Module SEFS Architecting

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Abstract

Understanding thecontext is essential to understand the problem and the solution space. We discuss the way companies work, the customer, business, and life cycle contexts, and how to scope the work.

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SEFS Architecting Fundamentals

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Abstract

Architecting transforms the needs and understanding of the current situation into a system specification and high-level design. The architecture description captures the overview, the rationale, and provides guidance and rules for the design.

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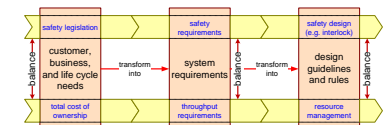status: preliminary draft
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Architecting and Design in the V-model

inputs
stakeholder needs
business objectives

architecting and design

specification

integration verification & validation

artifacts
models
prototypes
parts

architecture
guidelines
top-level design
rationale

design
partitioning
interfaces
functions
allocation

qualification
evidence

engineering

documentation
system and parts data
procedures

life cycle support

feedback

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Architecting Workflow

Project start

| Problem and context understanding | → | Stakeholders and their concerns and needs |

Context
Way of operating

| Solution exploration |

| Concept selection | → | Feasibility Risks |

| System definition | → | System requirements |

| System design | → | System |

Subsystem design

- Guidelines and Rules
- Rationale
- Partitioning → Work Breakdown
- Interfaces
- Functions
- Allocations

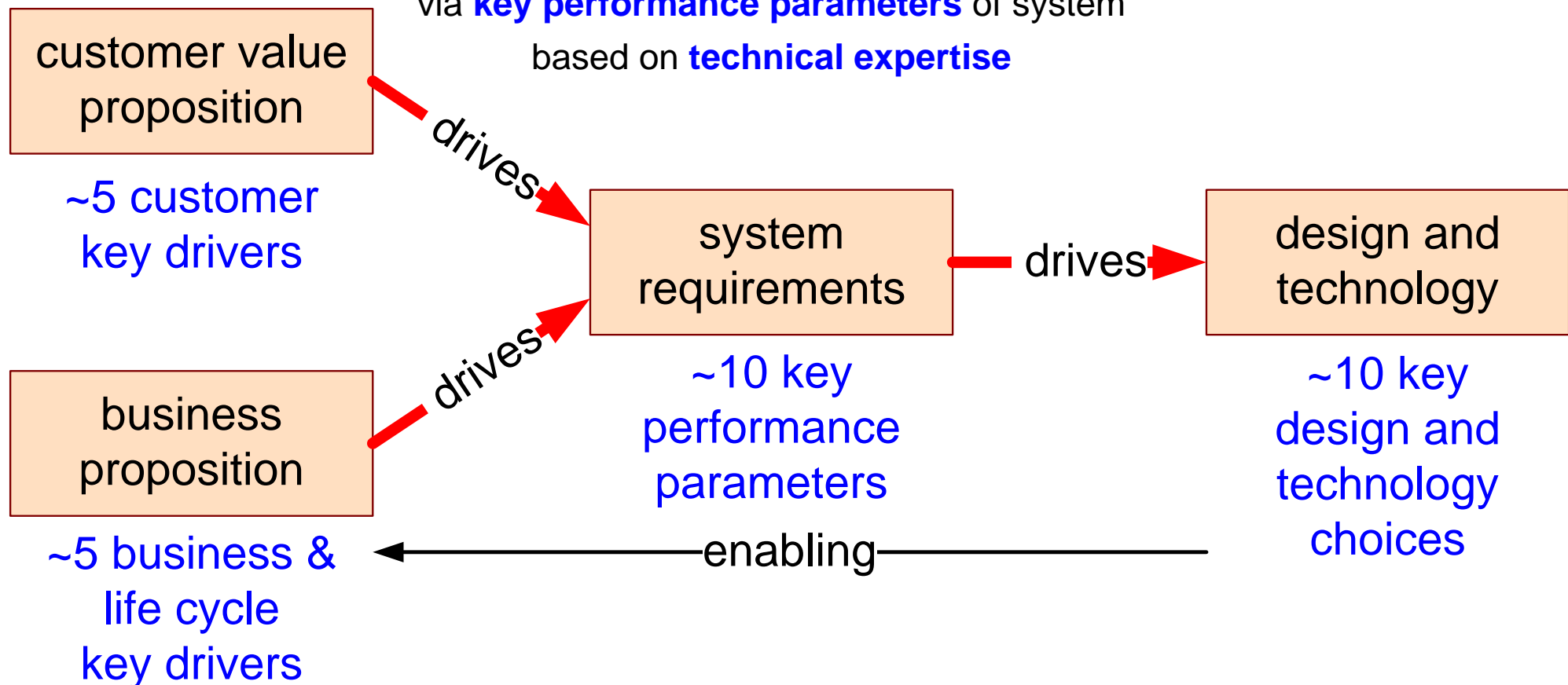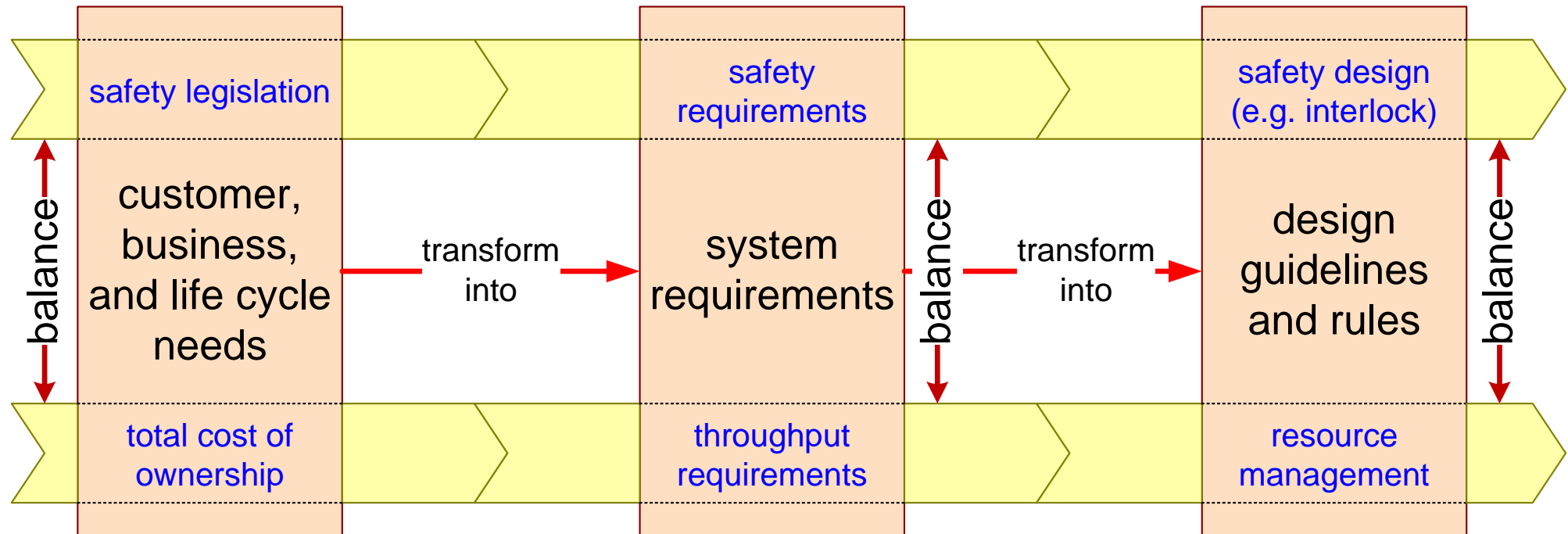USN   ESI

The Architecture Captures the Rationale

Systems Engineering: *Fitness-For-Purpose*

Achieving **customer** and **business key drivers**

via **key performance parameters** of system

based on **technical expertise**

customer value proposition

~5 customer key drivers

business proposition

~5 business & life cycle key drivers

drives →

drives →

system requirements

~10 key performance parameters

drives →

design and technology

~10 key design and technology choices

← enabling ──────────

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Architecture Provides Guidelines and Rules

SEFS Concept Selection

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Abstract

Concept selection is useful at many levels, from the customer application to the technology concept for specific functions. The Pugh matrix is a lightweight decision matrix facilitating early phase concept selections. When the design is crystallizing out, then trade-off analysis provides a more specific insight in the relation between specification and design parameters.
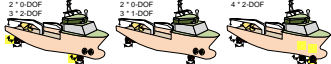
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Exploration and Analysis Flow of Concepts

vague problem statement

Problem understanding

Analysis

Decision

Monitor, verify, validate
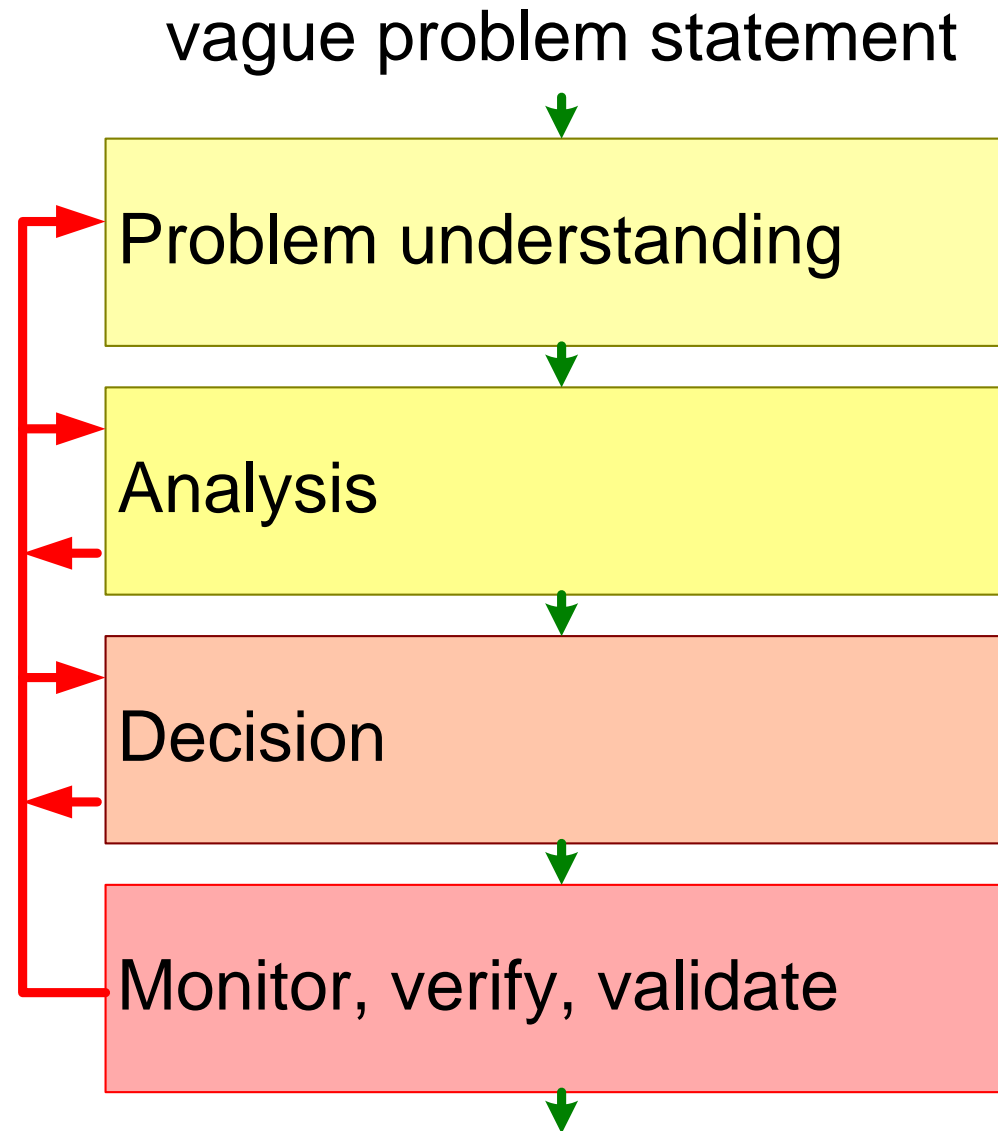
Pugh Matrix: a Light-Weight Decision Matrix

Define at least 3 concepts

Define 7 to 10 criteria for selection

Score the concepts against the criteria, for example using a scale from 1 to 5: 1 = very poor, 5 = very good

Recommend a concept with a rationale

	concept 1	concept 2	concept 3
criterion 1	1	3	5
criterion n	4	4	2
			recommended, because ...

Example of Pugh Matrix

2 * 0-DOF
3 * 2-DOF

2 * 0-DOF
3 * 1-DOF

4 * 2-DOF

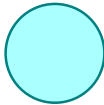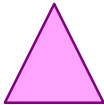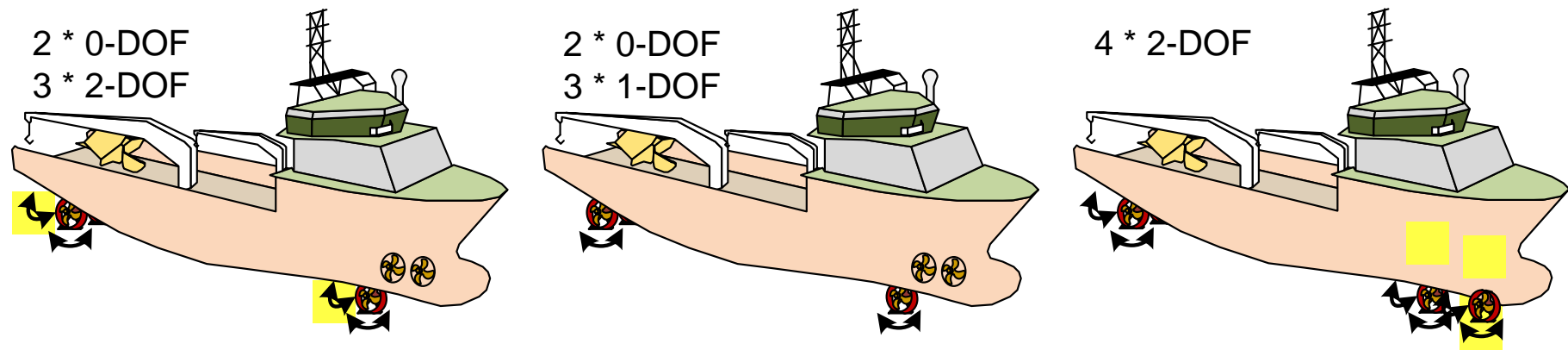|	Concept 1	Concept 2	Concept 3
Manoeuvrability	4	4	5
Energy consumption	5	3	5
Development Cost	3	4	2
Maturity (risk)	3	4	1
Purchasing Cost	3	4	3
Maintenance Cost	2	4	2

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Repeated Divergence and Convergence

concept selection
repeating
Pugh matrix

set-based design
repeating trade-studies

number of options

time
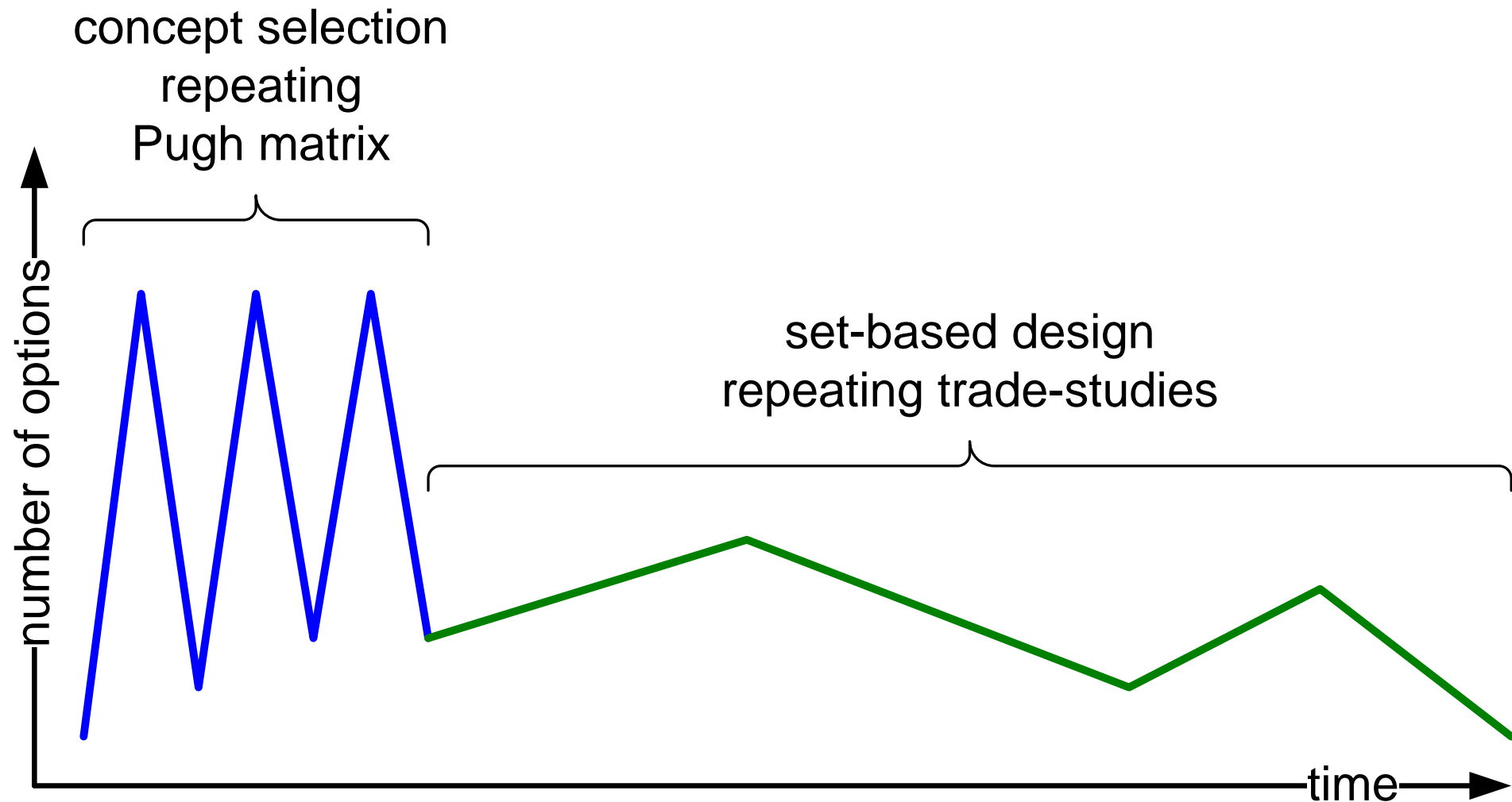
Set-based Design
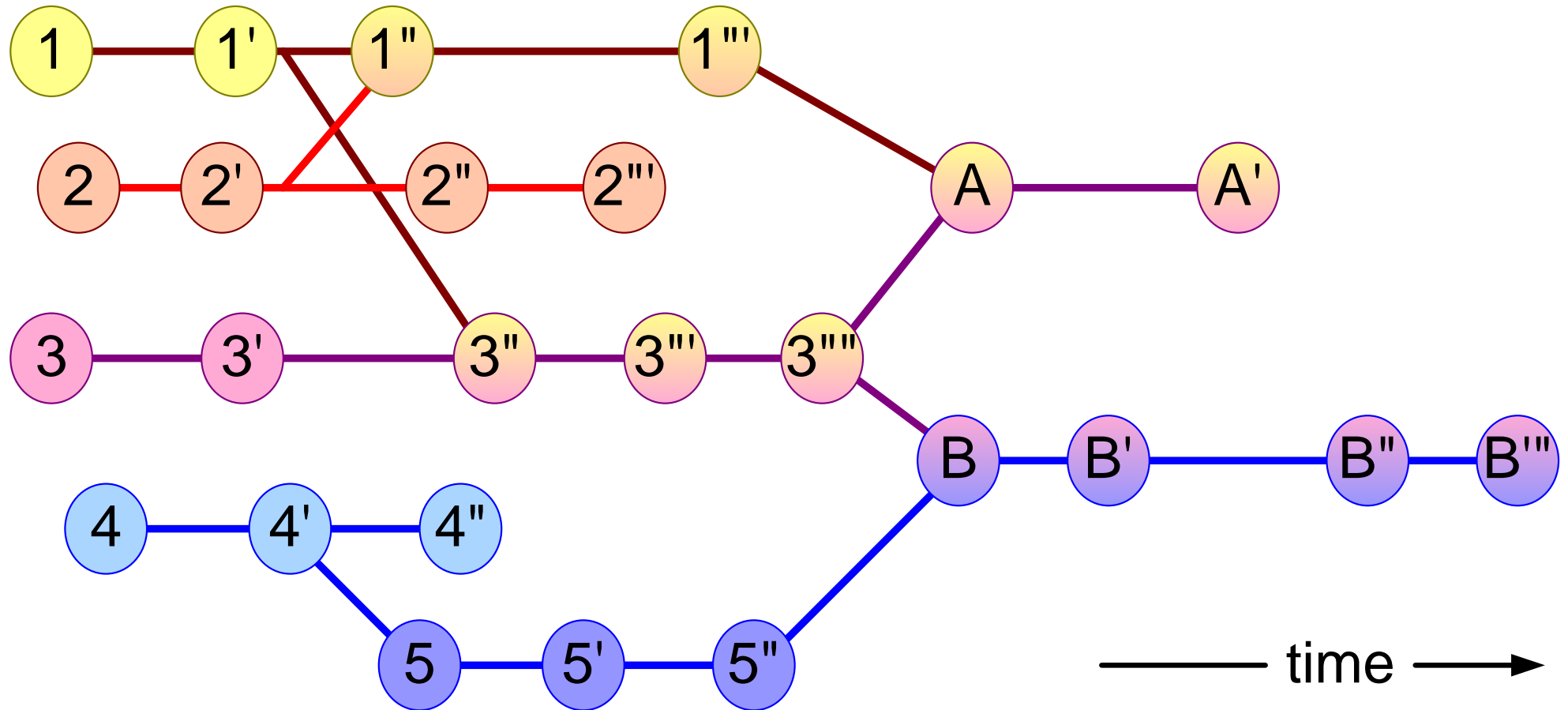
SEFS Dynamic Behavior

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Abstract

The desired system behavior and performance emerges from the interaction of the parts. The challenge in architecting is capturing the relevant dynamic behavior to facilitate reasoning about system behavior and performance.

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Interaction Results in Dynamic Behavior
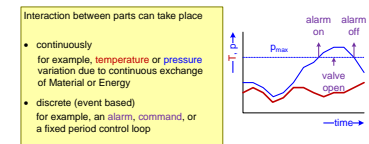
Interaction between parts takes place via exchange of

- **M**aterial

- **E**nergy

- **I**nformation

Simple Examples of MEI Flows

Material Flow

Sand
Soda → mixing → mixture of solids → melting → molten glass → shaping → glass objects
Other chemicals

Energy Flow

sun light → photo voltaic converting → DC electricity → inverting → AC electricity → transforming → High Voltage AC

Information Flow

image → process → enhanced image → detect objects → list of objects → classify → list of classified objects

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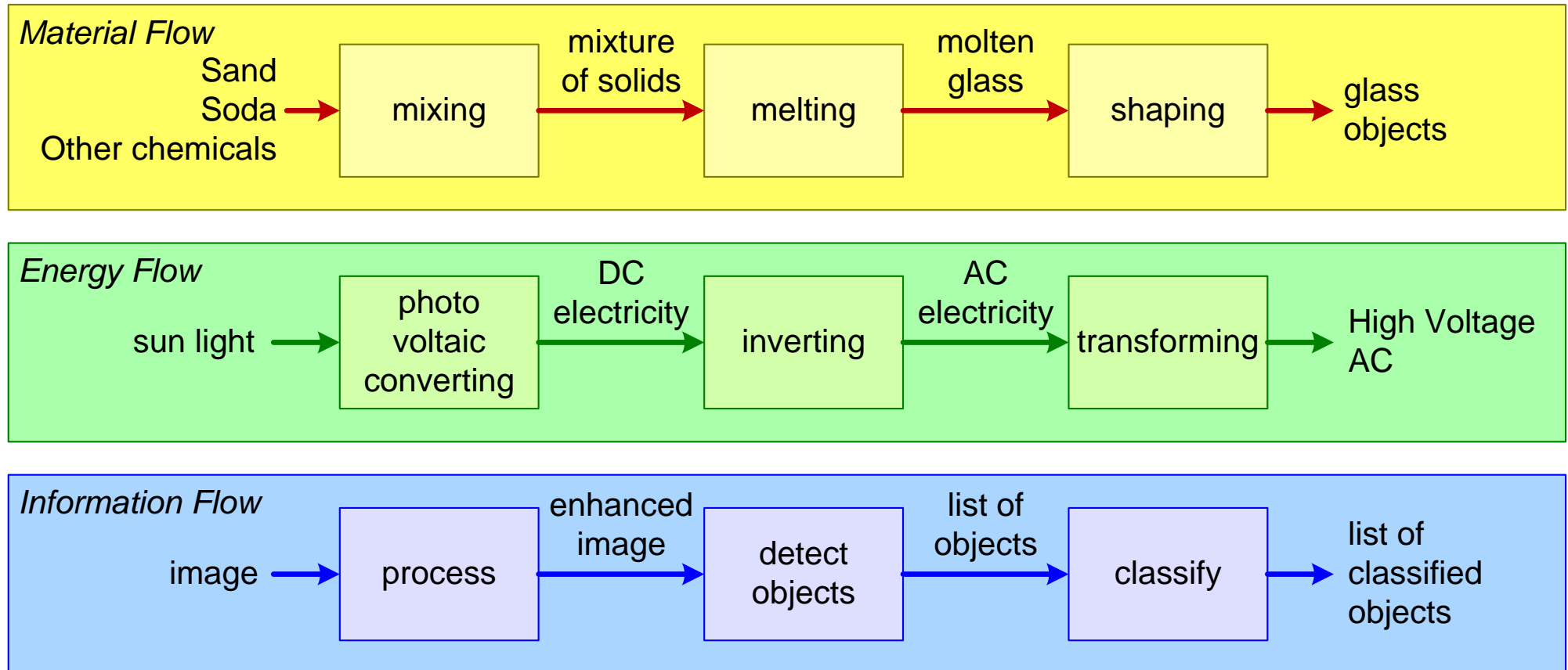
Dynamic Behavior and Time

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
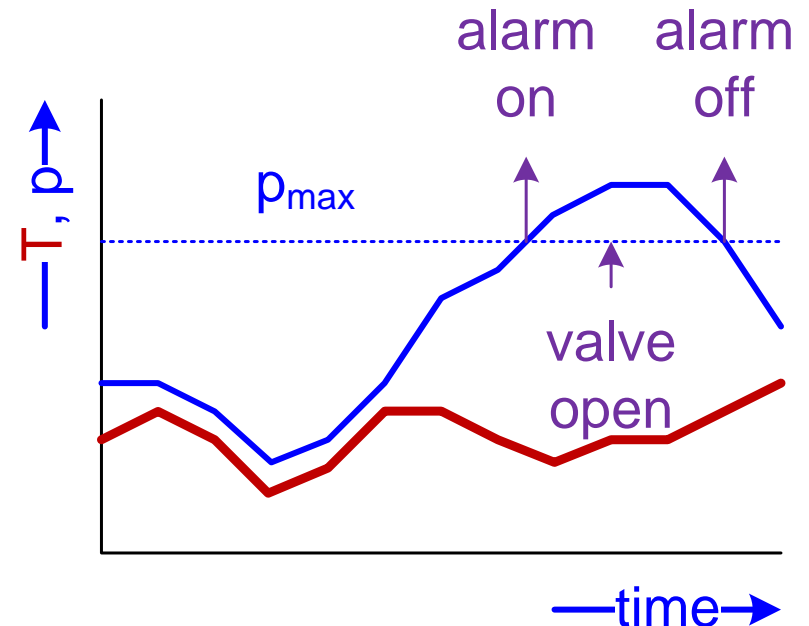
Simple Examples of Dynamic Behavior

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**)

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

evaluate situation

$p < p_{max}$

$p \geq p_{max}$

determine action

perform action

normal operation

pressure alarm

high pressure

pressure alarm off

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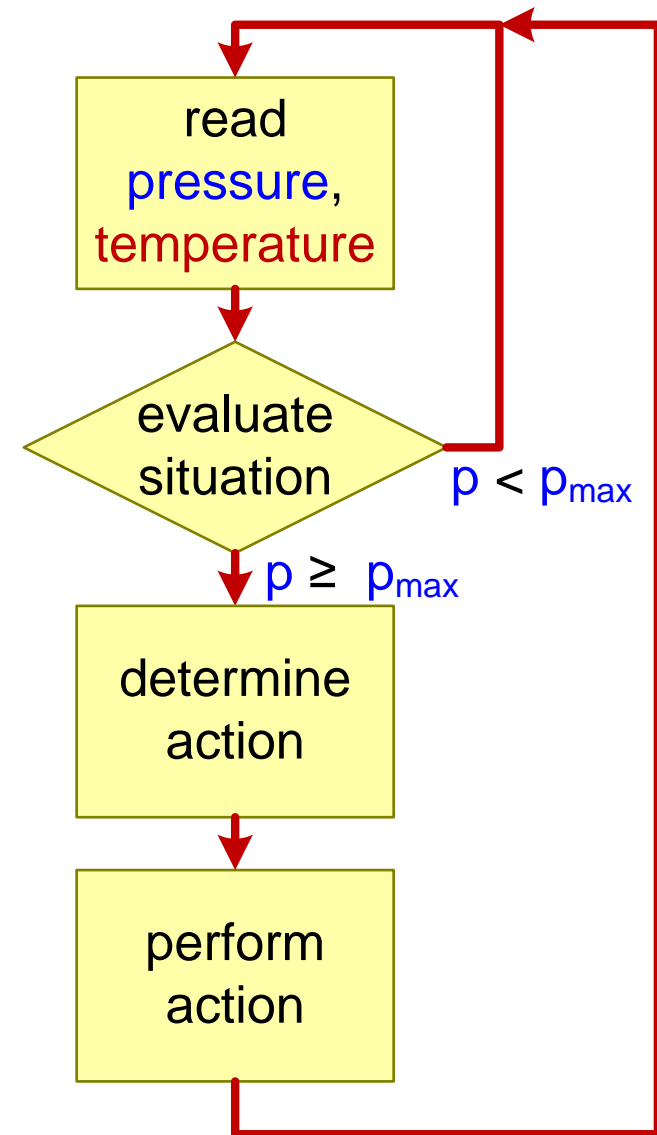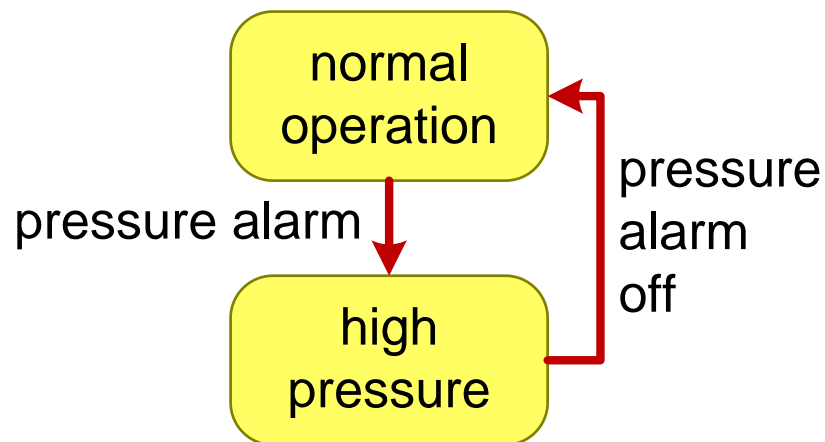
SEFS Modeling

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Abstract

In systems engineering we use many kinds of models. We use simulations for analysis, capture system structure information in MSBE models, and create conceptual models for understanding, communication, reasoning, and supporting decision making.

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First Principle Models

First principle model: a model based on **theoretical** principles.
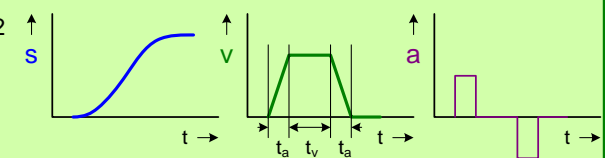
A first principle model **explains** the desired property from first principles from the **laws of physics**.

A first principle model **requires values** for **incoming parameters** to calculate results.

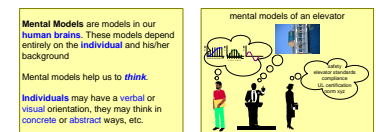first principle model $t_{\text{top floor}}$ elevator

$$v = \frac{dS}{dt} \qquad a = \frac{dv}{dt} \qquad j = \frac{da}{dt}$$

Position in case of uniform acceleration:

$$S_t = S_0 + v_0 t + \frac{1}{2} a_0 t^2$$

$$t_{\text{top floor}} = t_a + t_v + t_a$$

$$t_a = v_{max} / a_{max}$$

$$S(t_a) = \frac{1}{2} * a_{max} * t_a^2$$

$$S_{linear} = S_{\text{top floor}} - 2 * S(t_a)$$

$$t_v = S_{linear} / v_{max}$$

Empirical Models

Empirical model: a model based on **observations** and **measurements**.

An empirical model *describes* the observations.

An empirical model provides **no understanding**.

empirical model t_{move} elevator

$$t_{move} = a * n + b$$

floors
meters
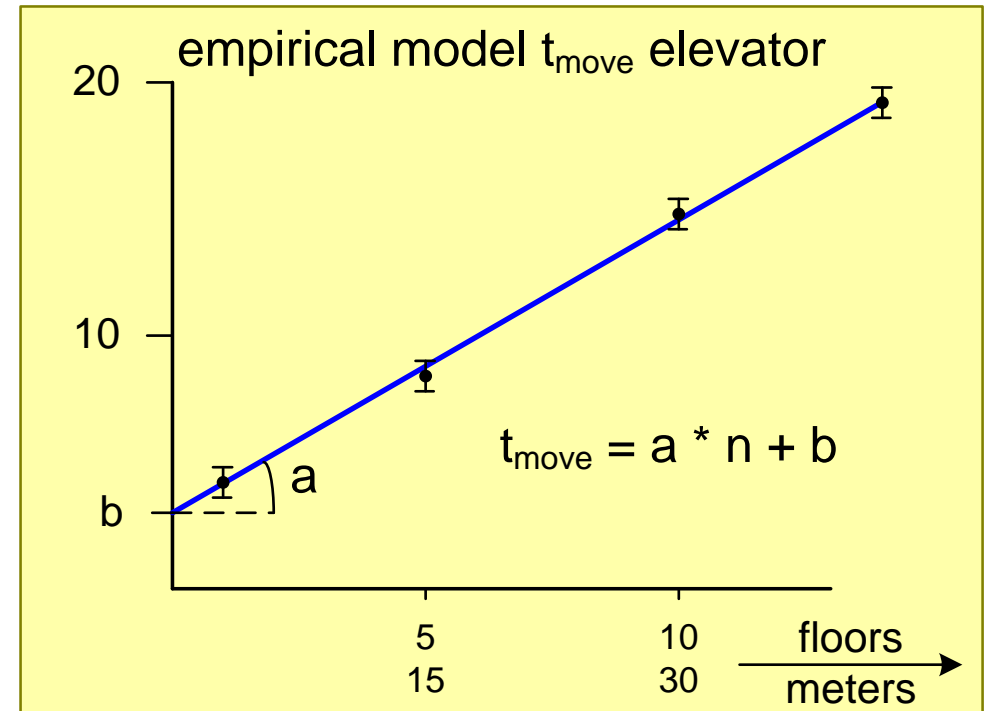
Conceptual Models

Conceptual model: a model **explaining observations** and **measurements** using a selection of **first principles**.

A conceptual model is a **hybrid** of empirical and first principle models; **simple** enough to **understand** and to **reason, realistic** enough to make **sense**.

conceptual model t_{move} elevator

$$t_{move} = v_{max} * n + b_{start/stop}$$

$$b_{start/stop} = f(acceleration, jerk)$$

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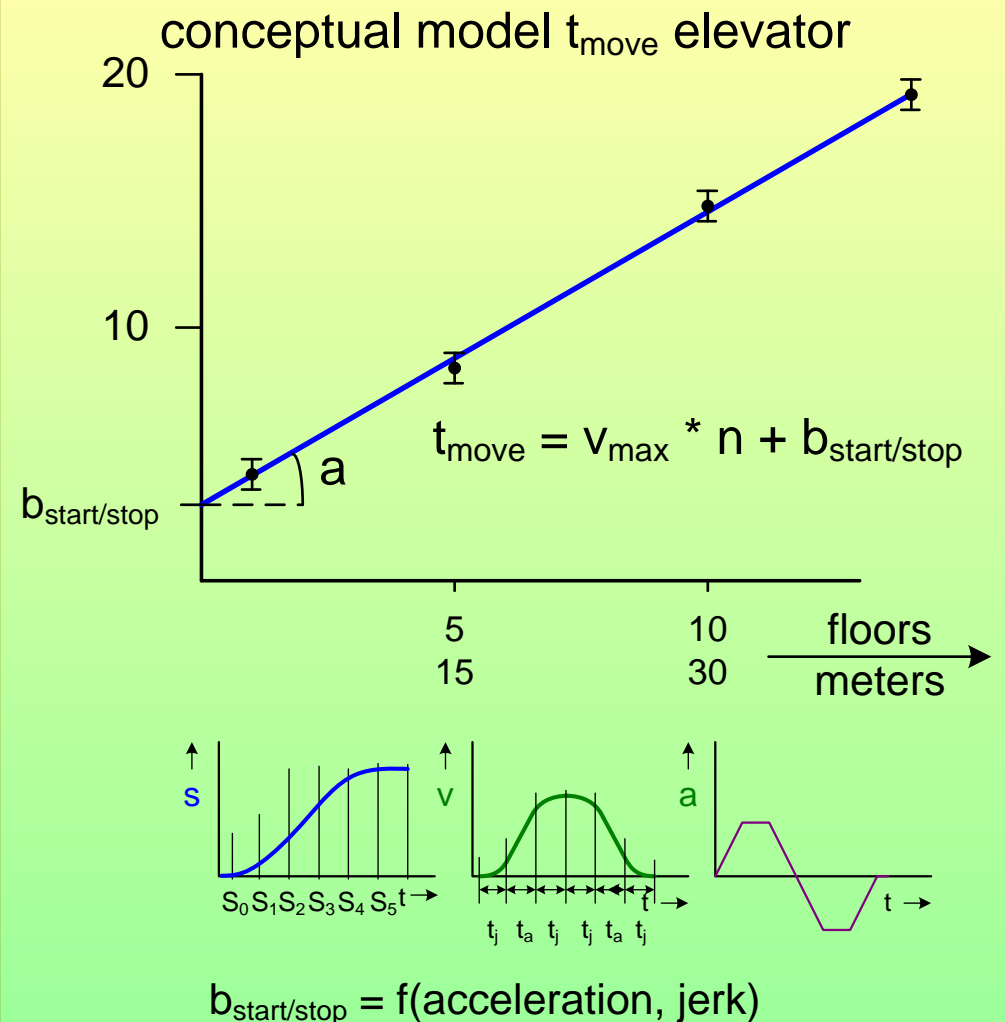
Mental Models

Mental Models are models in our **human brains**. These models depend entirely on the **individual** and his/her background

Mental models help us to *think*.

Individuals may have a verbal or visual orientation, they may think in concrete or abstract ways, etc.

mental models of an elevator

safety
elevator standards
compliance
UL certification
norm xyz

Simulations

Simulation: an executable model based on **first principle** and **empirical models**.

Designers run simulations to *explore*, *analyze*, and *gain insights*.

A simulation provides **understanding**, when **the users transform** the outcomes into **insights**.

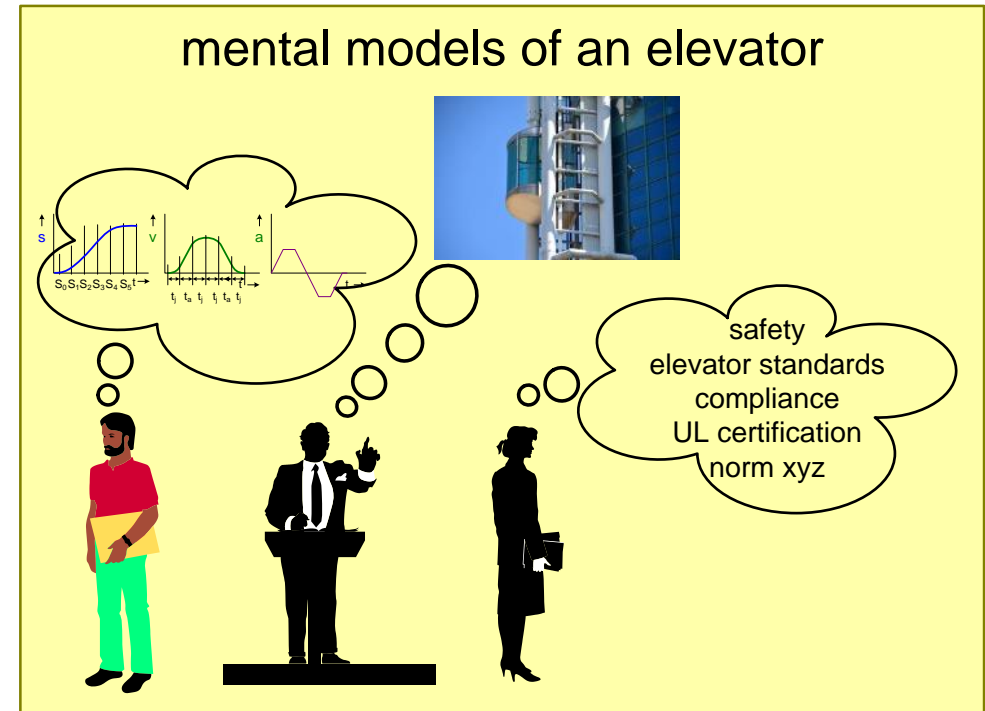## simulation of an elevator

dt	0.2	s
vmax	2.5	m/s
amax	1	m/s2

t (s)	s (m)	v (m/s)	a (m/s2)
0	0	0	1
0.2	0.02	0.2	1
0.4	0.08	0.4	1
0.6	0.18	0.6	1
0.8	0.32	0.8	1
1	0.50	1	1
1.2	0.72	1.2	1
1.4	0.98	1.4	1
1.6	1.28	1.6	1
1.8	1.62	1.8	1
2	2.00	2	1
2.2	2.42	2.2	1
2.4	2.88	2.4	1
2.6	3.38	2.6	0
2.8	3.90	2.6	0
3	4.42	2.6	0
3.2	4.94	2.6	0
3.4	5.46	2.6	0
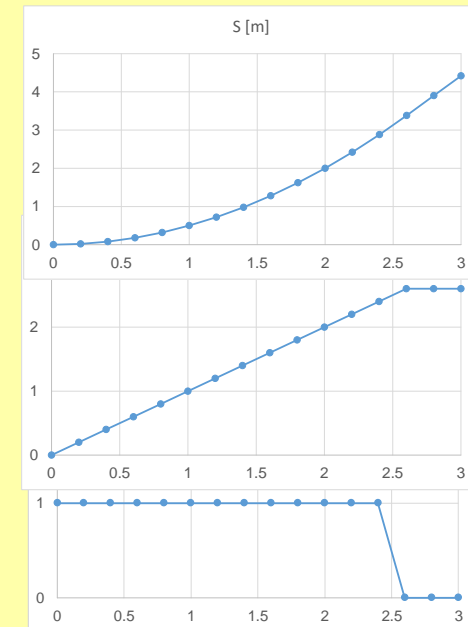
Product Structure and Documentation

The **Product Structure** prescribes the **parts hierarchy**. Each part in the hierarchy has associated **documentation** and **information** for the entire **life cycle.**

The Product Structure and associated documentation help the organization to *manage* all processes from creation to decommissioning and recycling, via **ERP**, **PDM**, **PLM** etc. systems.

product structure of an elevator

- elevator
  - shaft
  - cables
  - cage
    - frame — ceiling
    - walls — lighting
    - doors — climate
    - floor — UI
  - engine
  - control

documentation

specs	procurement
design	manufacturing
verification	transportation
training	installation
sales	configuration
	commissioning
	acceptance
	maintenance
	diagnosis
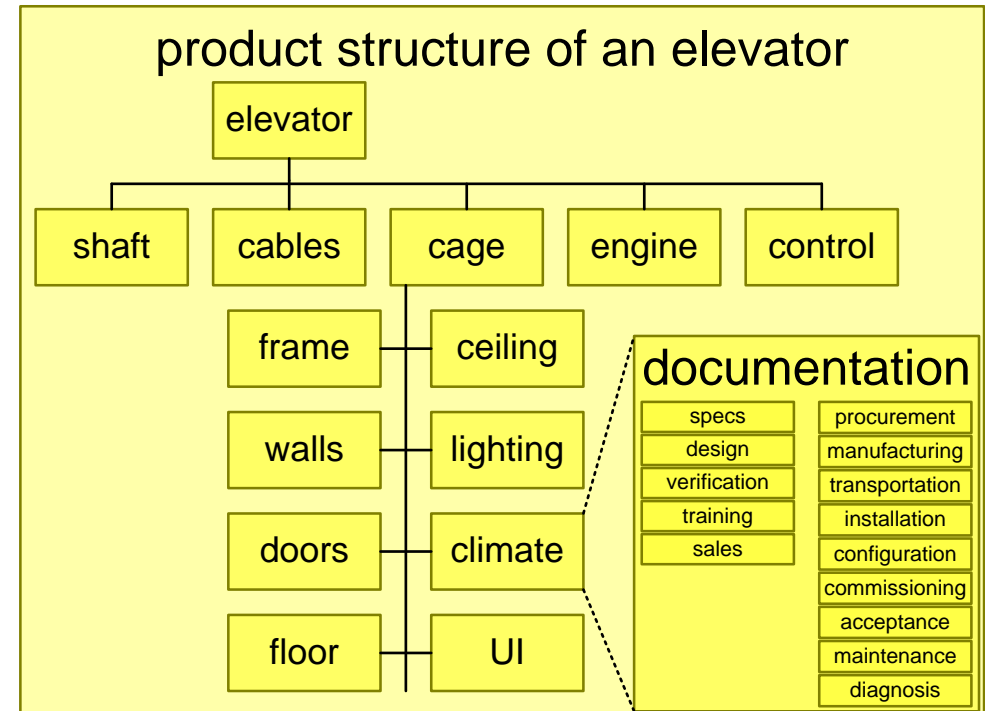
Map of Various Model Types

"Reality"

"Abstractions" simplifications

conceptual models
- understanding
- reasoning
- communication

mental models

configuration and version (ERP, PDM) documentation
- static information
- prescribes, describes system

simulation
- compressed time
- look inside
- many and extreme circumstances
- what if ...

hybrid, e.g. SIL, HIL
- partially closer to reality

the actual system in its context
- infinitely complex
- dynamic
- evolving
- nature and humans

digital twin
- as simulation
- using actual data
- real-time control
- health monitoring

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Conceptualization Reduces 3 to 5 Orders of Magnitude

conceptual model

simulation
(executable model)

3 to 5 orders
of magnitude

abstraction /
conceptualization

data increase

implementation *10..100

conceptual dynamics

-> full space * 100..1000

conceptual model t_{move} elevator

$t_{move} = v_{max} * n + b_{start/stop}$

$b_{start/stop} = f(acceleration, jerk)$

S, a, v, j
t_{floor}, t_v, t_a

simulation of an elevator
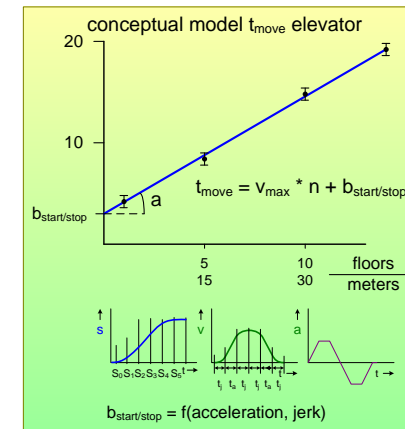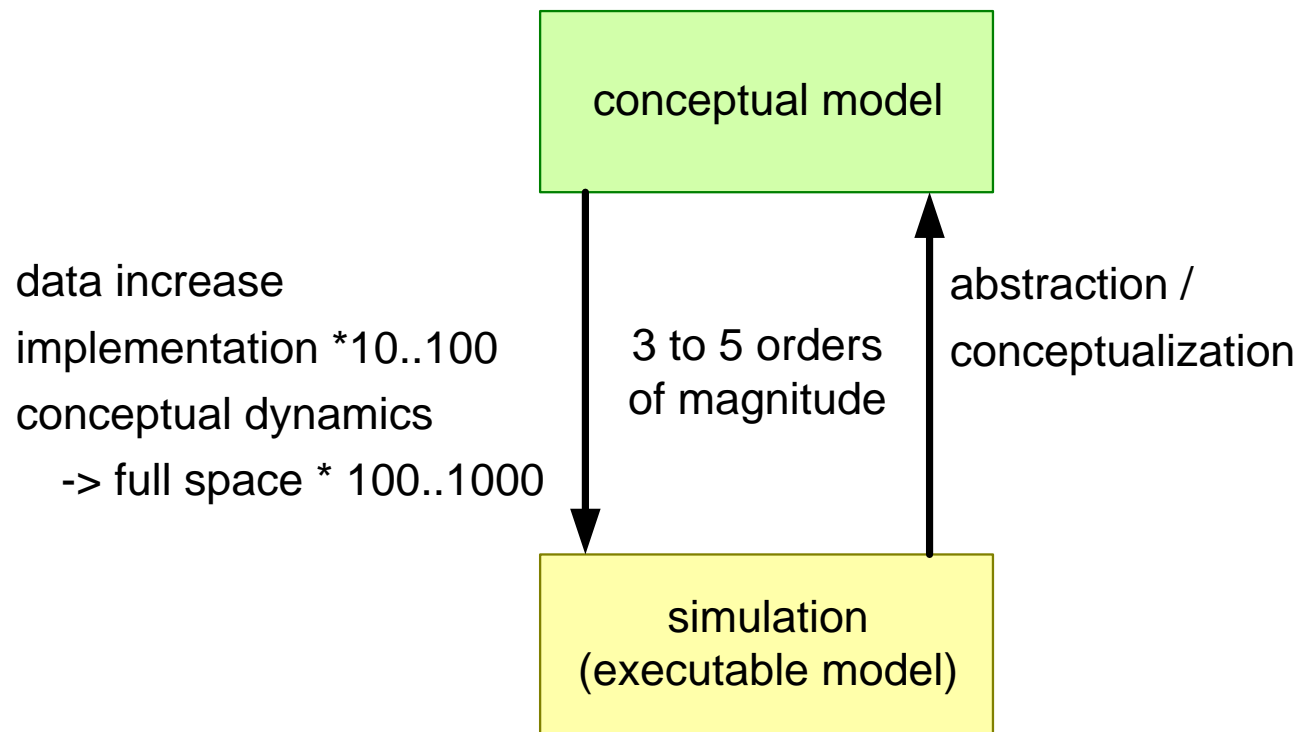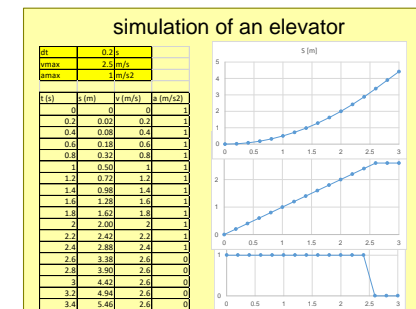
Conceptual Models are at All Levels