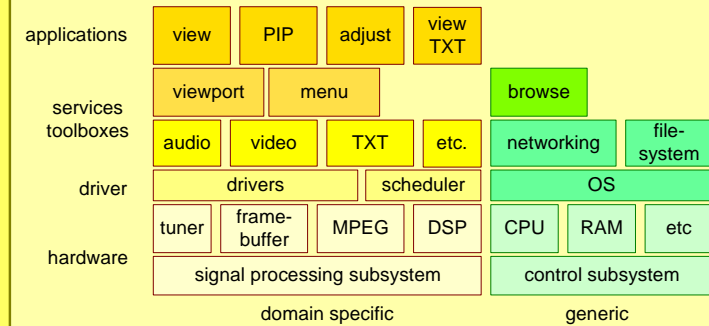


Possible Visualizations of Partitioning

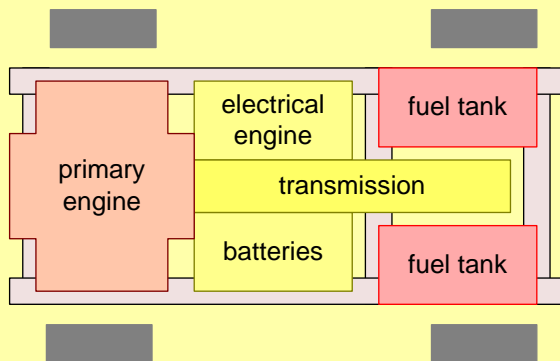
Choose a visualization from below



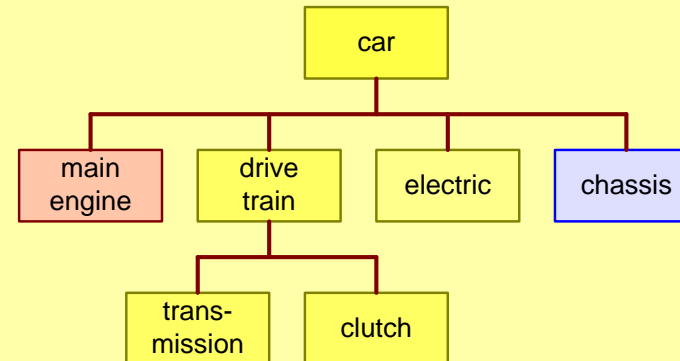
HW block diagram



SW layer diagram

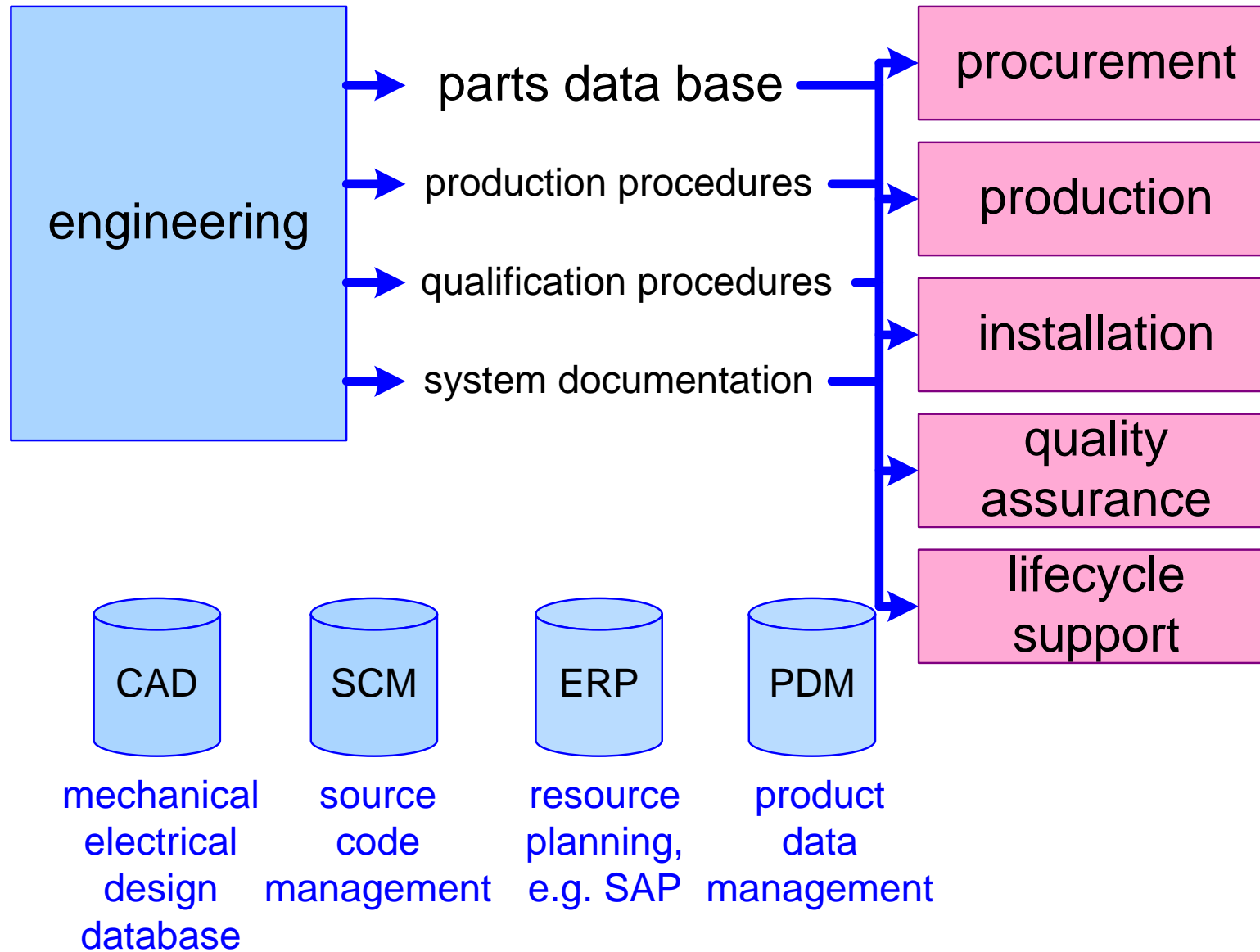


2D or 3D layout of system



abstract graph

Partitioning Dominates Many Processes



the part is cohesive

functionality and technology belongs together

the coupling with other parts is minimal

minimize interfaces

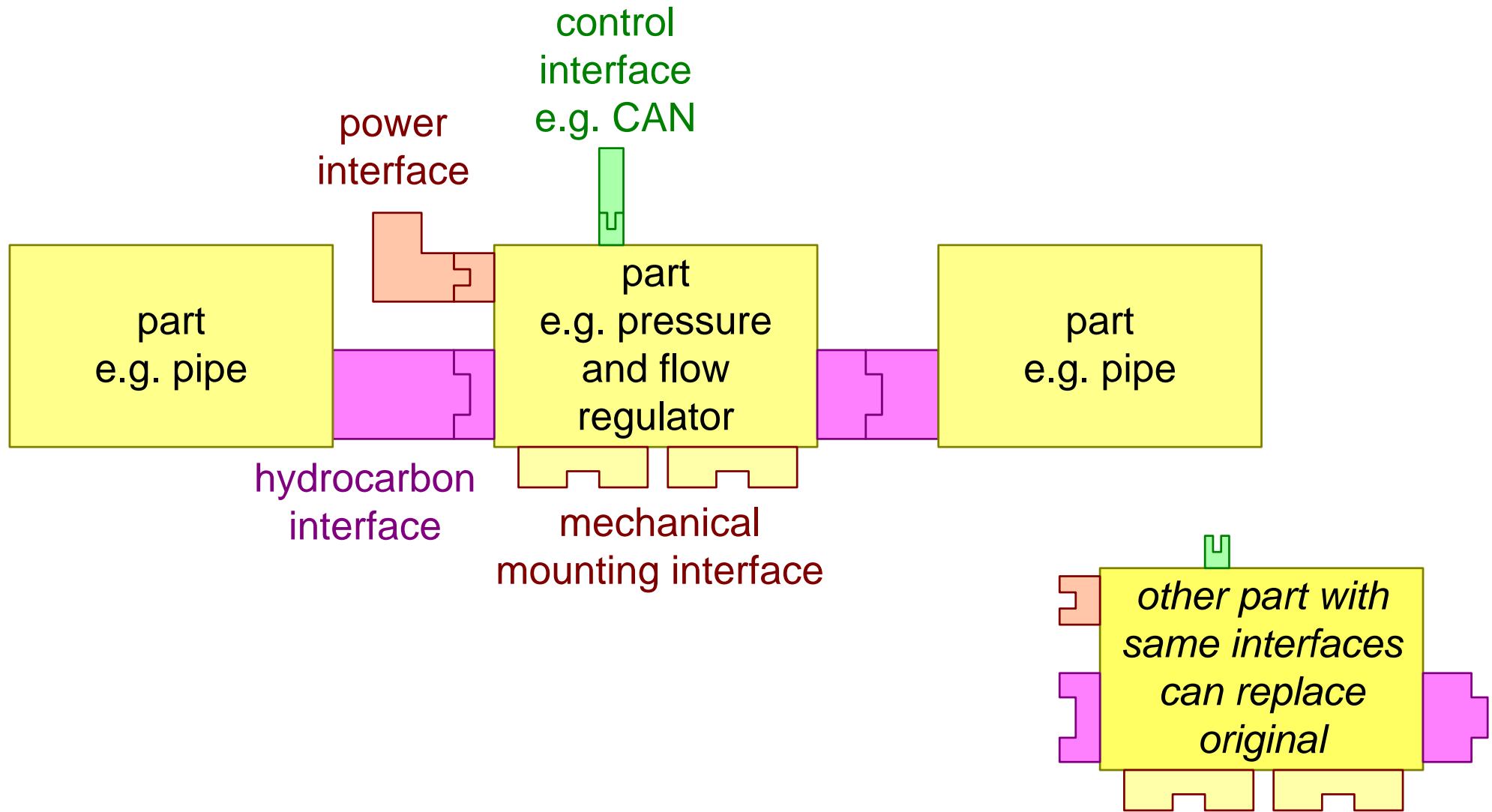
the part is self-sustained for production and qualification

can be in conflict with cost or space requirements

clear ownership of part

e.g. one department or supplier

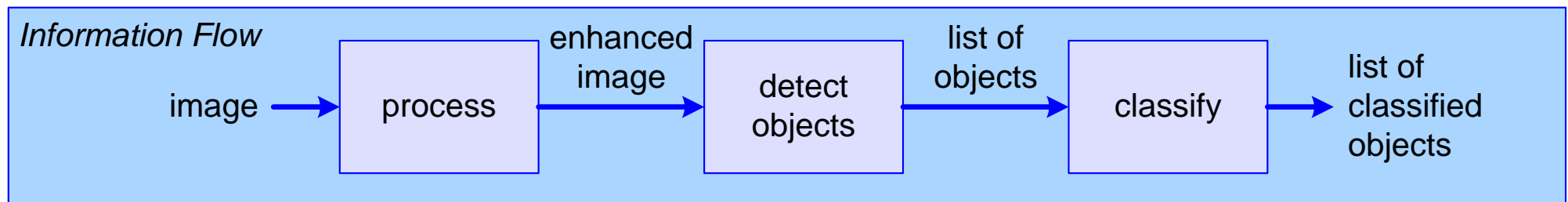
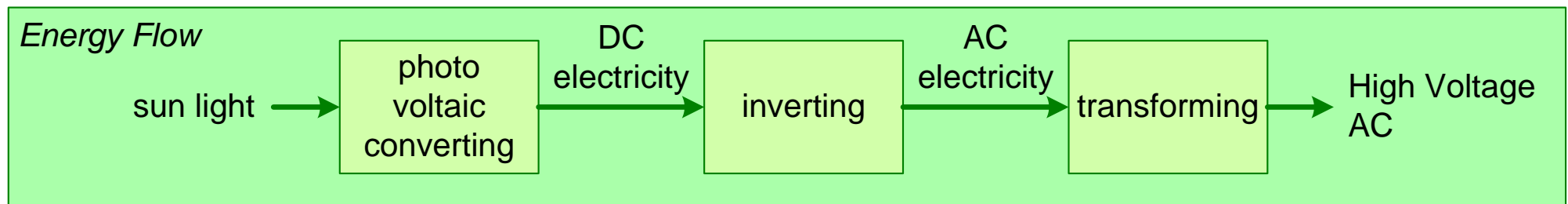
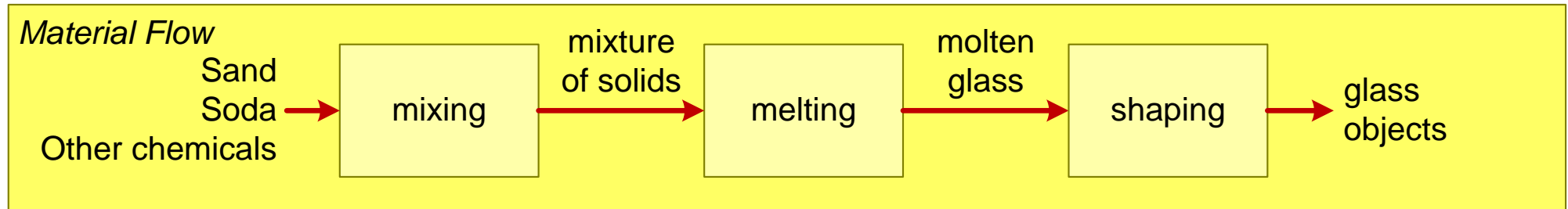
Decoupling via Interfaces



Interaction between parts takes place via exchange of

- **M**aterial
- **E**nergy
- **I**nformation

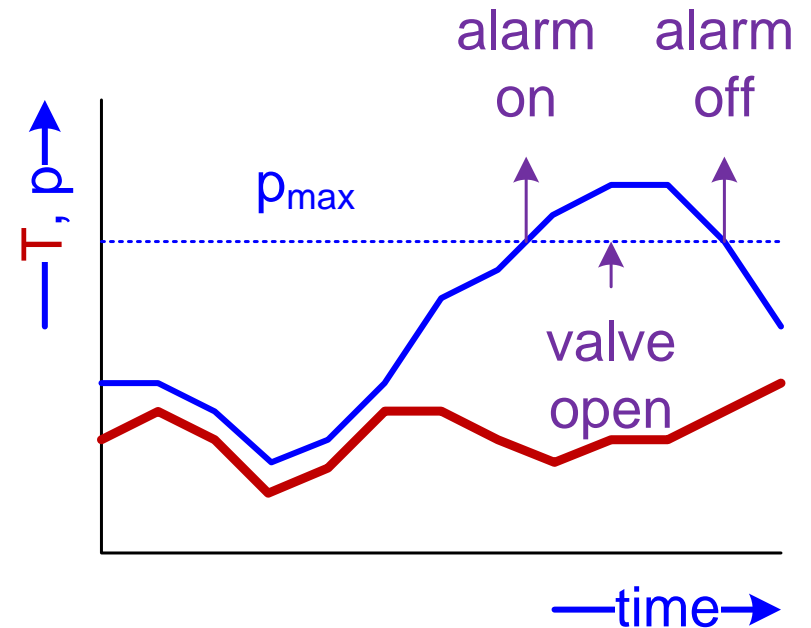
Simple Examples of MEI Flows



Dynamic Behavior and Time

Interaction between parts can take place

- continuously
for example, **temperature** or **pressure** variation due to continuous exchange of Material or Energy
- discrete (event based)
for example, an **alarm**, **command**, or a fixed period control loop



Simple Examples of Dynamic Behavior

Every second:

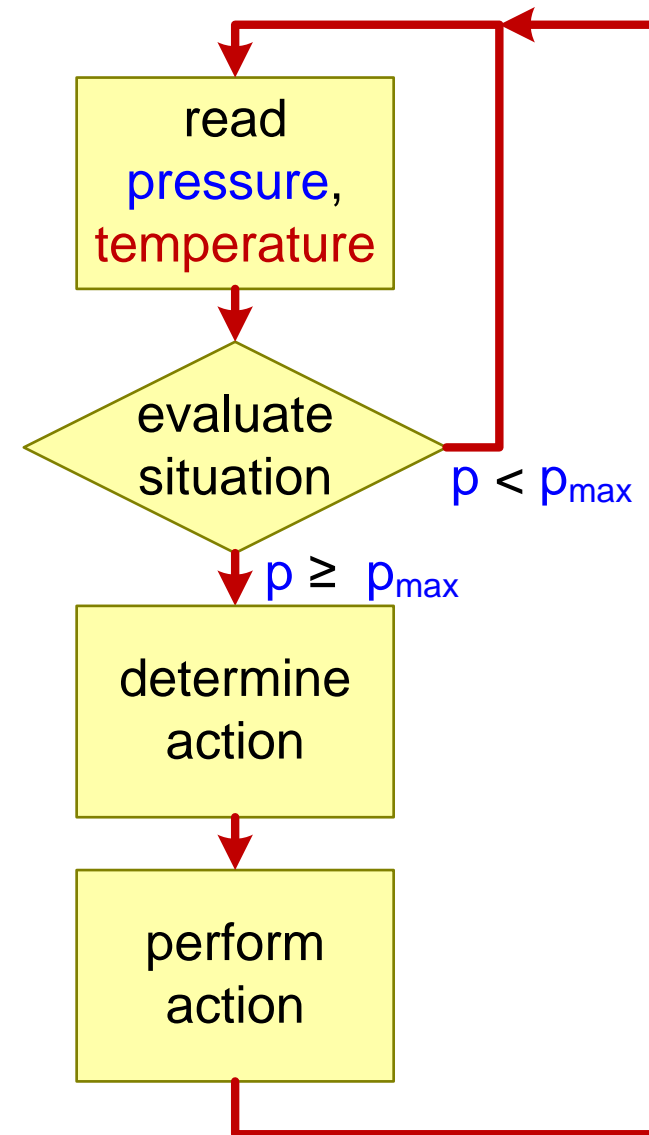
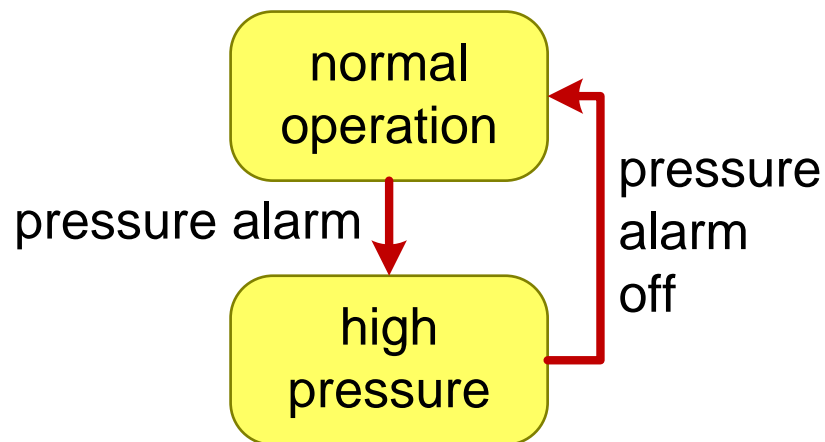
read **pressure**, **temperature**

evaluate situation (e.g., $p < p_{max}$)

determine action

(e.g., lower pressure by opening valve)

perform action (e.g. **open valve**)



Quantification

Size 2.4m * 0.7m * 1.3m

Weight 1450 Kg

Cost 30000 NoK

Reliability MTBF 4000 hr

Throughput 3000 l/hr

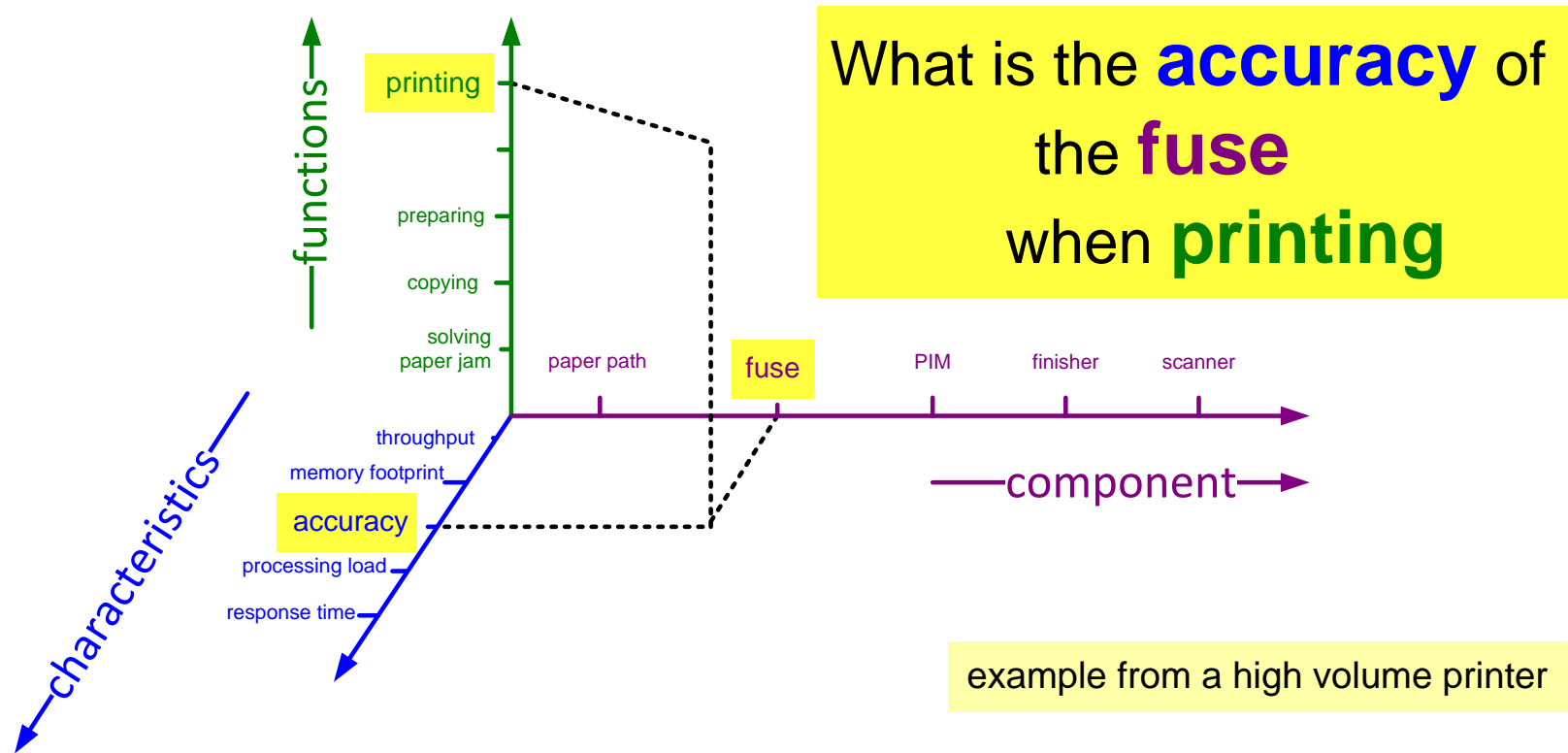
Response time 0.1 s

Accuracy +/- 0.1%

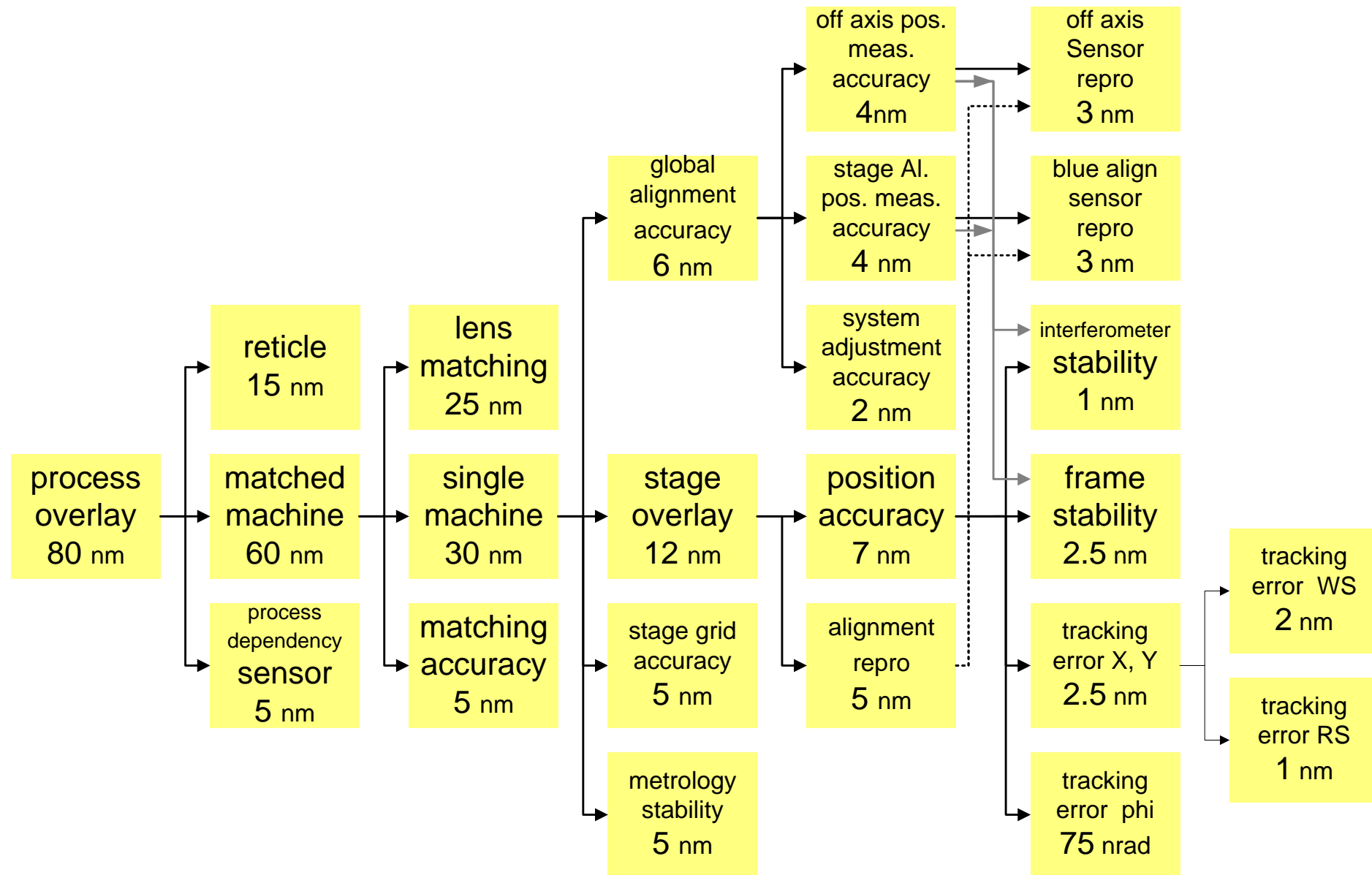
*many characteristics
of a system, function or part
can be quantified*

*Note that quantities
have a **unit***

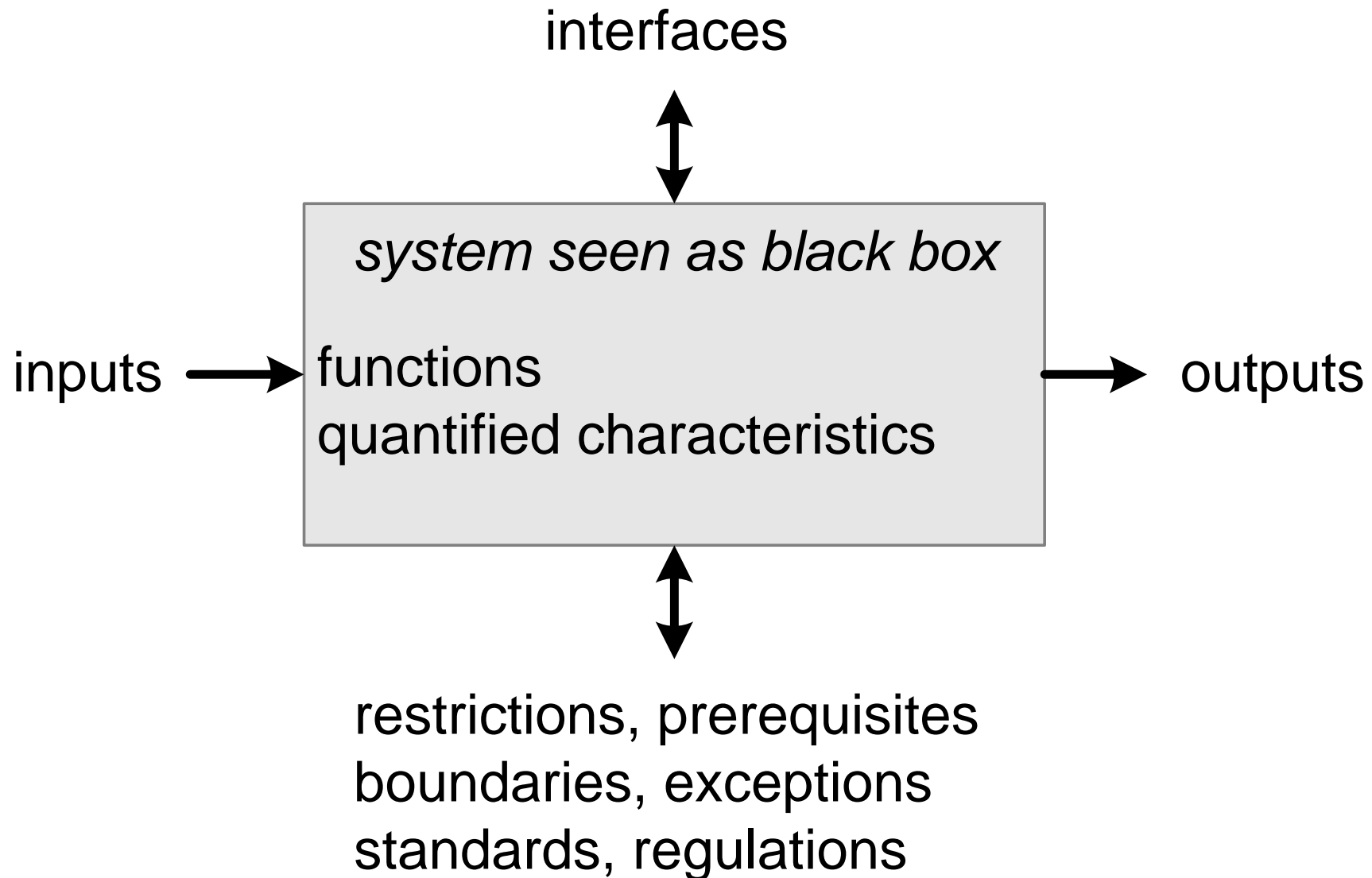
How about the **<characteristic>**
of the **<component>**
when performing **<function>**?



Technical Budget



The System-of-interest as Black Box



Key Performance Parameters

Key Performance Parameters are **SMART**

the most important

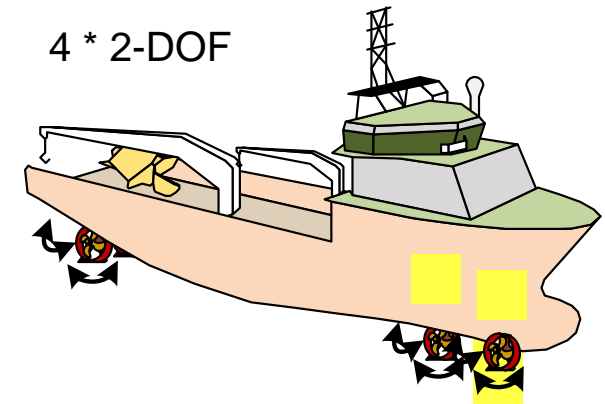
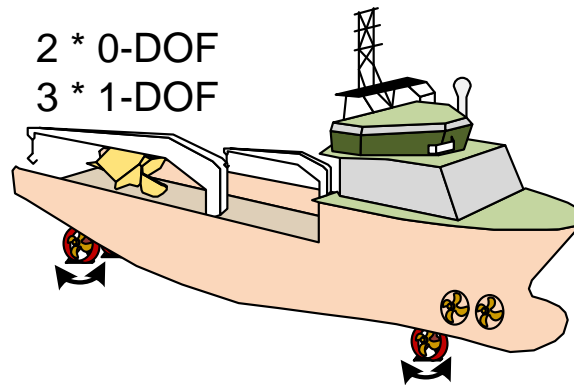
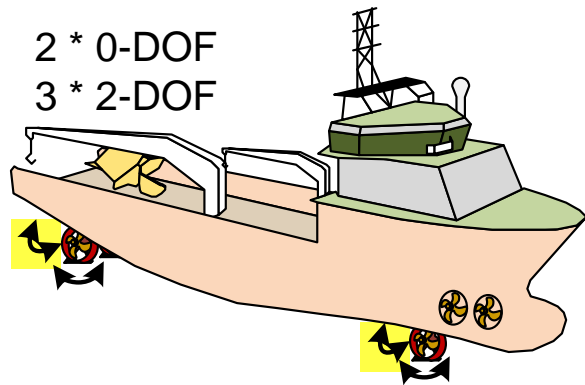
defined in use case:

the circumstances where the performance is valid

typical use with relevant (quantified!) context data

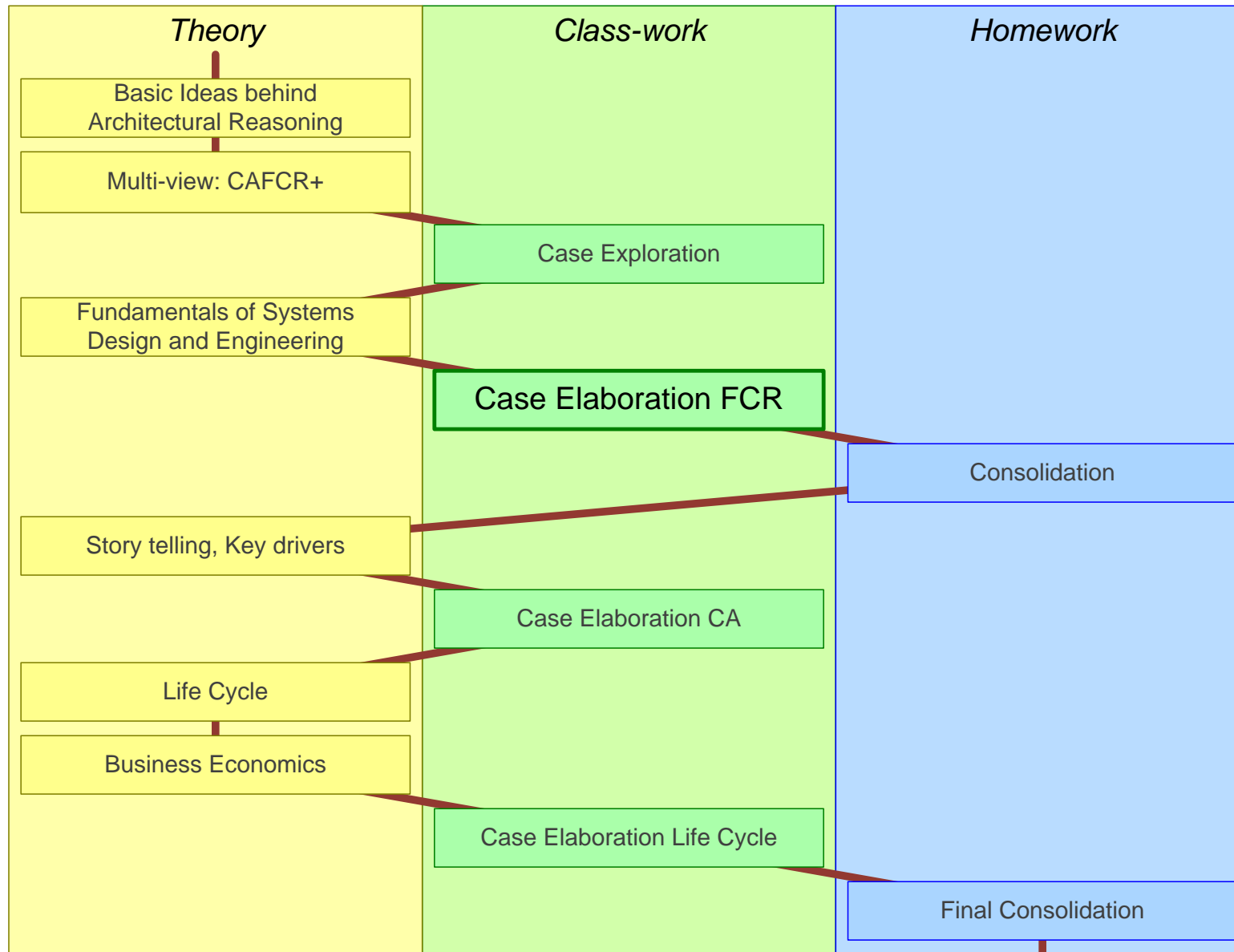
- **S**pecific quantified
- **M**easurable verifiable
- **A**chievable (Attainable, Action oriented, Acceptable, Agreed-upon, Accountable)
- **R**ealistic (Relevant, Result-Oriented)
- **T**ime-bounded (Timely , Tangible, Traceable)

Example of Pugh Matrix



Manoeuvrability	4	4	5
Energy consumption	5	3	5
Development Cost	3	4	2
Maturity (risk)	3	4	1
Purchasing Cost	3	4	3
Maintenance Cost	2	4	2

Case Elaboration FCR-views



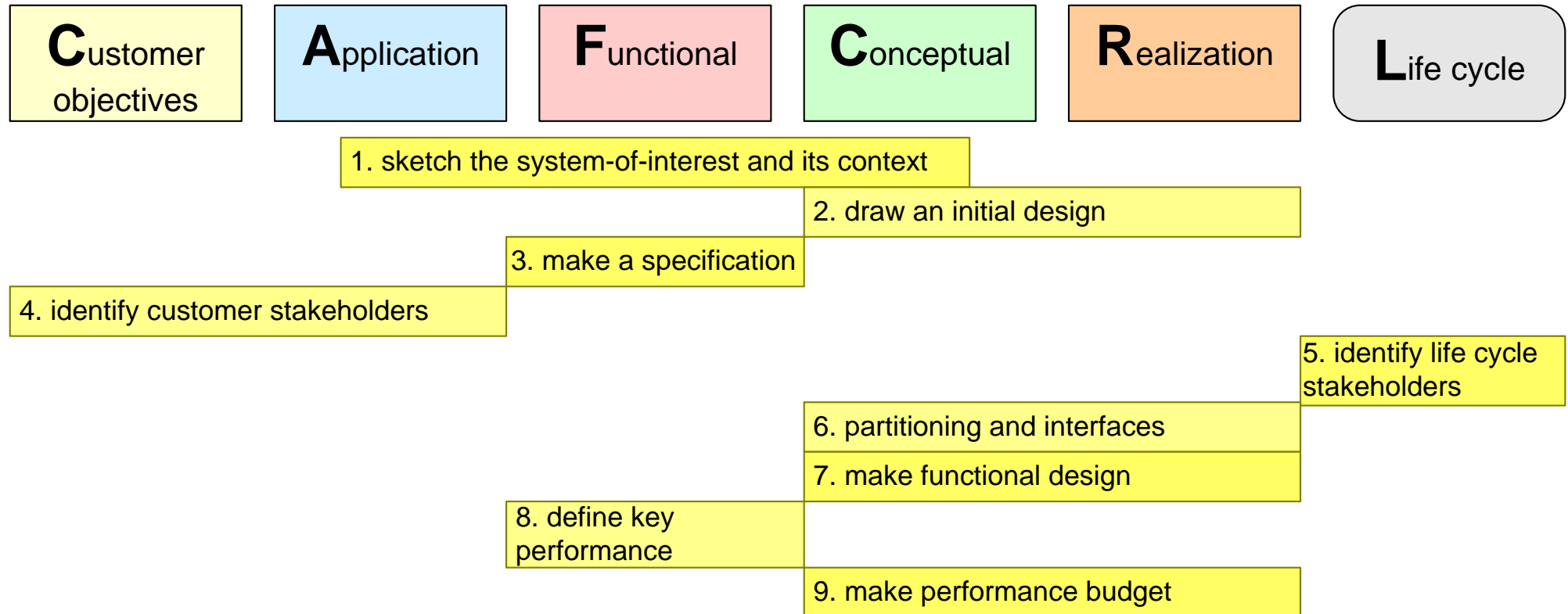
Class-work Day 2: Elaboration

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



Homework after Day 2

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

Develop two alternative solutions/concepts

Compare the three solutions using a Pugh matrix

define 5..10 criteria for comparison

score the solutions on a scale from 1 (poor) to 5 (very good)

recommend a solution with a rationale

Make a list of questions triggered by the first iteration

Search for facts to ease the next class-work

Submit as draft presentation via Canvas

Home work instructions

Homework instructions

presentation

filename: BSEAR team<your teamnumber/name> homework<number>

e.g. BSEAR team1 homework1.ppt

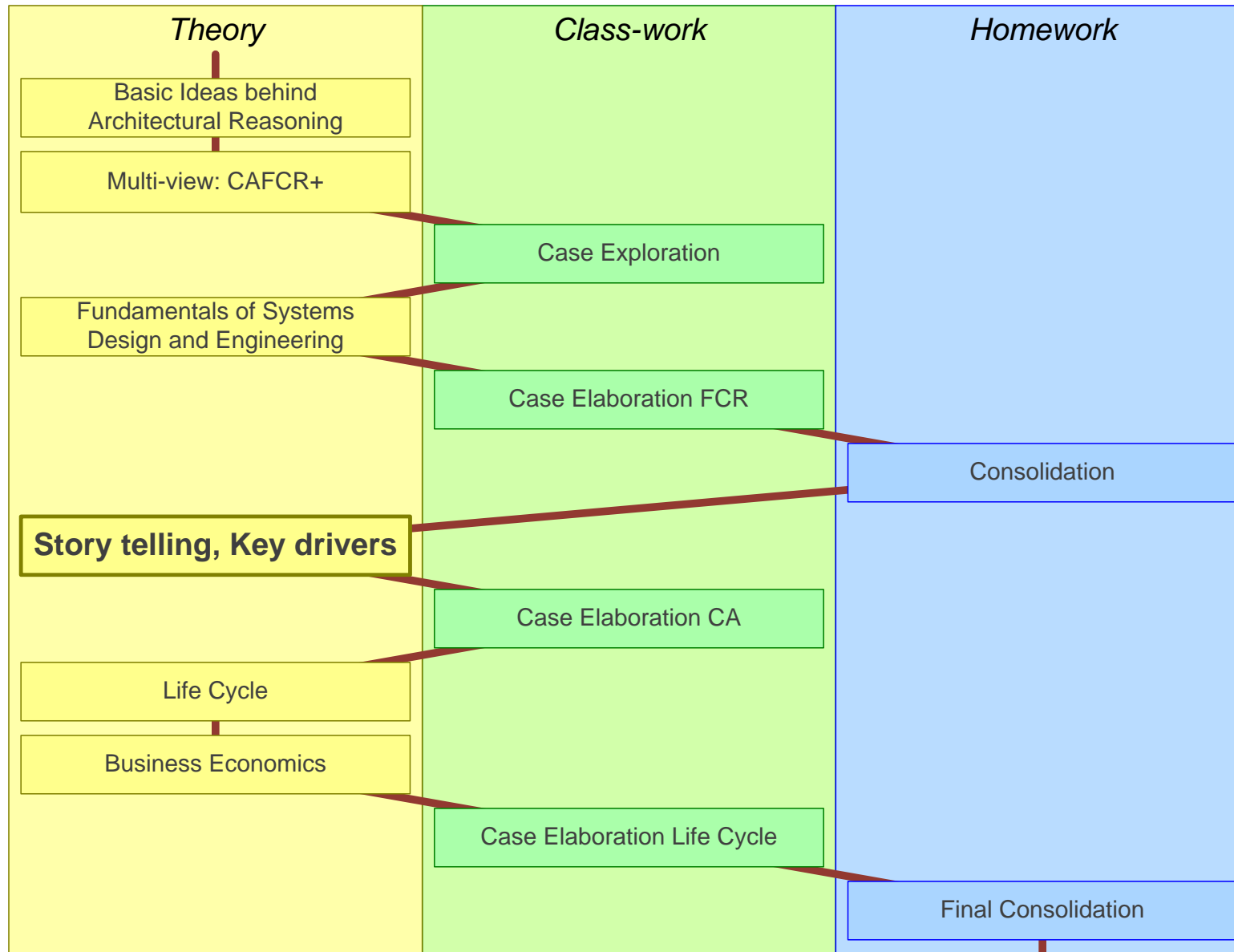
all team members on front page

upload homework to Canvas

Questions email to: <gerrit . muller@ gmail . com>

from/cc: <all email addresses of team members>

Story Telling and Key Drivers



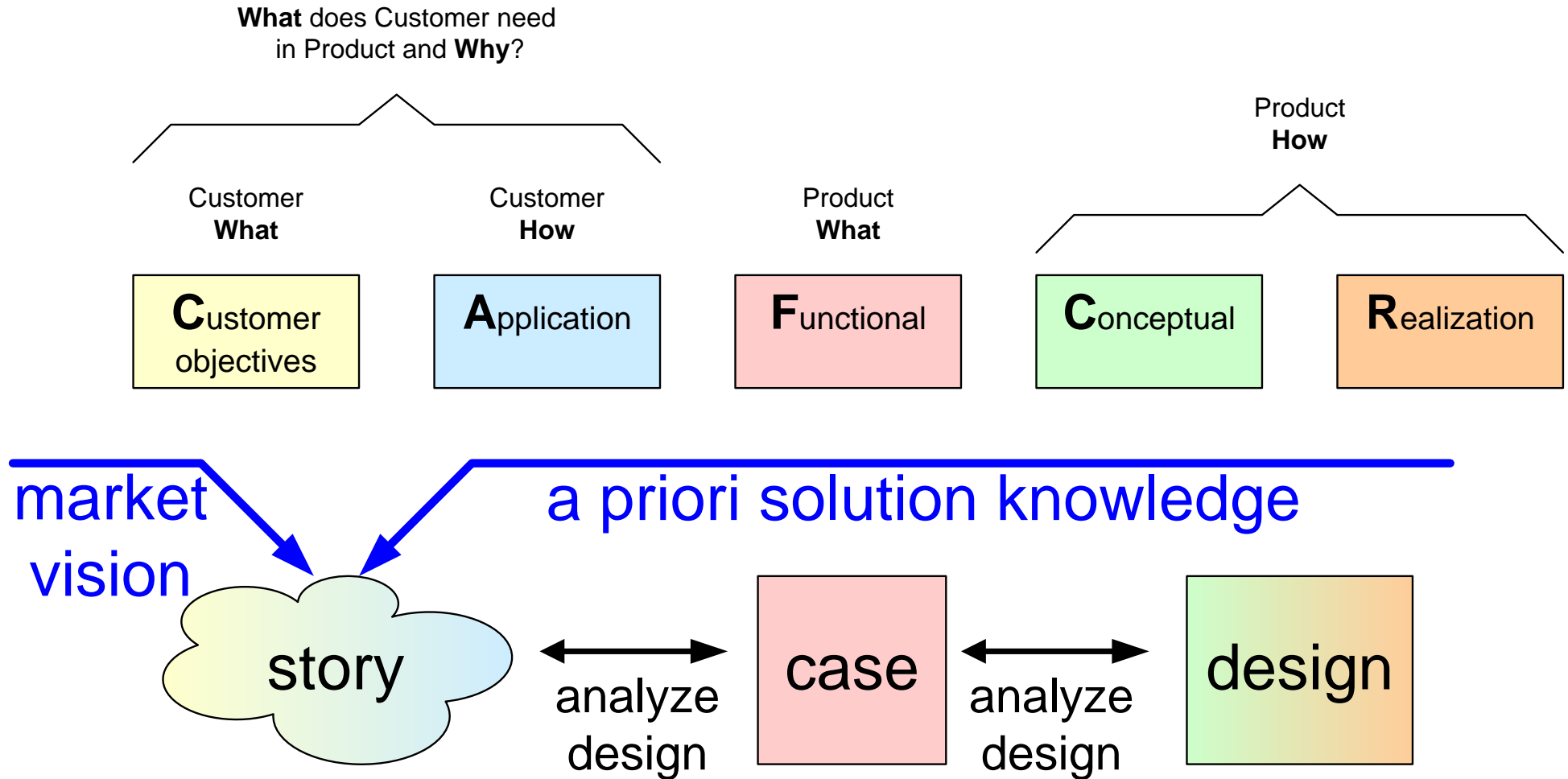
Theory Block: Understanding Customers

Story telling

Customer Key Driver Graph

Context

From story to design



Example story layout

ca. half a page of plain English text

A day in the life of Bob

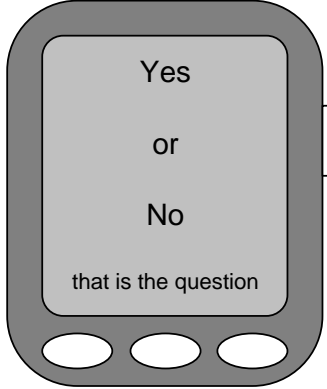
bla blah bla, rabarber music
bla bla composer bla bla
qwwwety30 zepps.

nja nja njet njippie est quo
vadis? Pjotr jaleski bla bla
bla brree fgfg gsg hgrg

mjmm bas engel heeft een
interessant excuus, lex stelt
voor om vanavond door te
werken.

In the middle of the night he
is awake and decides to
change the world forever.

The next hour the great
event takes place:



Yes
or
No
that is the question

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

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

He opens his PDA, logs in and enters his provate secure unquie 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.

draft or sketch of some essential appliance

Criteria for a good story

Customer objectives
Application

- accessible, understandable

"Do you see it in front of you?"

Customer objectives
Application

- valuable, appealing

attractive, important

"Are customers queuing up for this?"

Conceptual
Realization

- critical, challenging

"What is difficult in the realization?"

"What do you learn w.r.t. the design?"

Application

- frequent, no exceptional niche

"Does it add significantly to the bottom line?"

Application
Functional

- specific

names, ages, amounts, durations, titles, ...

Example of a story

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 of 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.



source: Roland Mathijssen
Embedded Systems Institute
Eindhoven

Value and Challenges in this story

Customer objectives

Application

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

Conceptual

Realization

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

Story: Workover Anno 2015



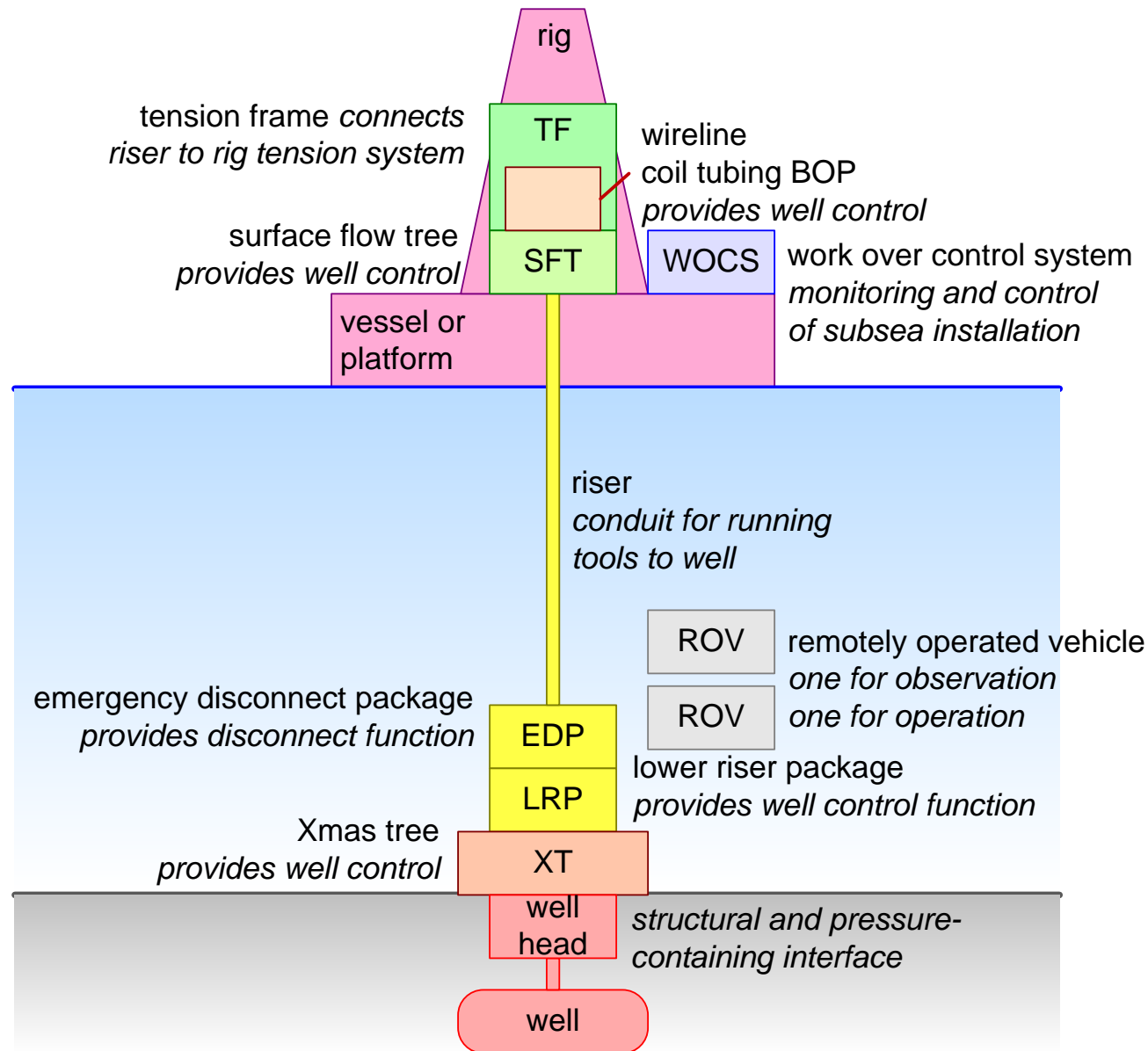
On September 4, Captain Frode Johansen was discussing the plans for the upcoming workover of South Gullfaks (see <http://www.npd.no/en/Publications/Facts/Facts-2011/Chapter-10/Gullfaks-Sor-/>) with his crew. Their vessel had been out of operation for recertification of the equipment much longer than 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.

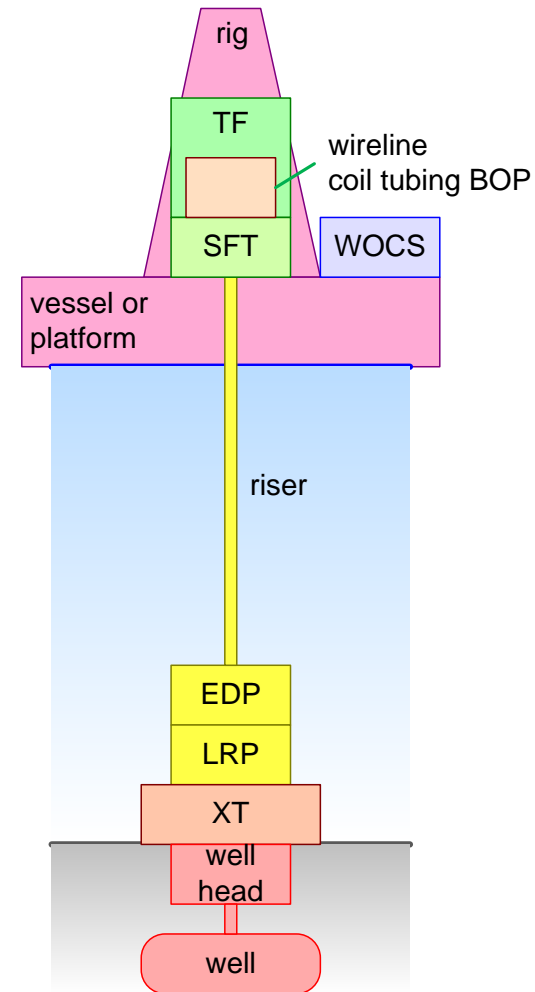
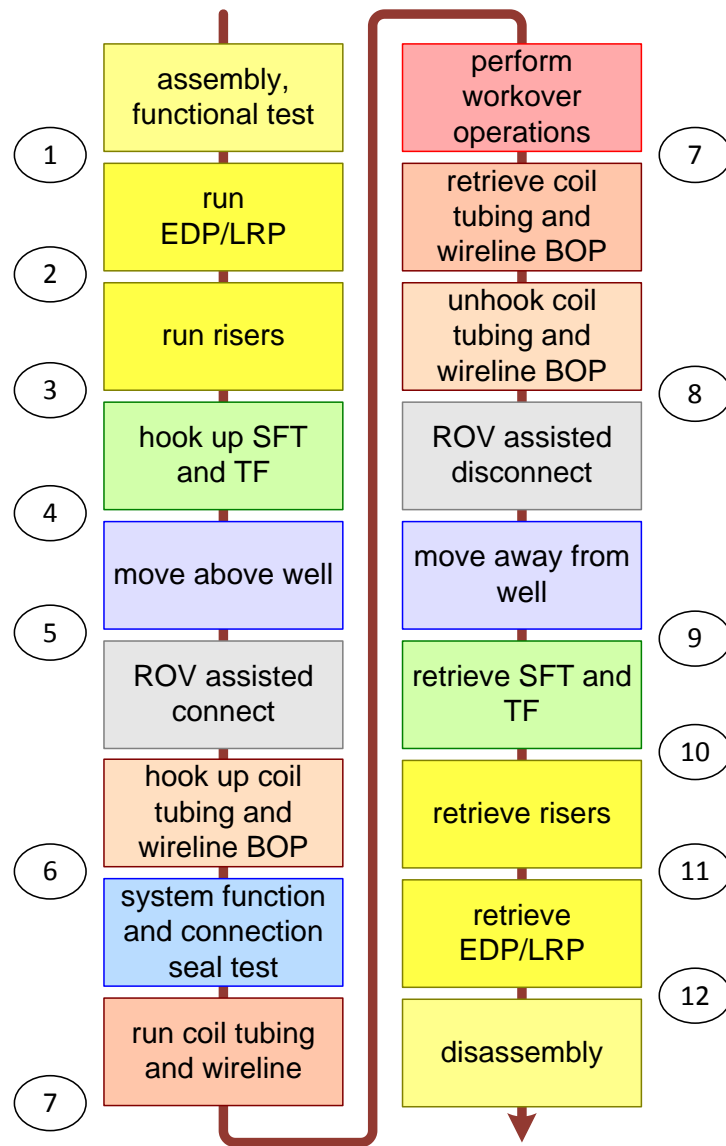
The weather forecast shows a depression close to Iceland that moves slowly in Norway's direction. If they can start deployment of the riser on September 7, then they probably finish the workover before the storm associated with the depression is too severe.

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.

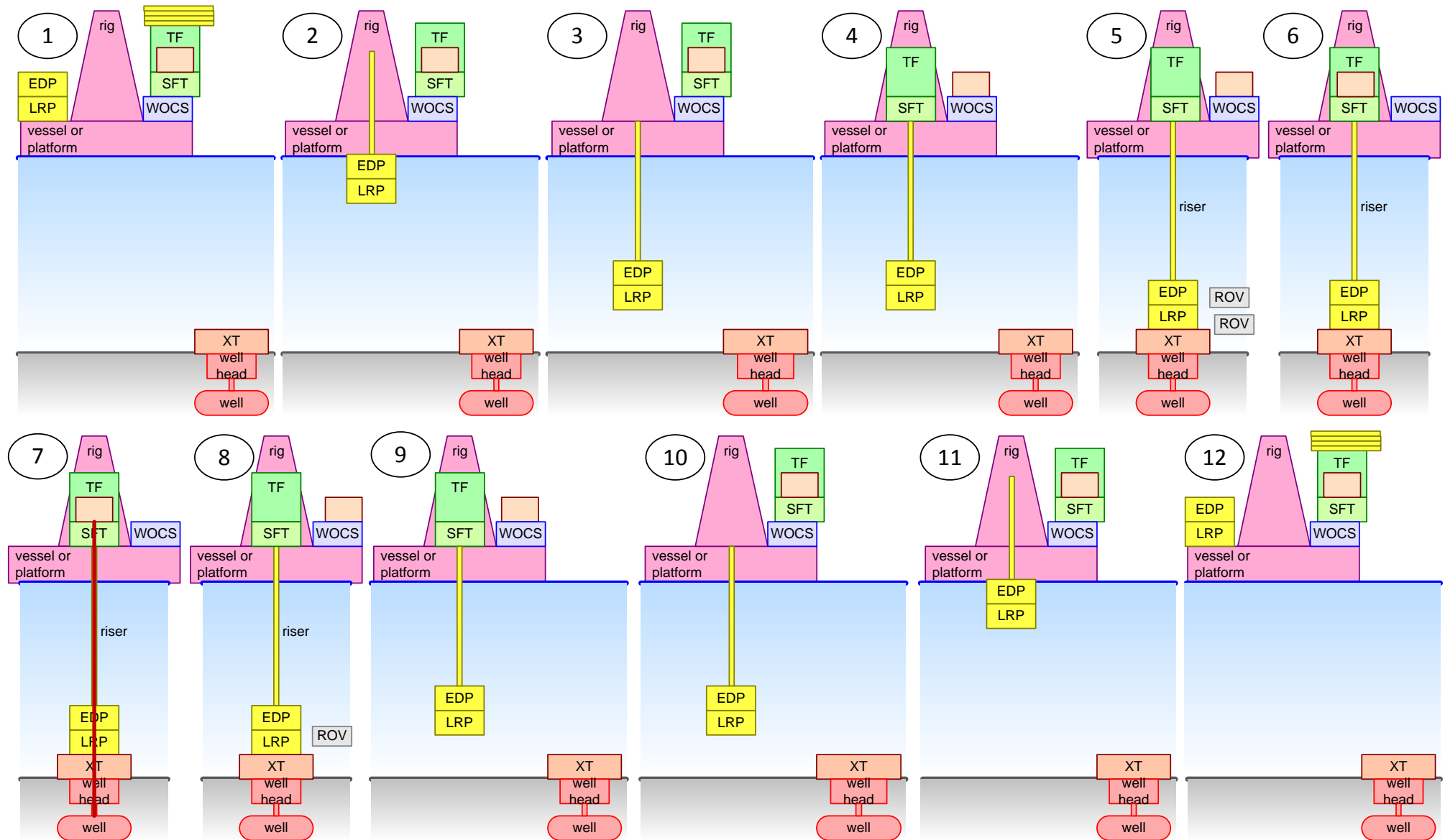
Annotated Physical Diagram of WorkOver System



Typical Workover Operation

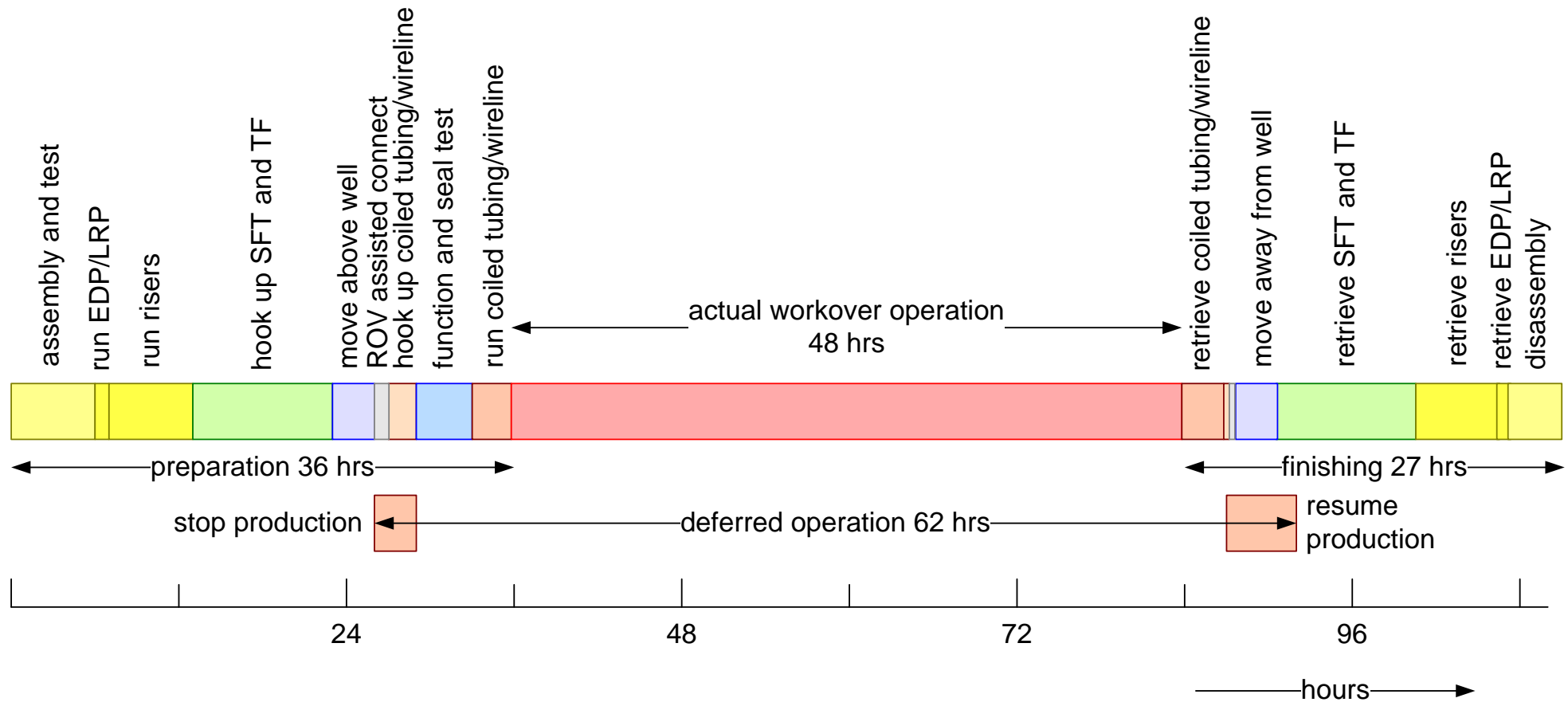


Typical Workover Operation as Cartoon

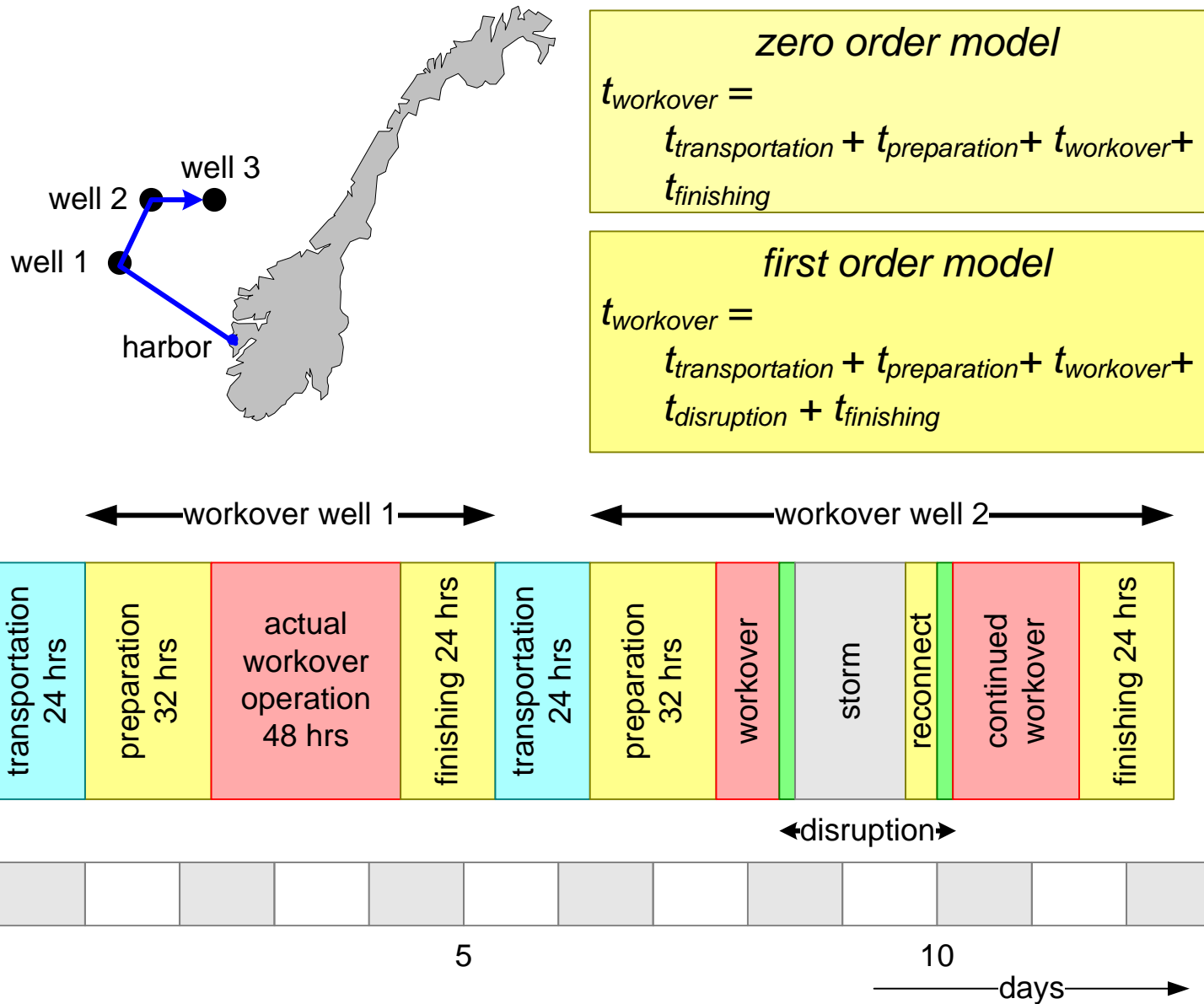


Typical Workover Operation on Timeline

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



Typical Workover Operation Context



0-order Cost Model Workover Operation

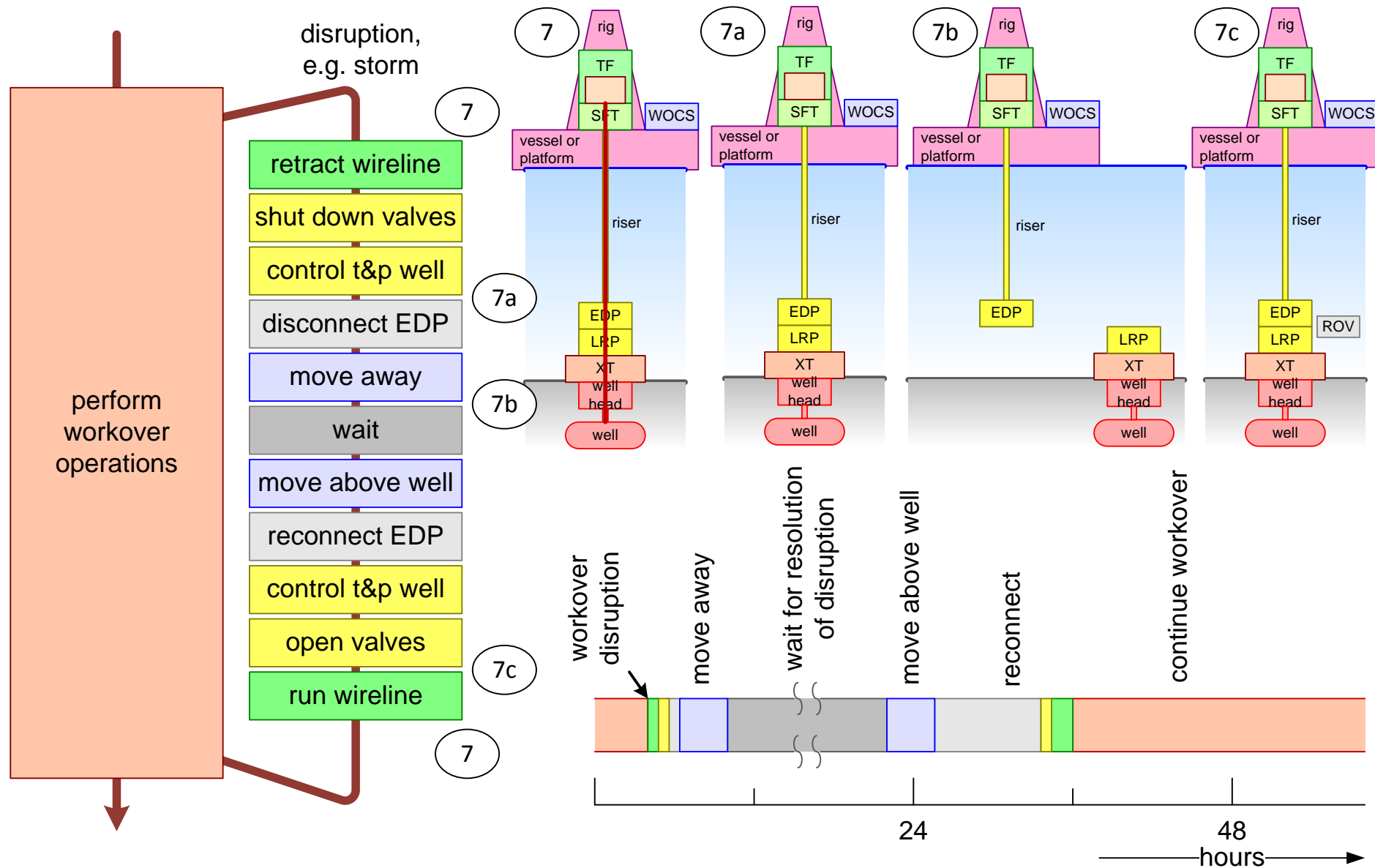
<i>workover cost per day</i>	<i>assumed cost (MNoK)</i>	<i>workover duration</i>	<i>estimated duration (hours)</i>
platform, rig	2	transportation	24 <i>production loss</i>
equipment	0.2	preparation	36 6
crew	0.1	workover	48 48
total	2.3 MNoK/day	finishing	27 8
		total	135 (5.6 days) 62 (2.6 days)

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

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

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

Disruption Workover Operation



First order Cost Model Workover Operation

<i>workover cost per day</i>	<i>assumed cost (MNoK)</i>	<i>workover duration</i>	<i>estimated duration (hours)</i>
platform, rig	2	workover 0-order average disruption duration overhead disruption frequency 1 st order disruption correction	<i>production loss</i> 135 (5.6 days) 62 (2.6 days)
equipment	0.2		72
crew	0.1		11
total	2.3 MNoK/day		0.3
<i>deferred operation per day</i>	<i>assumed cost (MNoK)</i>	<i>total</i>	162 (6.7 days) 89 (3.7 days)
production delay	0.1		
ongoing cost operation	0.2		
total	0.3 MNoK/day		

$$1^{\text{st}} \text{ order COST} = \text{COST}_{\text{workover/day}} * t_{\text{workover}} + \text{COST}_{\text{deferred op./day}} * t_{\text{deferred op.}}$$

$$\sim = 2.3 * 6.7 + 0.3 * 3.7 \sim = 16.5 \text{ MNoK / workover}$$

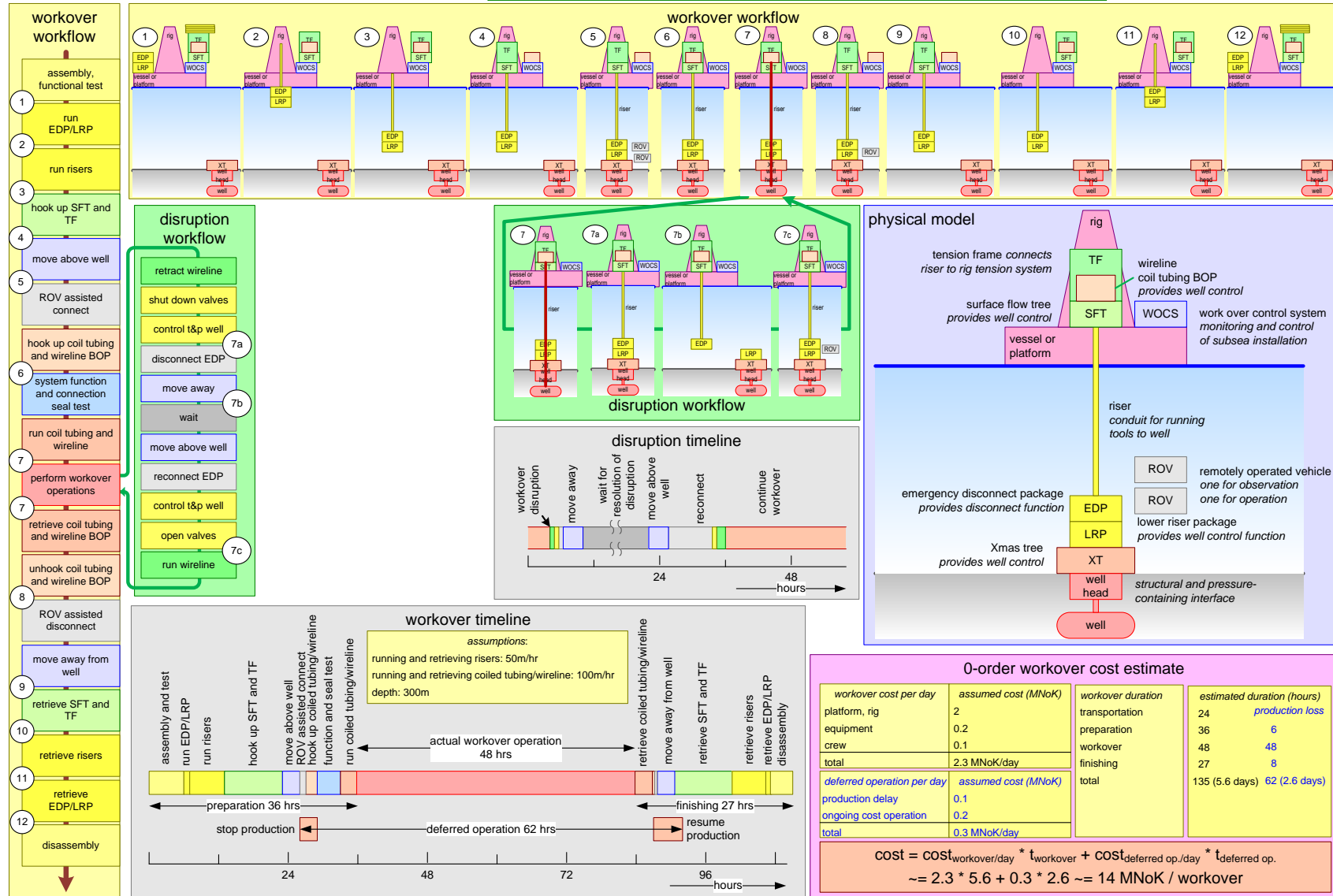
$$0\text{-order cost} \sim = 14 \text{ MNoK ; disruption cost} \sim = 2.5 \text{ MNoK}$$

Workover Example Summary

Workover operation; architecture overview

This A3 based on the work of SEMA participants: Martin Moberg^a, Tormod Strand^b, Vazgen Karlsen^c, and Damien Wee^d, and the master project paper by Dag Jostein Klever^e. ^aAker Solutions, ^fMC Technologies

version 2.2 Gerrit Muller

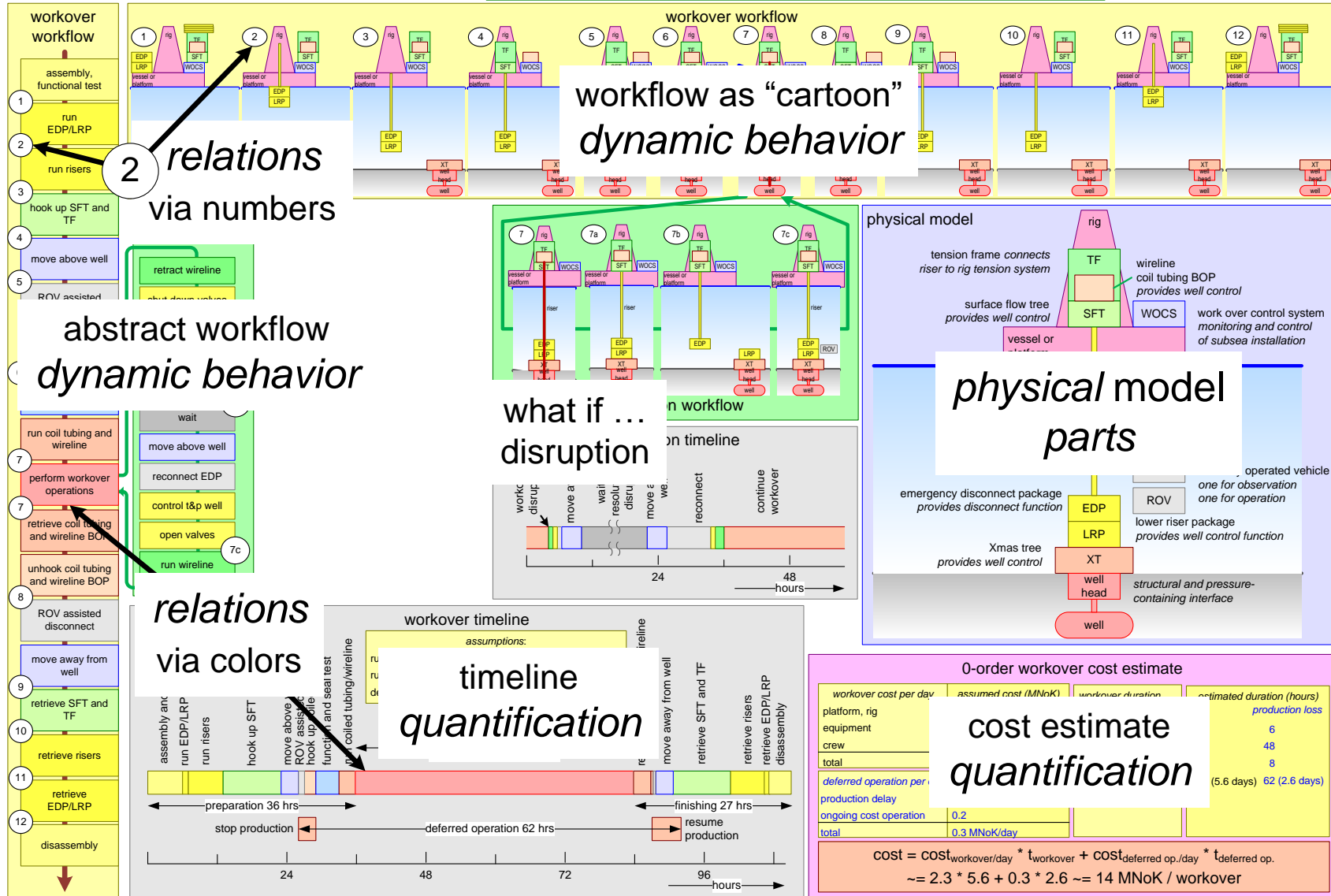


A3 Architecture Overview

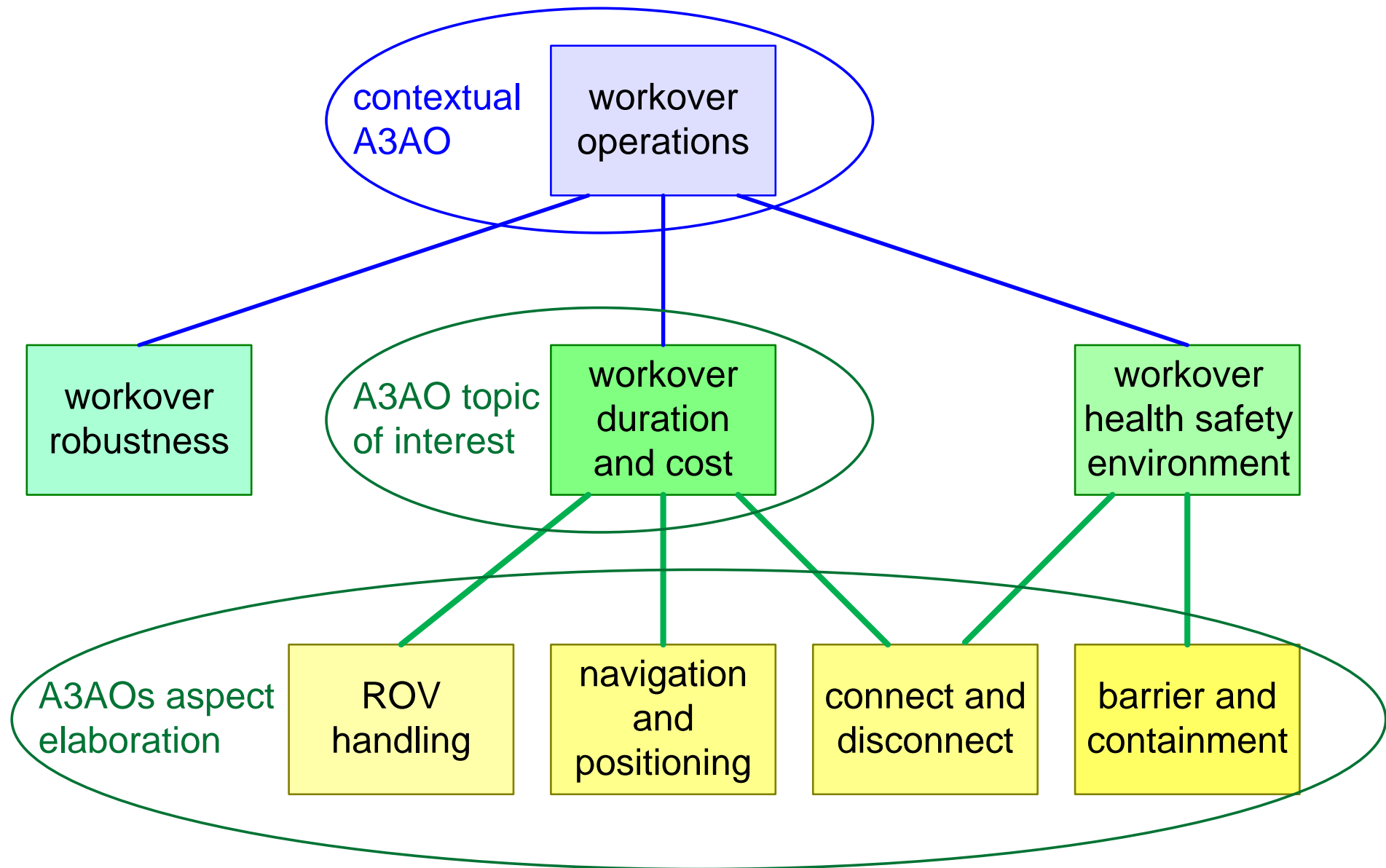
Workover operation; architecture overview

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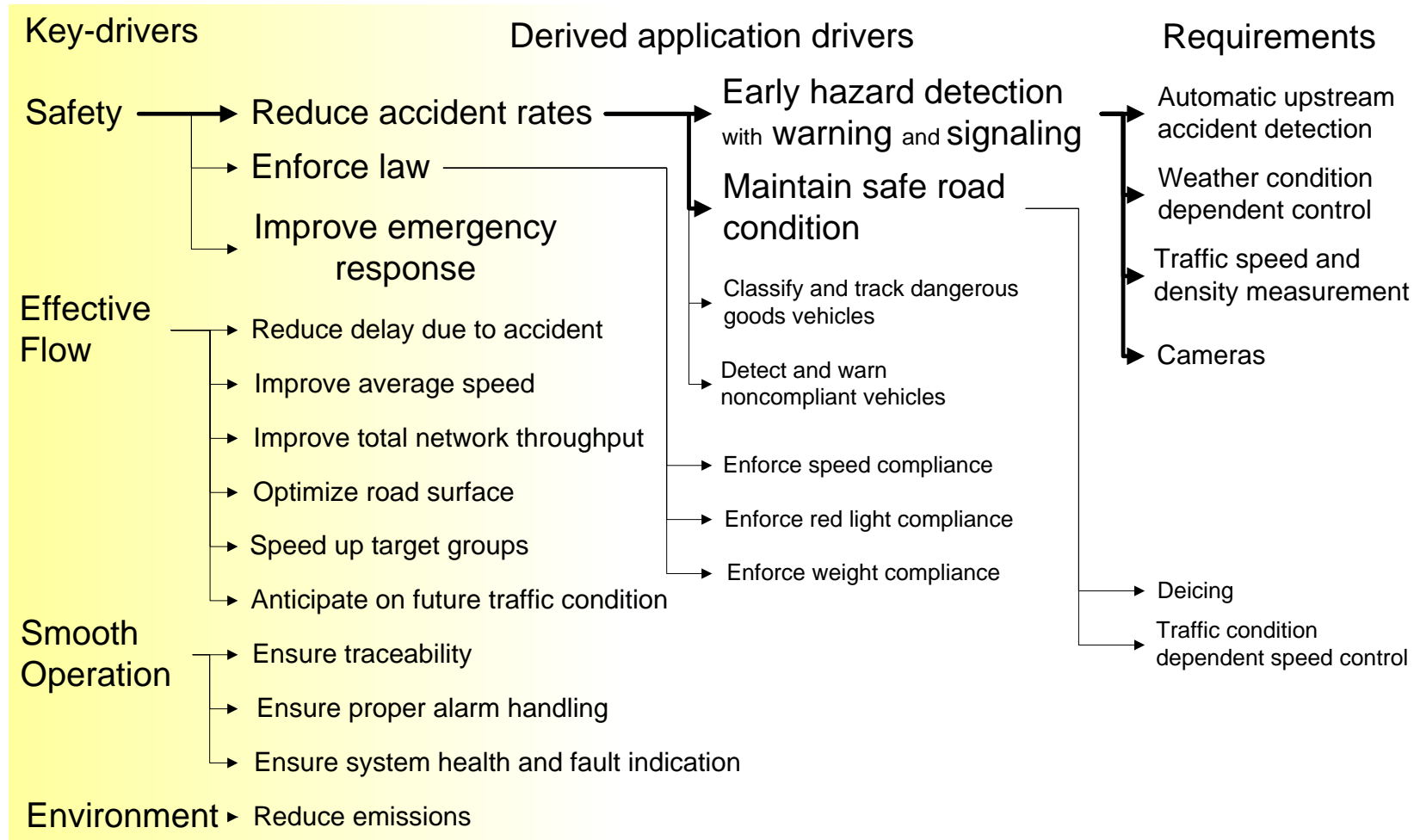
version 2.2 Gerrit Muller



Levels of A3s

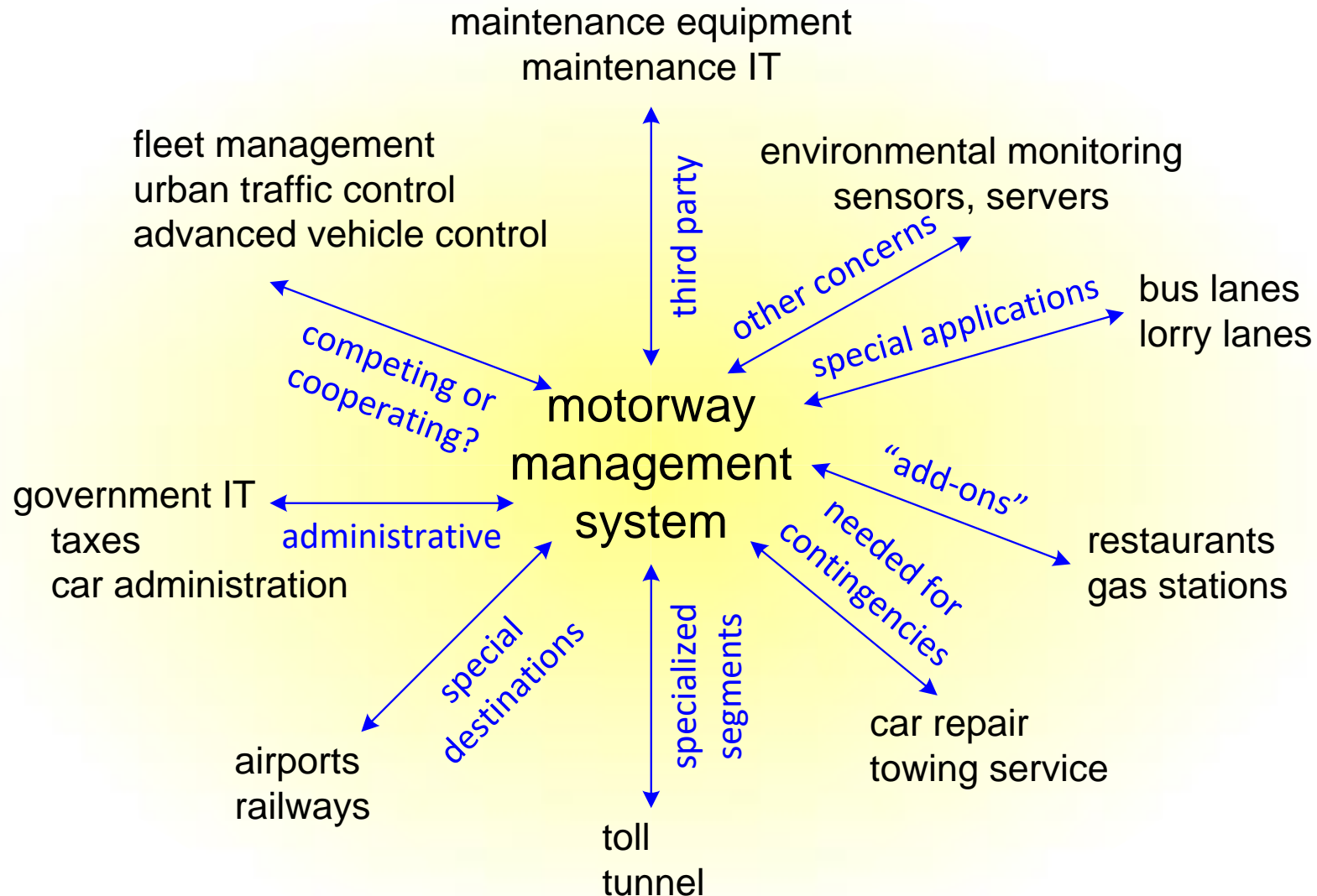


Example Graph for Motorway Management System

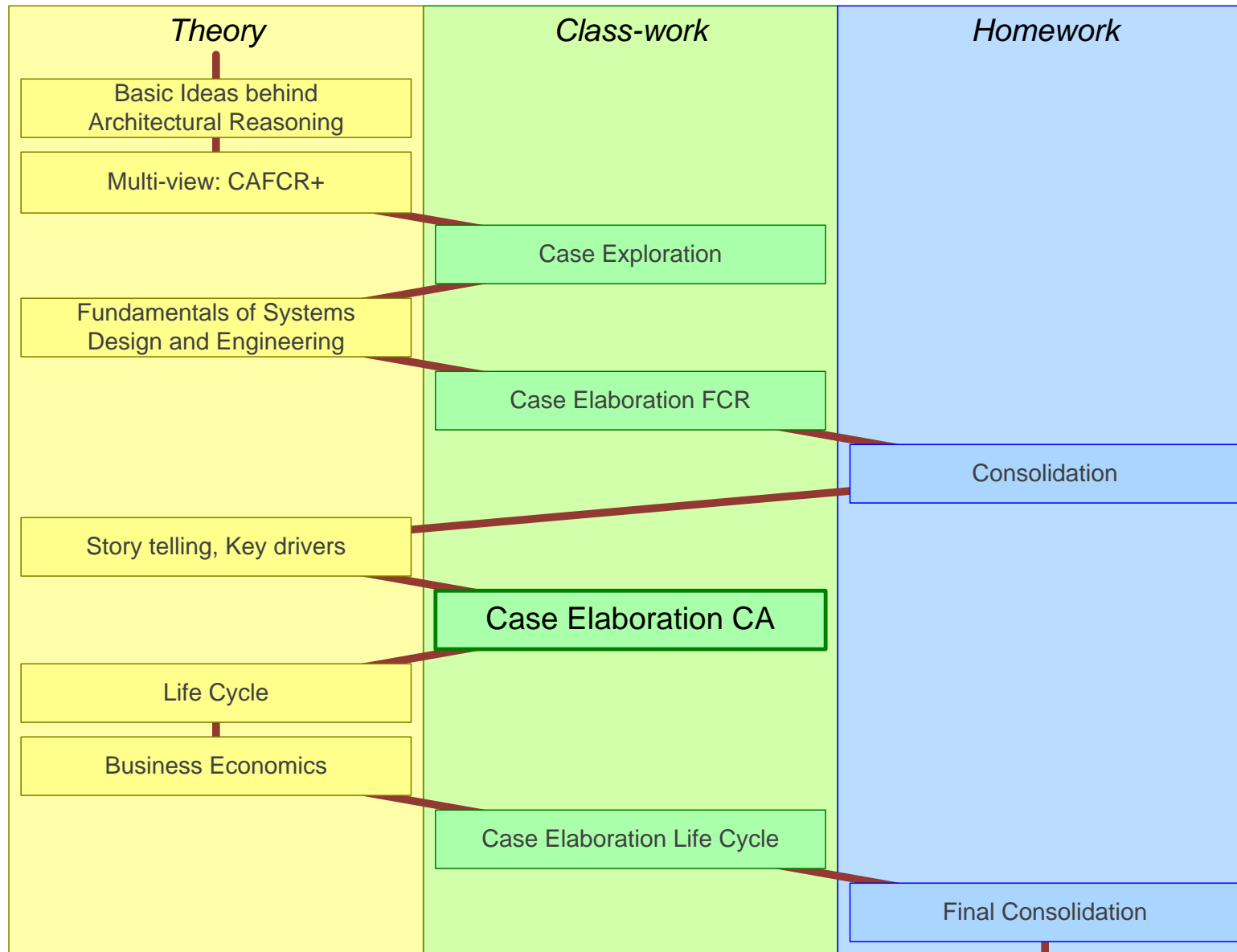


Note: the graph is only partially elaborated for application drivers and requirements

Example Context of Motorway Management System



Case Elaboration CA-views



Class-work Day 3: Elaboration CA-views

Continue second iteration by elaborating CA views

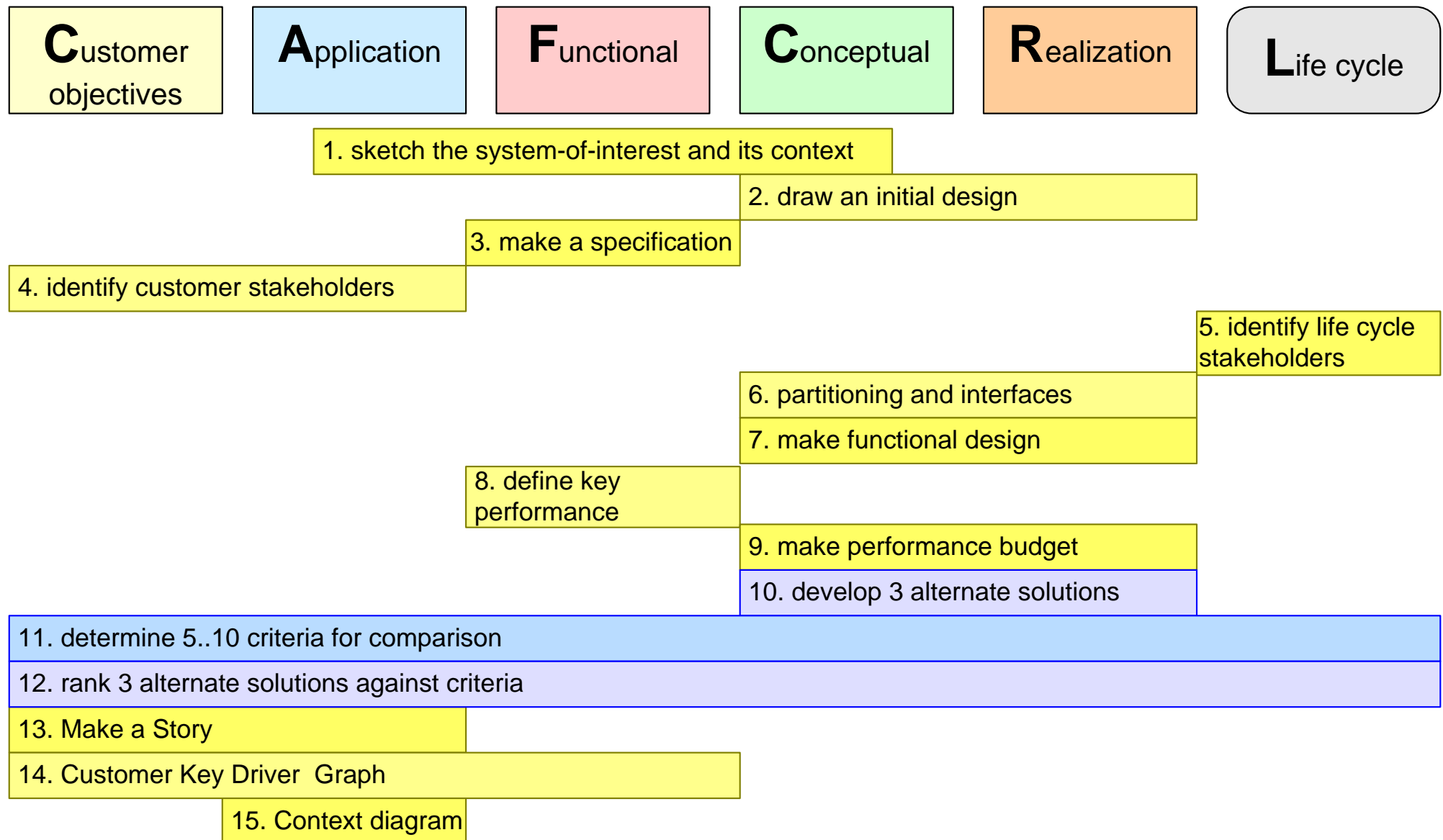
Use time-boxes of about 40 minutes

- 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

Class-work Day 3 mapped on CAFCR



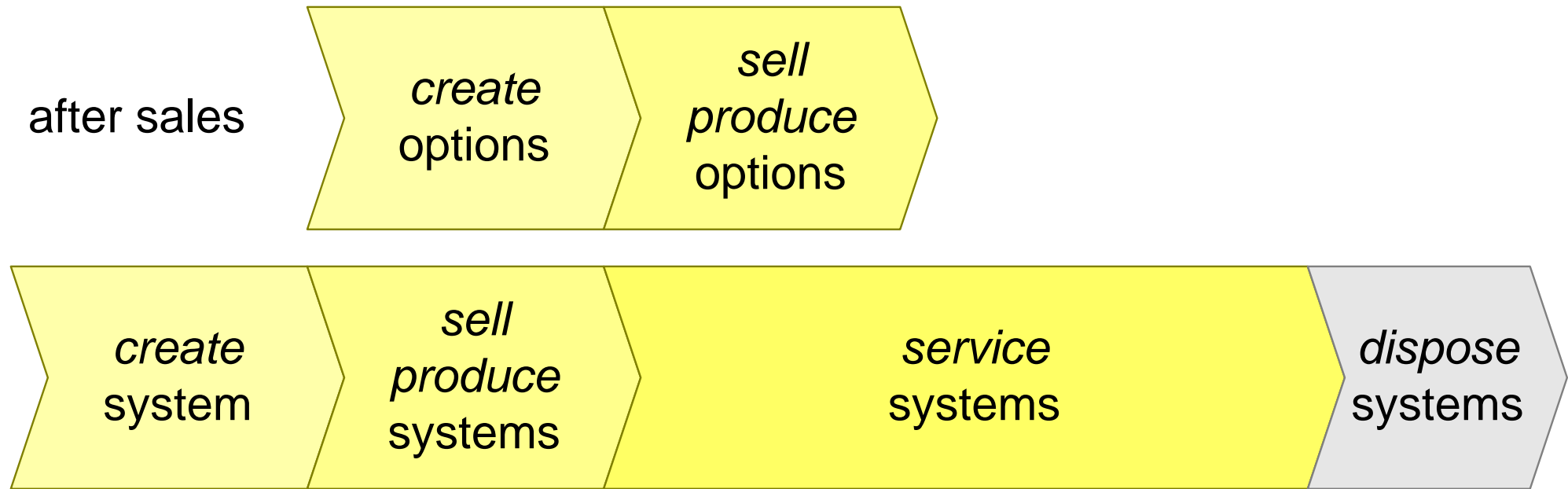
Theory Block: Life Cycle

Life Cycle

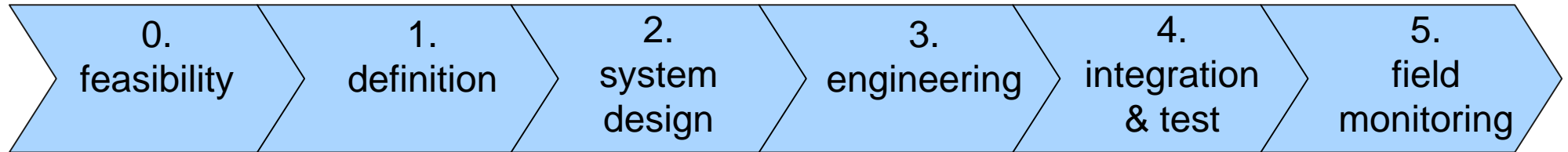
Conception and Development

From Deployment to Decommissioning and Disposal

Product Life Cycle



System Development



sales

product documentation

logistics

supply chain

production

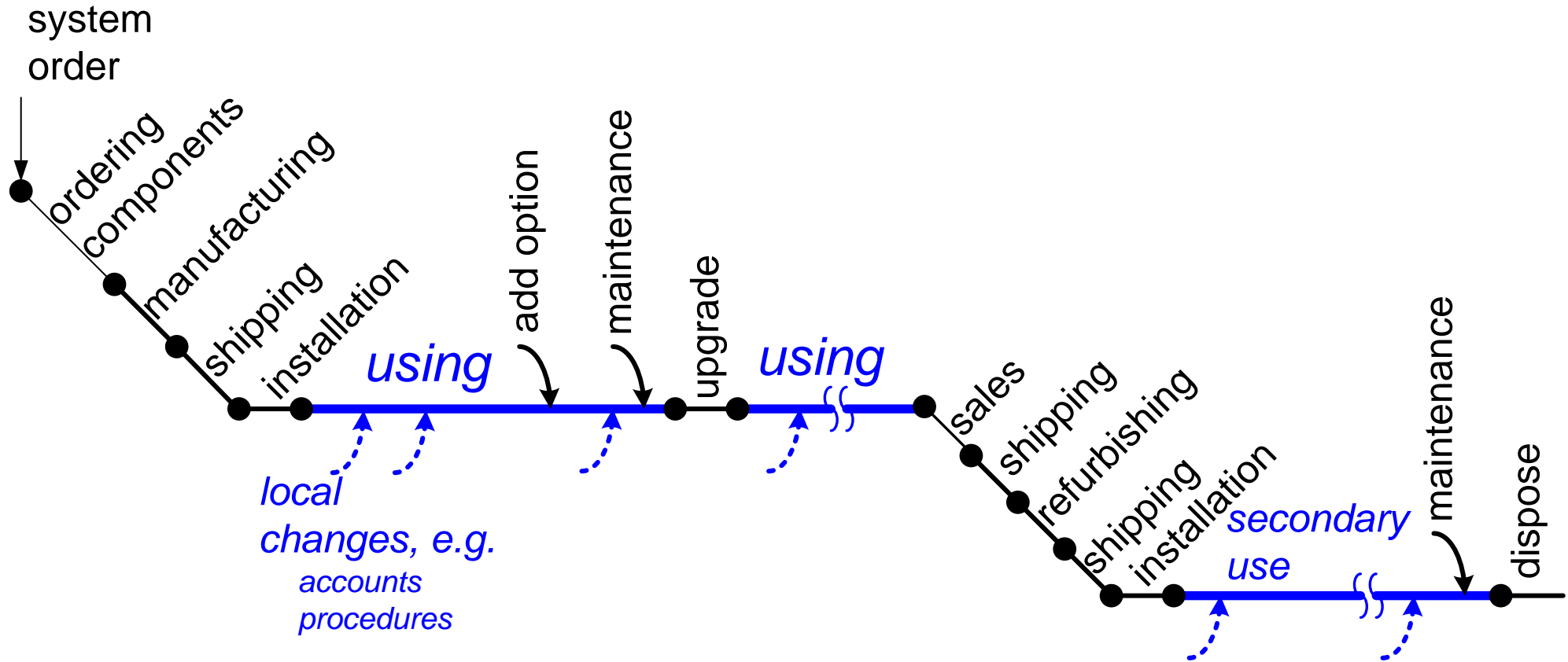
production and qualification procedures

service

service procedures

development & engineering: marketing, project management, design

Individual System Life Cycle



Theory Block: Business Economics

Simple Cash flow model

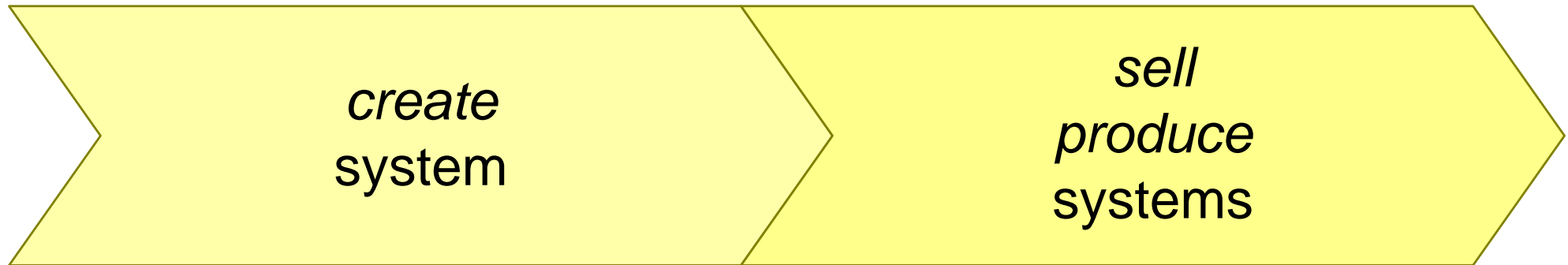
Business models

Cost of Ownership

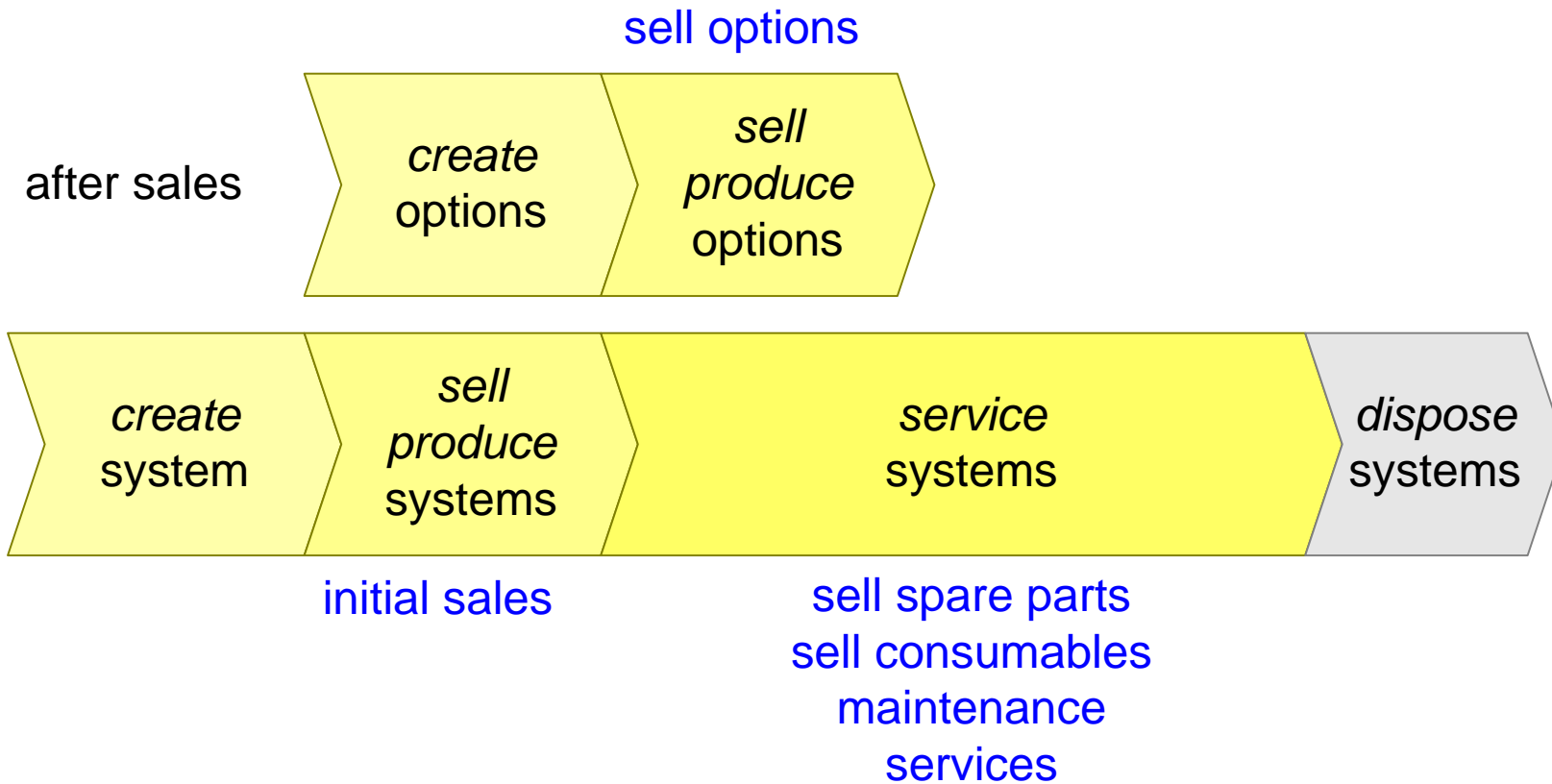
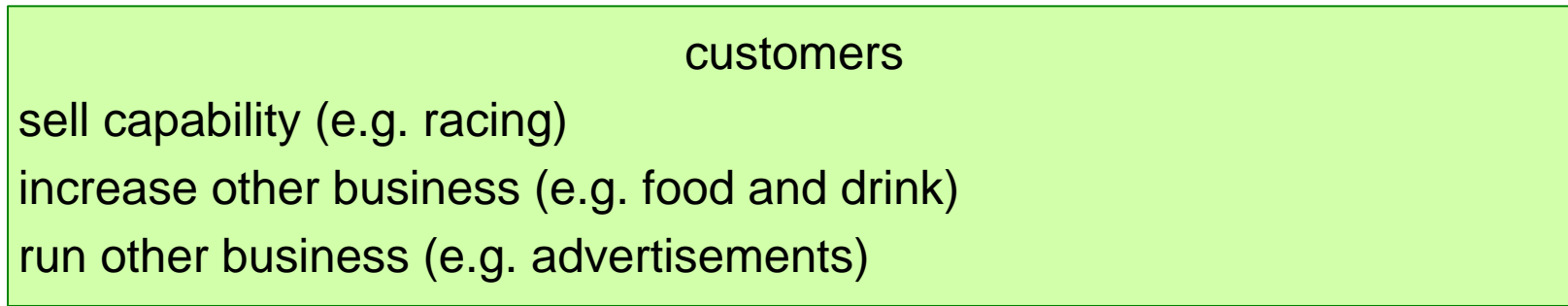
Expenses and Income

investment:
development cost

expenses:
purchase materials
labour
income:
system sales



Business Models



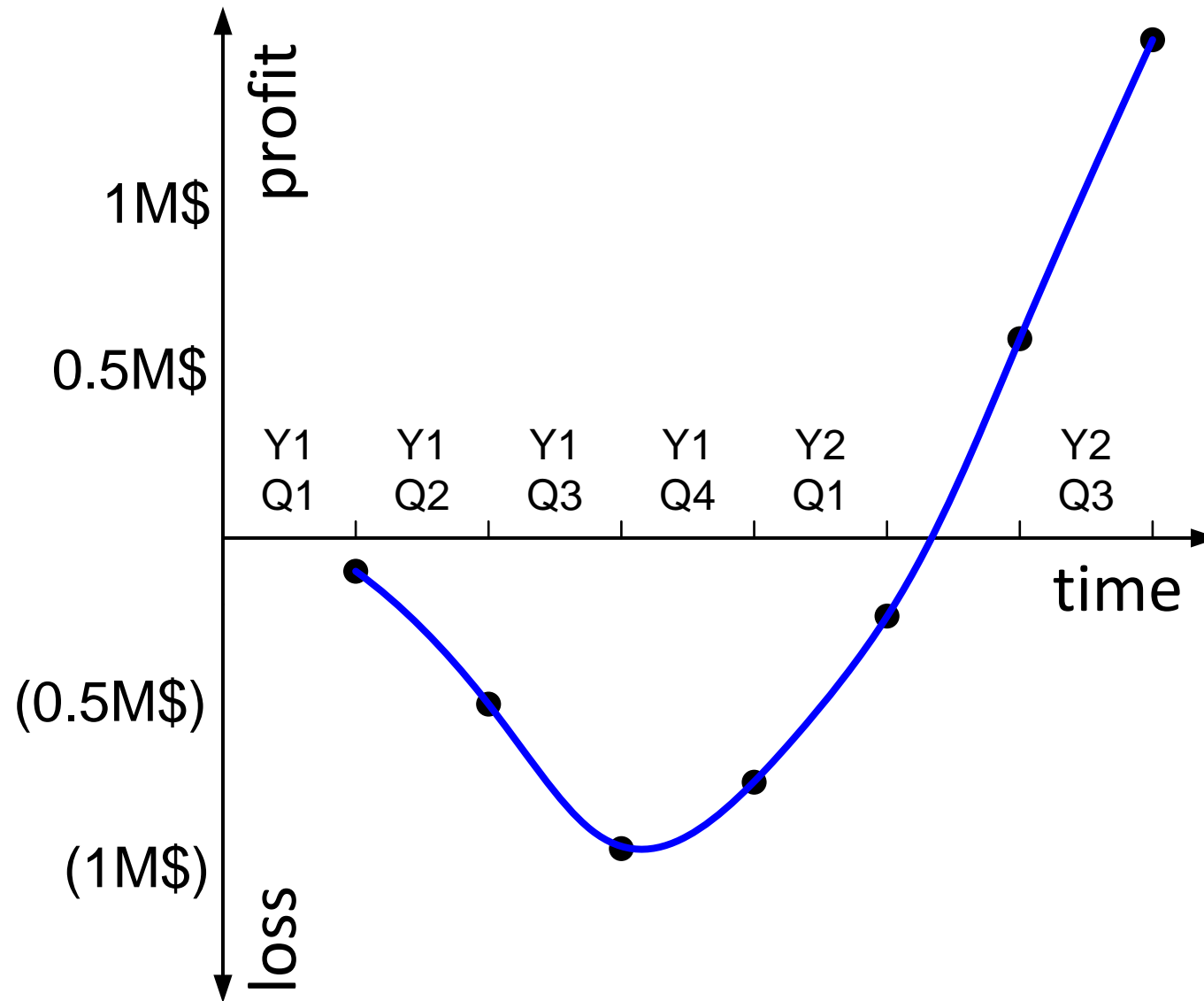
Example Cash Flow calculation

	Y1 Q1	Y1 Q2	Y1 Q3	Y1 Q4	Y2 Q1	Y2 Q2	Y2 Q3
investments	100k\$	400k\$	500k\$	100k\$	100k\$	60k\$	20k\$
sales volume (units)	-	-	2	10	20	30	30
material & labour costs	-	-	40k\$	200k\$	400k\$	600k\$	600k\$
income	-	-	100k\$	500k\$	1000k\$	1500k\$	1500k\$
quarter profit (loss)	(100k\$)	(400k\$)	(440k\$)	200k\$	500k\$	840k\$	880k\$
cumulative profit	(100k\$)	(500k\$)	(940k\$)	(740k\$)	(240k\$)	600k\$	1480k\$

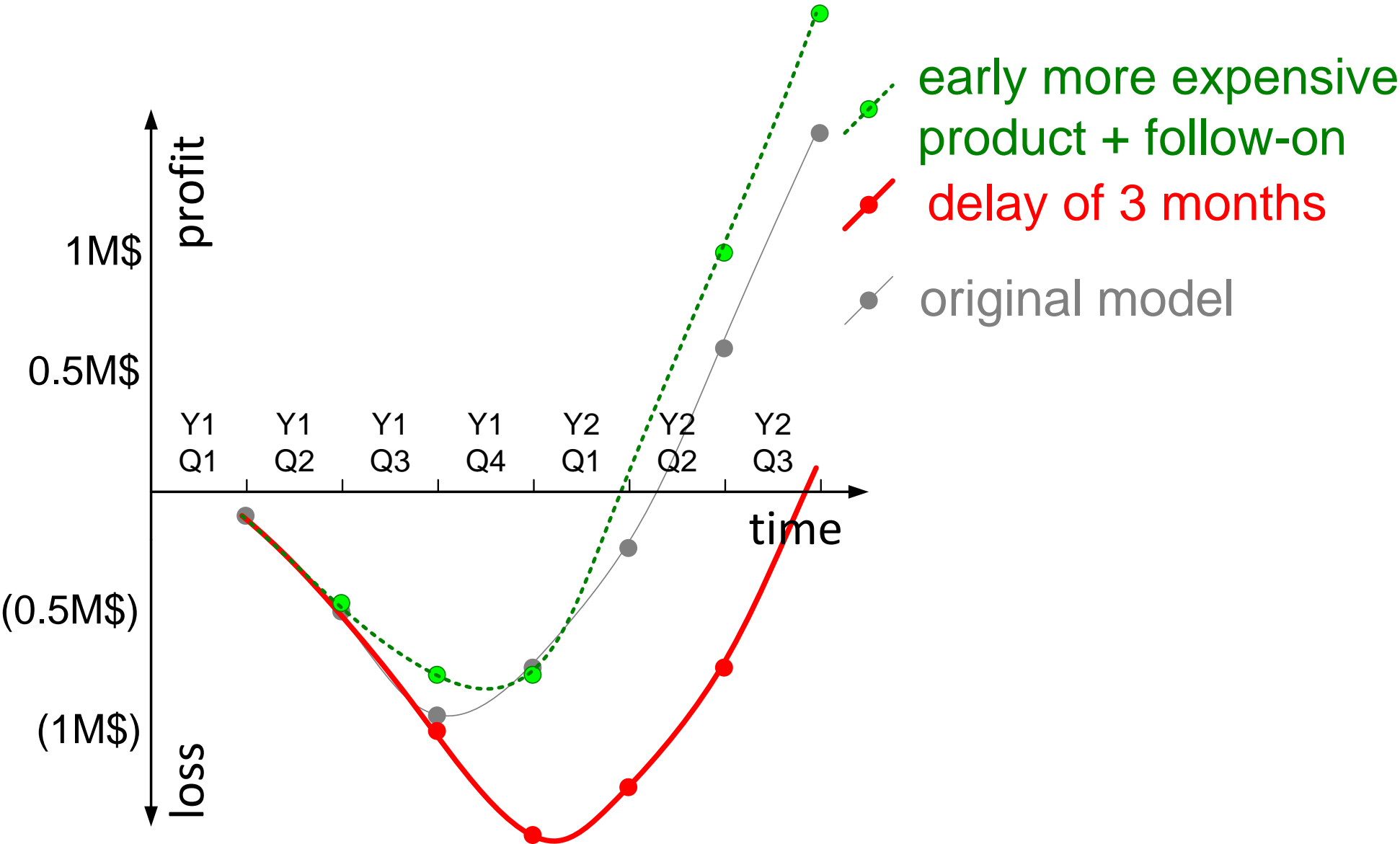
cost price / unit = 20k\$
sales price / unit = 50k\$

*variable cost = sales volume * cost price / unit*
*income = sales volume * sales price / unit*
quarter profit = income - (investments + variable costs)

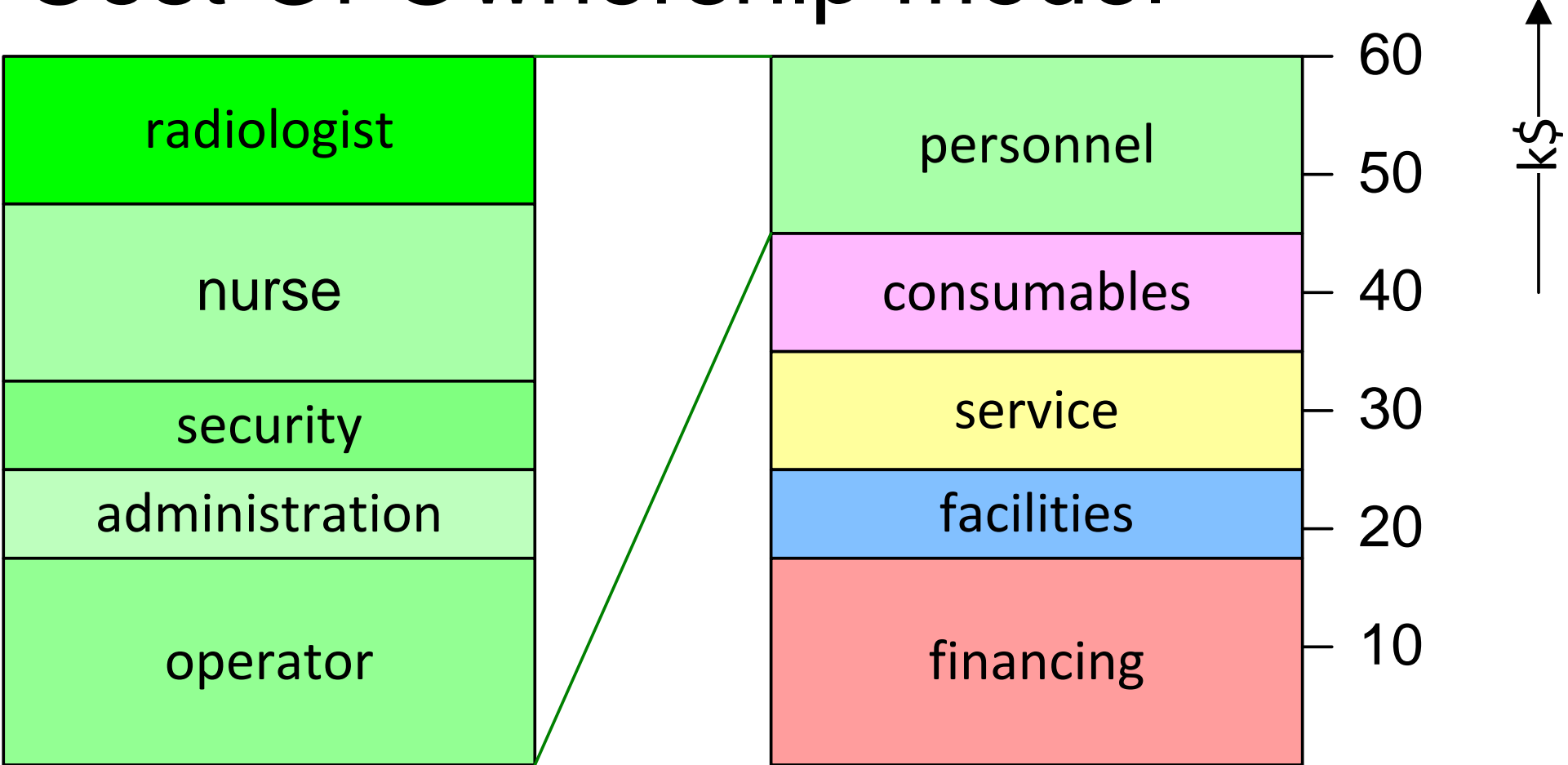
Cash Flow as Function of Time



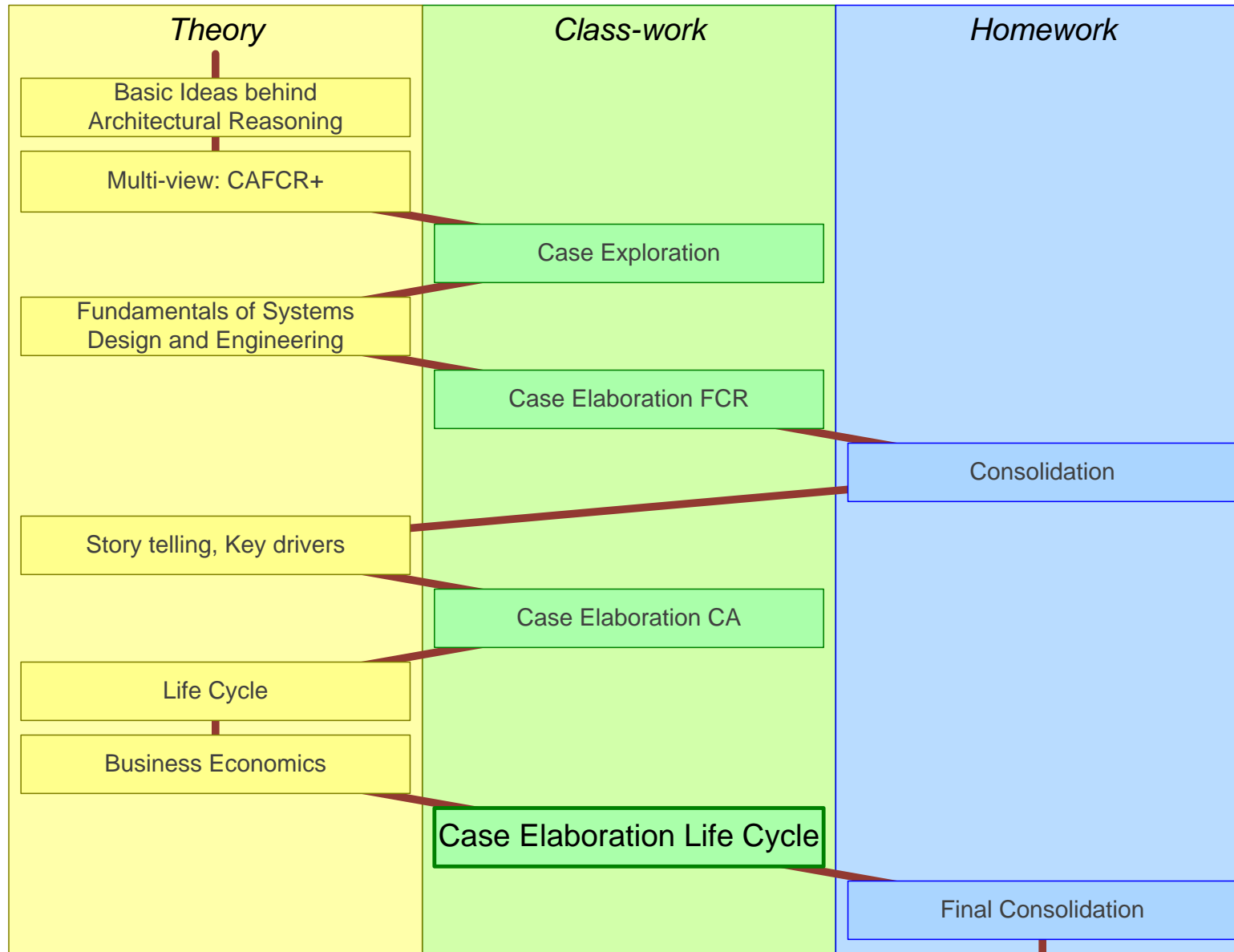
What If...?



Cost Of Ownership model



Case Elaboration Life Cycle-view



Class-work Day 4: Elaboration Life Cycle

Continue second iteration by elaborating life cycle view

Use time-boxes of about 30 minutes

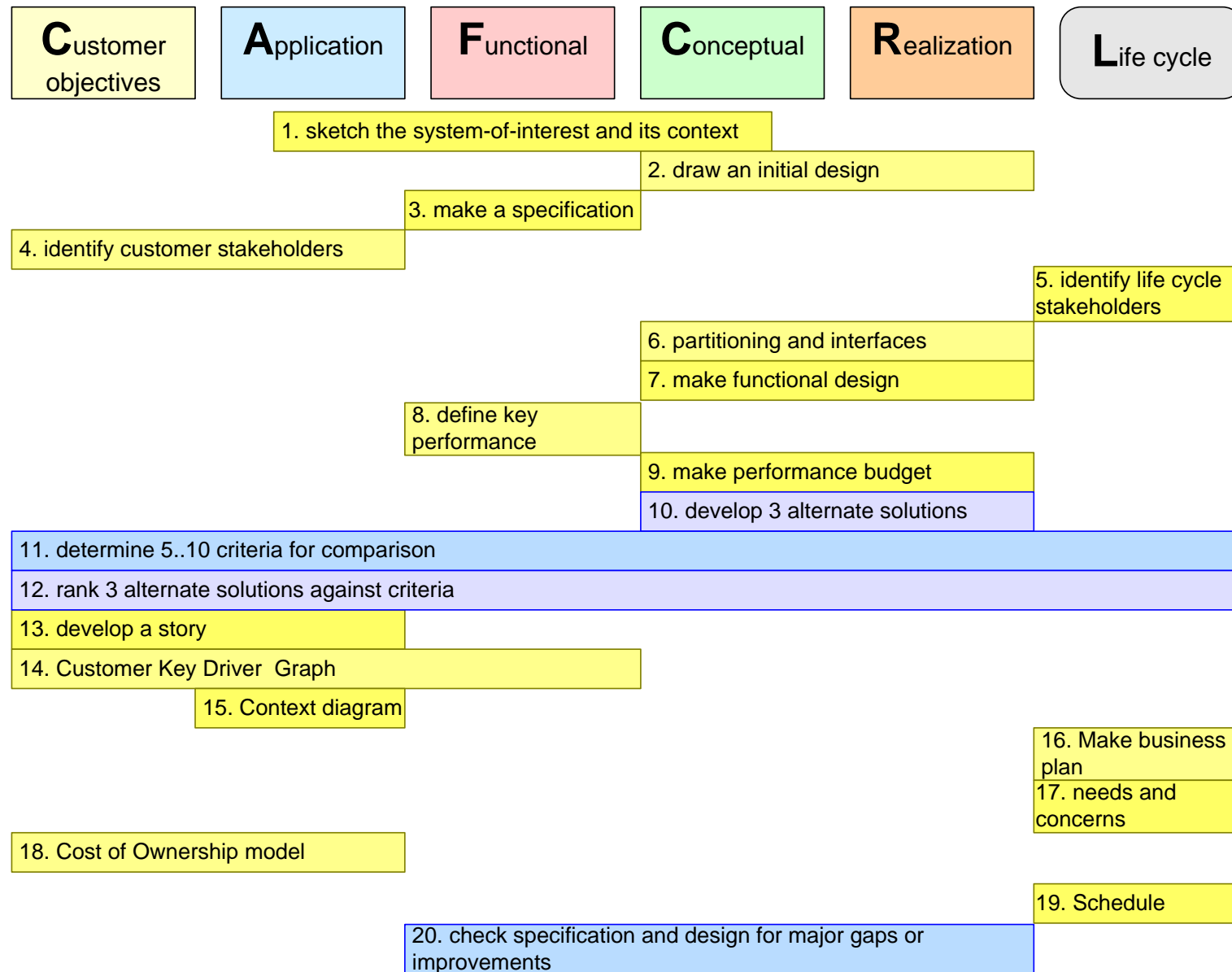
- Develop a business plan for your company
 - determine your role in the value chain
 - determine income, expenses, and investments
 - estimate cash flow as function of time
- Identify needs and concerns from life cycle stakeholders
 - determine life cycle key drivers and key performance parameters

- Make a Cost of ownership estimate for customers

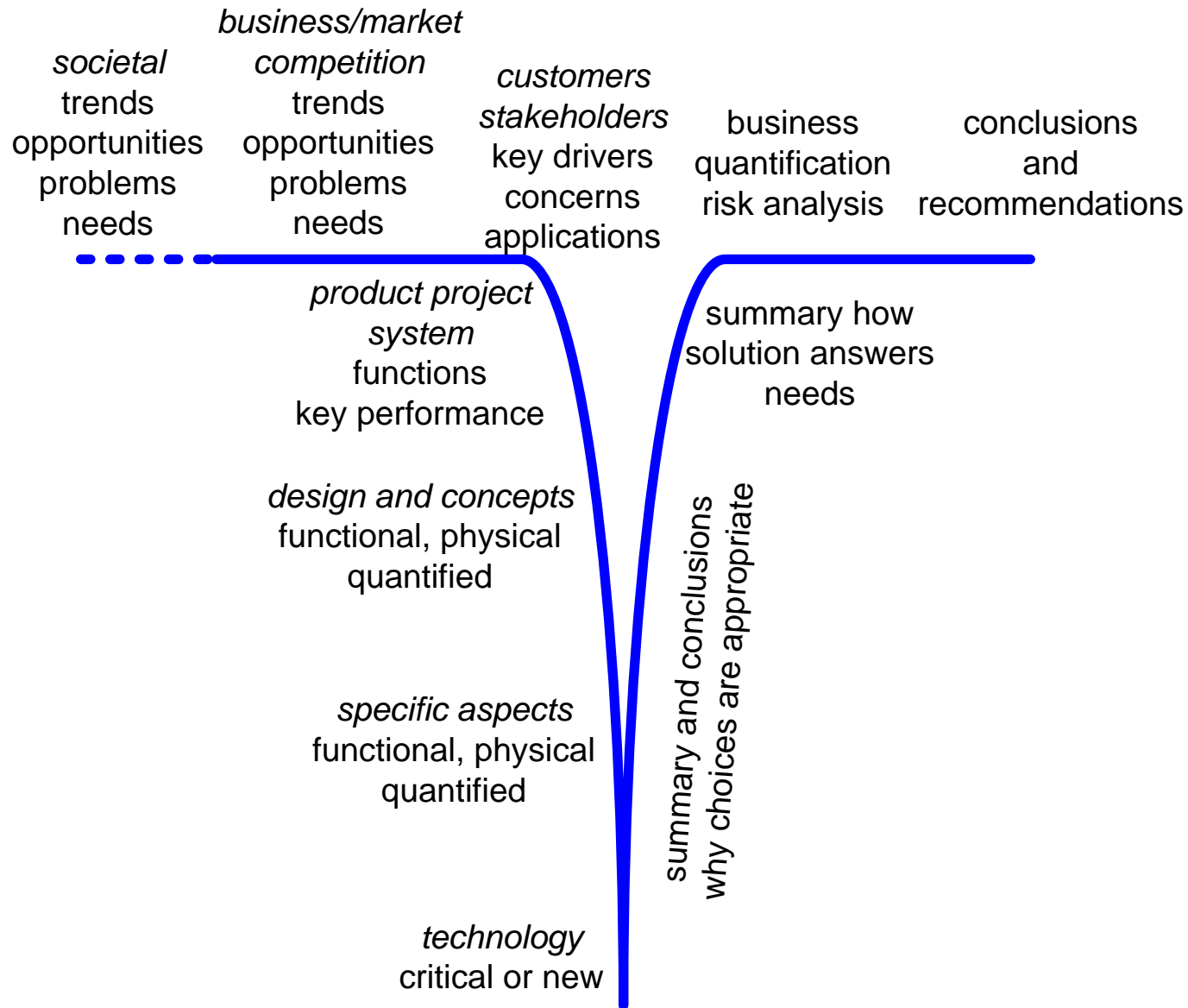
Use time-box of about 20 minutes for the remaining task

- Make a schedule for development and start of deployment

Class-work Day 4 mapped on CAFCR



T-shaped Presentation



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-shaped presentation for your management, covering all 4 days; its main purpose is to make an initial go/no-go decision

Submit this presentation via Canvas

Write an individual reflection report, max 2 A4s:

What are your main learning points?

What aspects deserve most attention in next phase of your project? Explain why.

Submit this individual reflection report via Canvas

Summary Architectural Reasoning

Objective: Awareness

Make engineering students aware of:

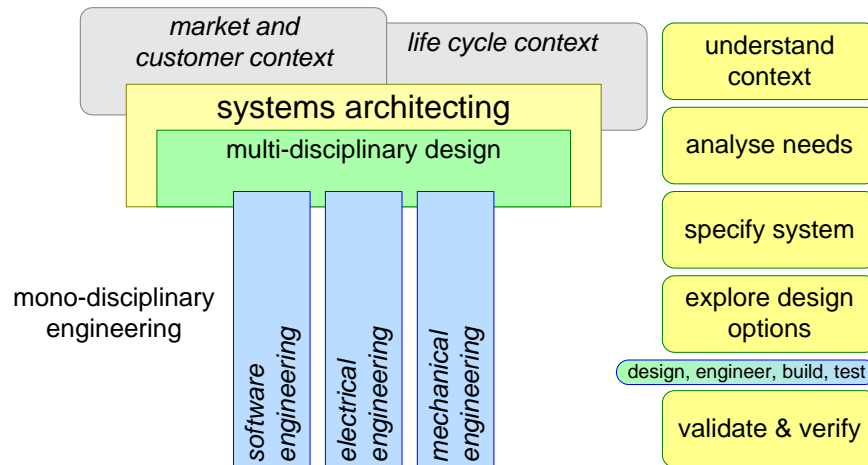
- other disciplines
- “systems” design and engineering
- customers and life cycle as contexts of the system
- the impact of needs on design decisions

Objective: Experience

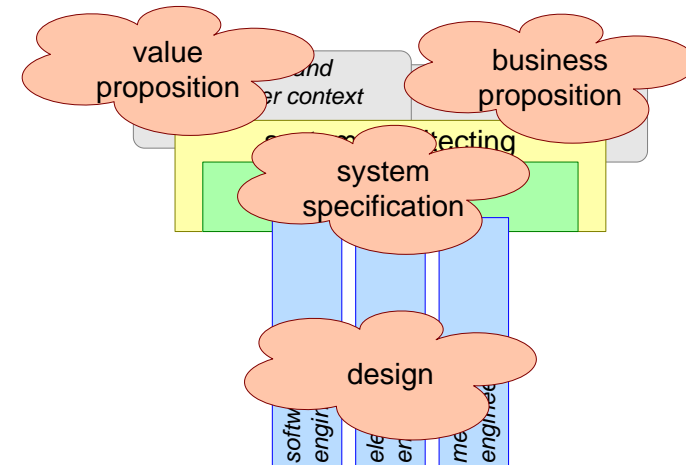
Let engineering students apply and experience:

- multiple views
- visualizations
- simplification
- iteration
- quantification

Stretch, Stretch, Stretch

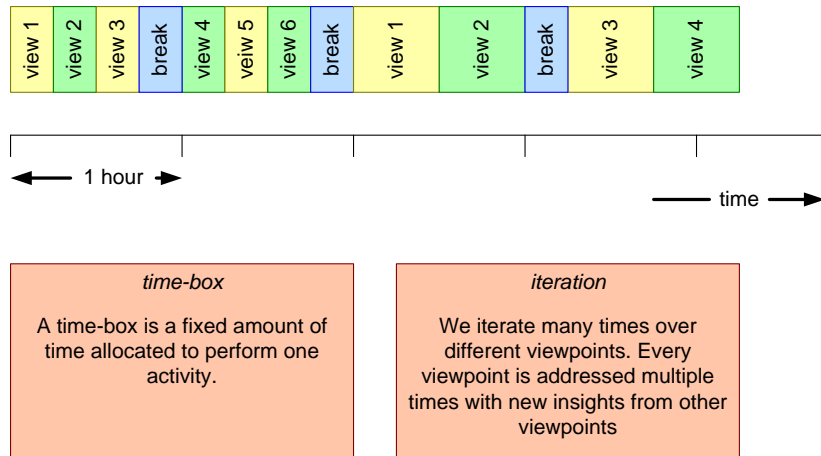


Main Deliveries

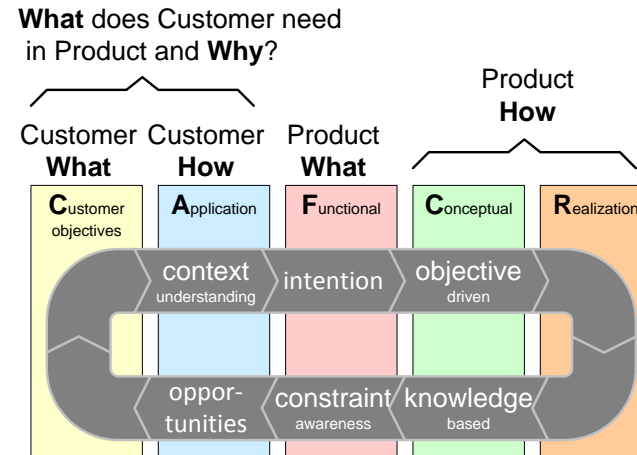


Summary CAFCR

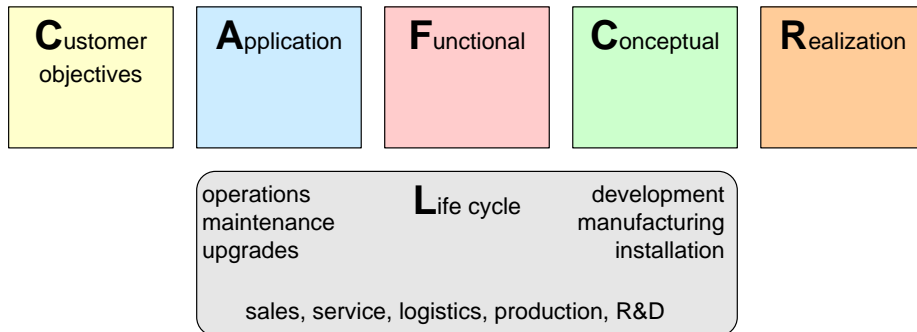
Time-boxing and Iteration



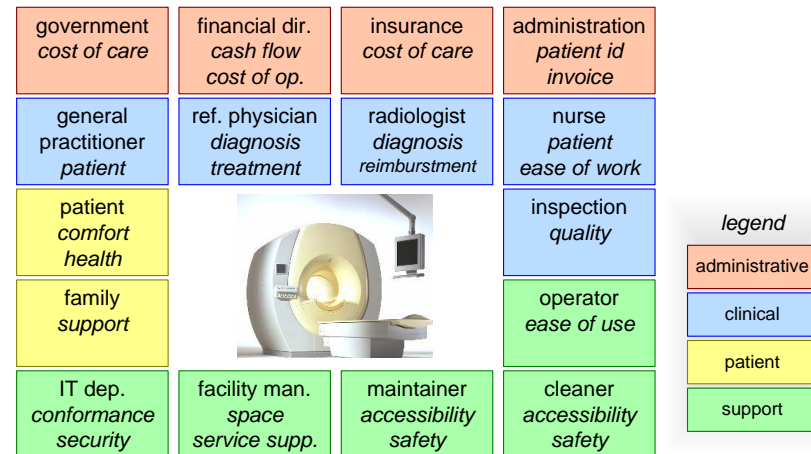
CAFCR views



CAFCR+

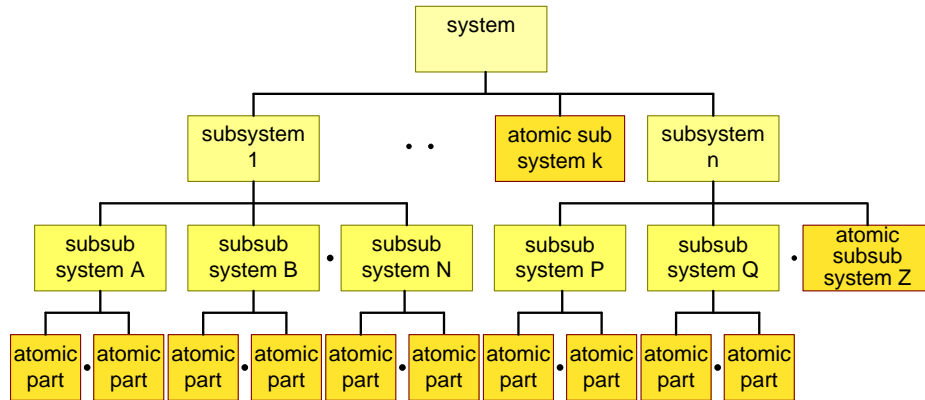


Stakeholders and Concerns

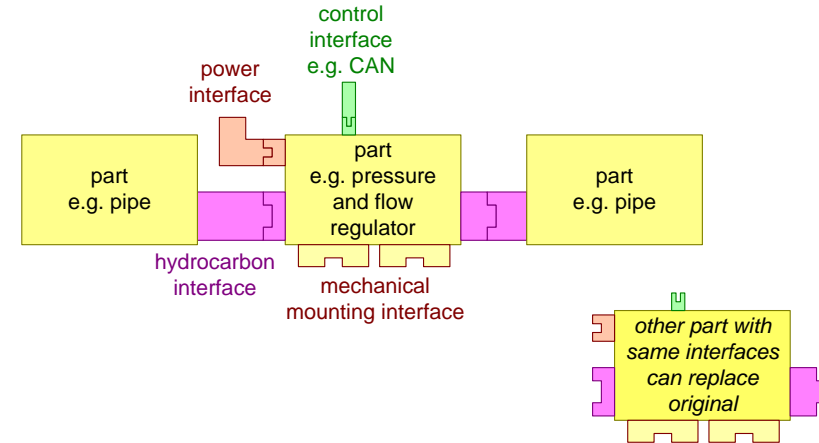


Summary Fundamentals Systems Engineering & Design

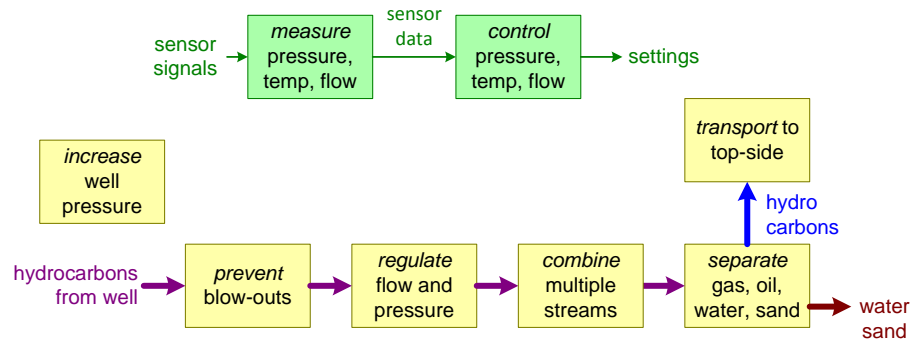
Partitioning



Interfaces



Functional Model



Key Performance Parameters

Key Performance Parameters are **SMART**

- **S**pecific quantified
- **M**asurable verifiable
- **A**chievable (Attainable, Action oriented, Acceptable, Agreed-upon, Accountable)
- **R**ealistic (Relevant, Result-Oriented)
- **T**ime-bounded (Timely, Tangible, Traceable)

the most important

defined in use case:

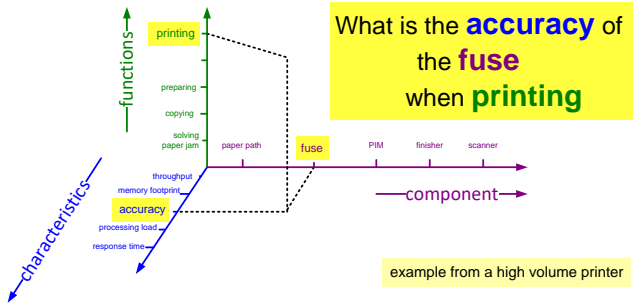
the circumstances where the performance is valid

typical use with relevant (quantified!) context data

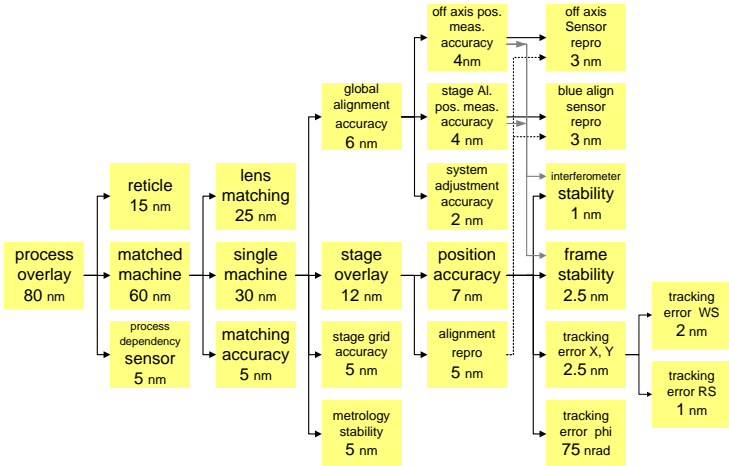
Summary Fundamentals Systems Engineering & Design (2)

Combining 3 Dimensions

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



Technical Budget



Concept Selection

Swivel concept selection

evaluation criteria	weight	CBV	clamp	dynamic
Maturity	10	5	2	2
Development level		50	20	50
Cost	20	4	2	5
Hardware cost		80	40	100
Development cost		100	20	40
Design robustness	25	5	3	3
Design life		125	75	75
swivel cycles		5	4	5
pressure cycles		125	100	125
Pressure range		4	4	4
internal		100	100	100
external		2	5	2
Temperature range		4	100	4
Installation	20	2	3	4
Initial installatio/retrieval		40	60	80
Connection/disconnection		2	4	5
Operation	25	1	4	5
Swivel resistance		25	100	125
Spool Length Short		3	5	125
Spool Length Long		2	4	100
Hub loads		2	50	4
Σ points		985	1165	1290

from master paper Halvard Bjørnsen, 2009

EDP-LRP connection

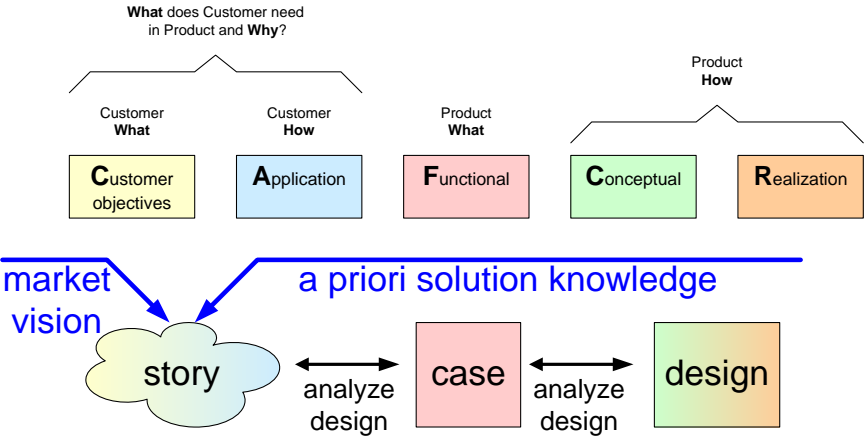
Evaluation Criteria	Score	Concepts			
		1	2	3	4
Time to connect		-	+	+	+
Need for ROV		-	+	+	+
Design		-	+	+	+
Robustness		-	+	+	+
Connector design		-	S	S	+
Number of parts		-	-	+	+
Handle roll-off		+	-	S	+
Influence other		+	S	-	S
Redundancy		+	-	-	S
Design		+	-	-	-
Interchangeability		+	-	-	-
Cost		-	-	-	-
HW cost		S	S	-	S
Manufacturing cost		+	-	S	-
Engineering cost		-	+	+	+
Service cost		-	-	S	+
Maturity		-	-	S	+
Σ Pos.		7	7	5	3
Σ Neg.		1	3	4	3
Σ Net		6	3	4	7
Pos.		3	4	2	1

from master paper Dag Jostein Klever, 2009

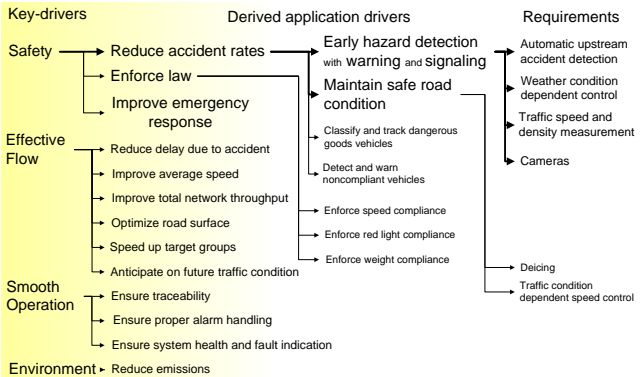
intentionally left blank

Summary Customer Understanding

Story Telling

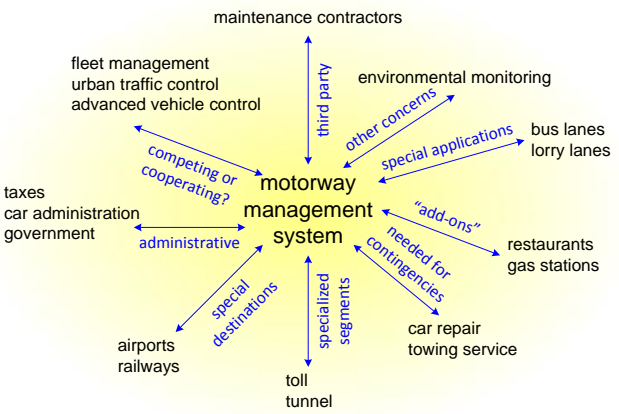


Key Driver Graph

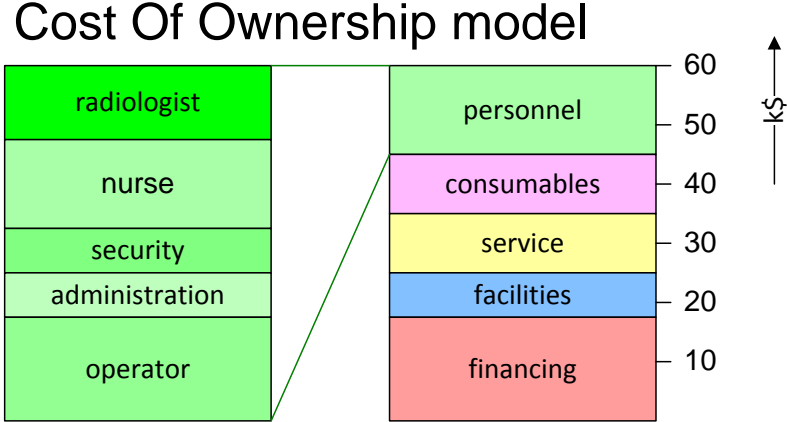


Note: the graph is only partially elaborated for application drivers and requirements

System Context

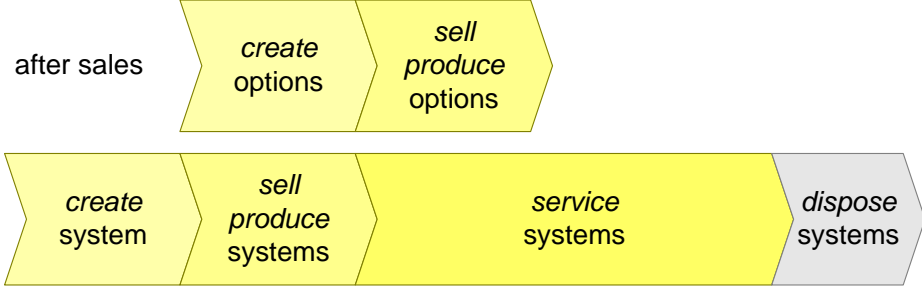


Cost of Ownership Model

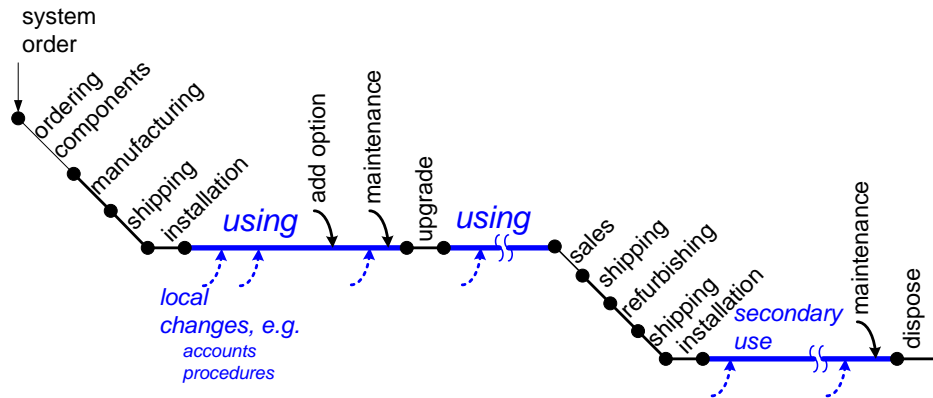


Summary Life Cycle and Business Economics

Product Life Cycle



System Life Cycle



Cash Flow

	Y1 Q1	Y1 Q2	Y1 Q3	Y1 Q4	Y2 Q1	Y2 Q2	Y2 Q3
investments	100k\$	400k\$	500k\$	100k\$	100k\$	60k\$	20k\$
sales volume (units)	-	-	2	10	20	30	30
material & labour costs	-	-	40k\$	200k\$	400k\$	600k\$	600k\$
income	-	-	100k\$	500k\$	1000k\$	1500k\$	1500k\$
quarter profit (loss)	(100k\$)	(400k\$)	(440k\$)	200k\$	500k\$	840k\$	880k\$
cumulative profit	(100k\$)	(500k\$)	(940k\$)	(740k\$)	(240k\$)	600k\$	1480k\$

$cost\ price / unit = 20k\$$
 $sales\ price / unit = 50k\$$
 $variable\ cost = sales\ volume * cost\ price / unit$
 $income = sales\ volume * sales\ price / unit$
 $quarter\ profit = income - (investments + variable\ costs)$

Hockey Stick

