Systems Engineering tooling

Hot Or Not – Systems Engineering track

Ton Peijnenburg – VDL ETG, TU/e HTSC

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Deputy managing director VDL ETG T&D

2014 - present
VDL ETG T&D - Manager Systems Engineering

2010 - 2013
VDL ETG T&D - Manager Advanced Developments

2005 - present
TU/e High Tech Systems Centre - Fellow

2008 - 2010
FEI - R&D Manager Phenom

2002 - 2007
Philips Electronics North America - Mechtronics System Manager

1992 - 2002
Philips Innovation Services - Development Engineer

1985 - 1992
Eindhoven University of Technology - Ir (MSc) Electrical Engineering

VDL ETG

7 FACTORIES
+ 2 R&D facilities

SPREAD ACROSS
3 CONTINENTS

REVENUE
>950M€

± 3500 EMPLOYEES

50% EXPORT

COMPANY ACTIVITIES
DIVIDED AMONG **6 MARKETS**

STRONG BALANCE SHEET POSITION
SOLVENCY **60%**

250,000 M²
PRODUCTION SURFACE AREA

VDL Enabling Technologies Group – market segments

We serve many high-end equipment markets as Tier-1 supplier

Semiconductor Capital Equipment

Led Manufacturing Equipment

Solar Production Equipment

Analytical Equipment

Medical Equipment

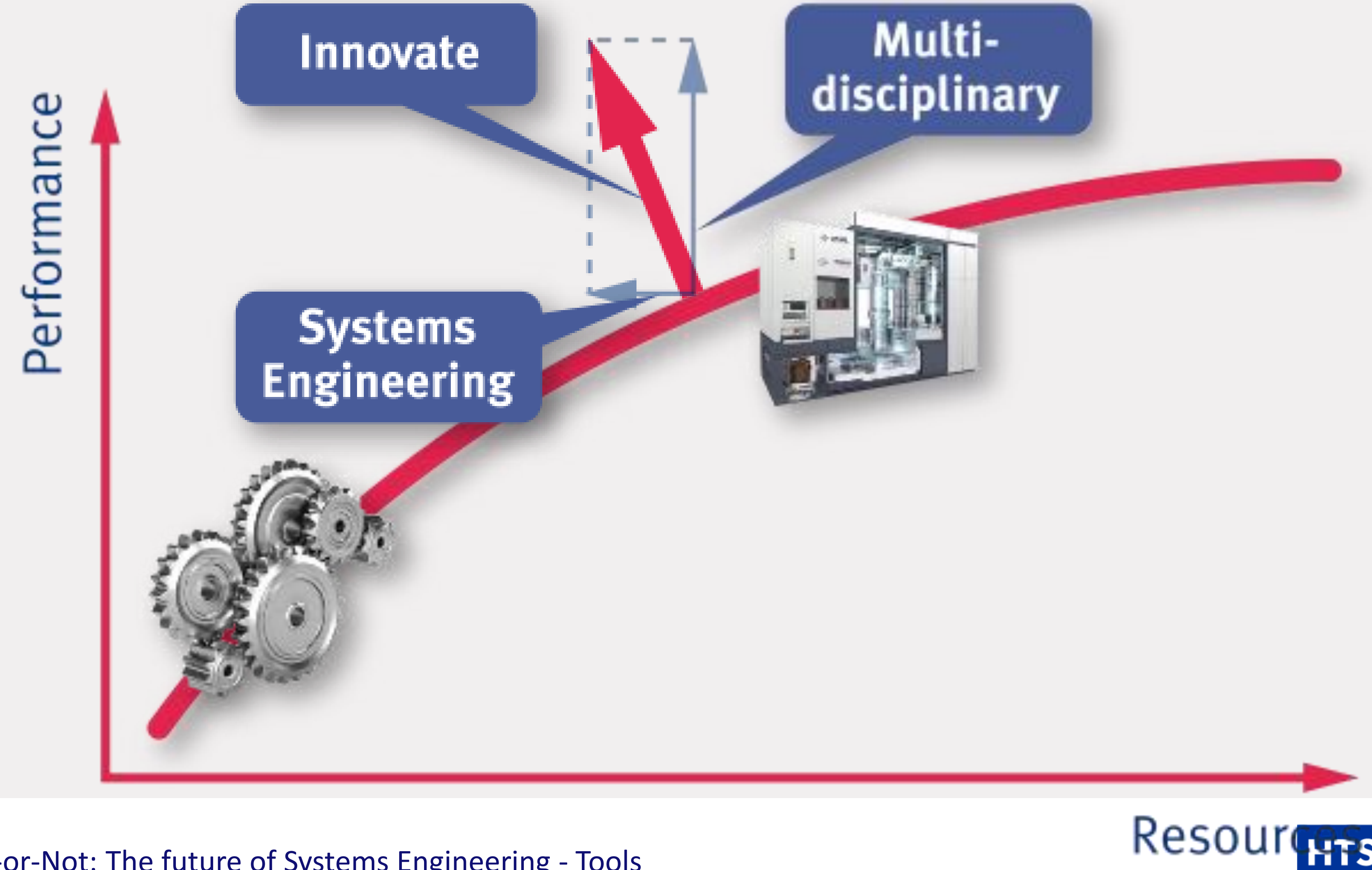
Science & Technology

From…

… turnkey projects to…

… full Life Cycle Management

Resources versus Performance

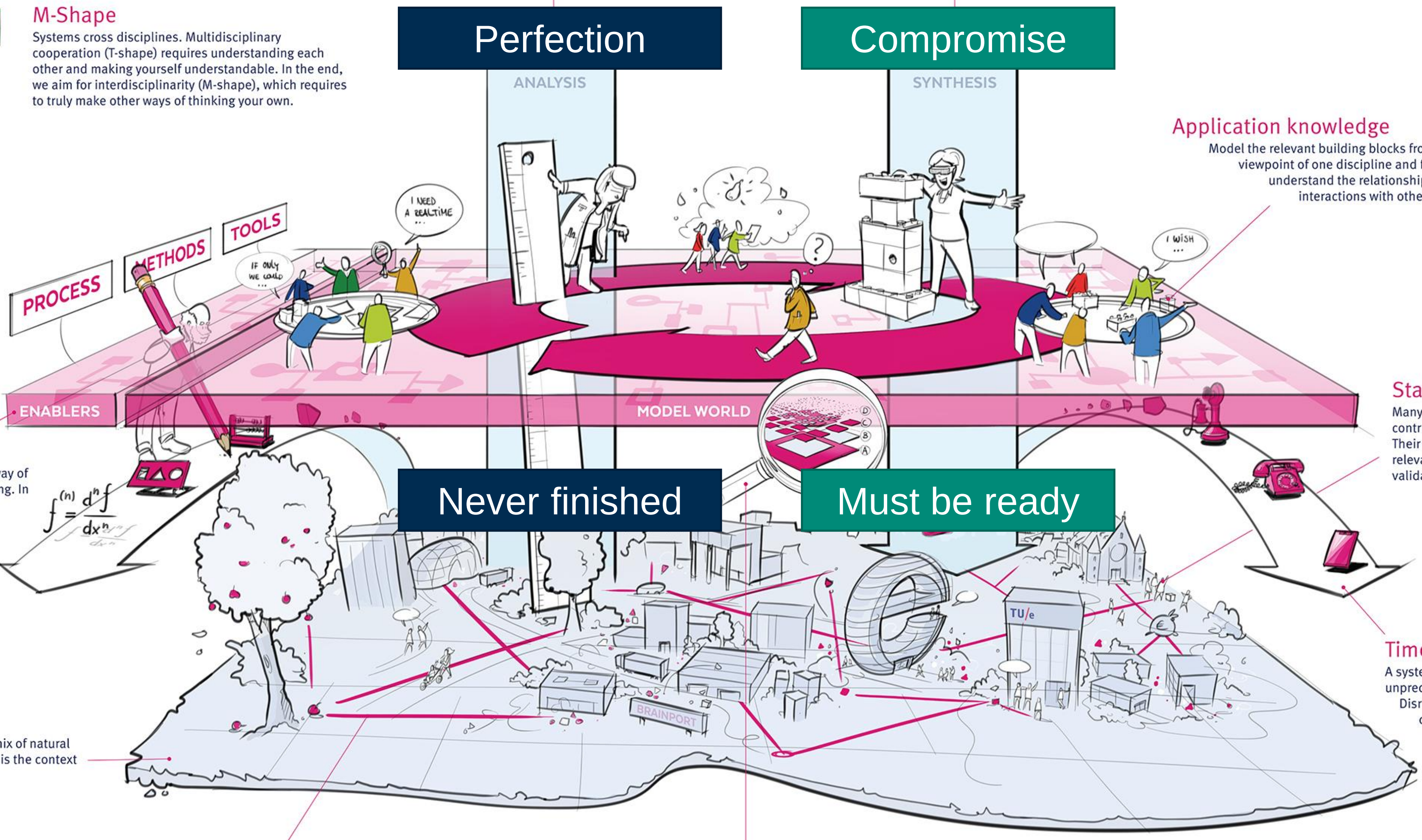


Systems Thinking

M-Shape
Systems cross disciplines. Multidisciplinary cooperation (T-shape) requires understanding each other and making yourself understandable. In the end, we aim for interdisciplinarity (M-shape), which requires to truly make other ways of thinking your own.

Analysis is the understanding of the world, through measuring the functional elements and construct complex models to describe reality.

Synthesis is to create coherent solutions by reviewing alternatives and create new elements or relationships between them.



Application knowledge
Model the relevant building blocks from the viewpoint of one discipline and from there understand the relationships and interactions with other domains.

Stakeholders
Many and different stakeholders contribute and influence the system. Their viewpoints and concerns are relevant to the constraints and the validation of solutions.

Enablers determine the way of looking, analysing and predicting. In addition to process, tools and methods, they also define the boundaries of the modelling potential and therefore have to be developed along on time.

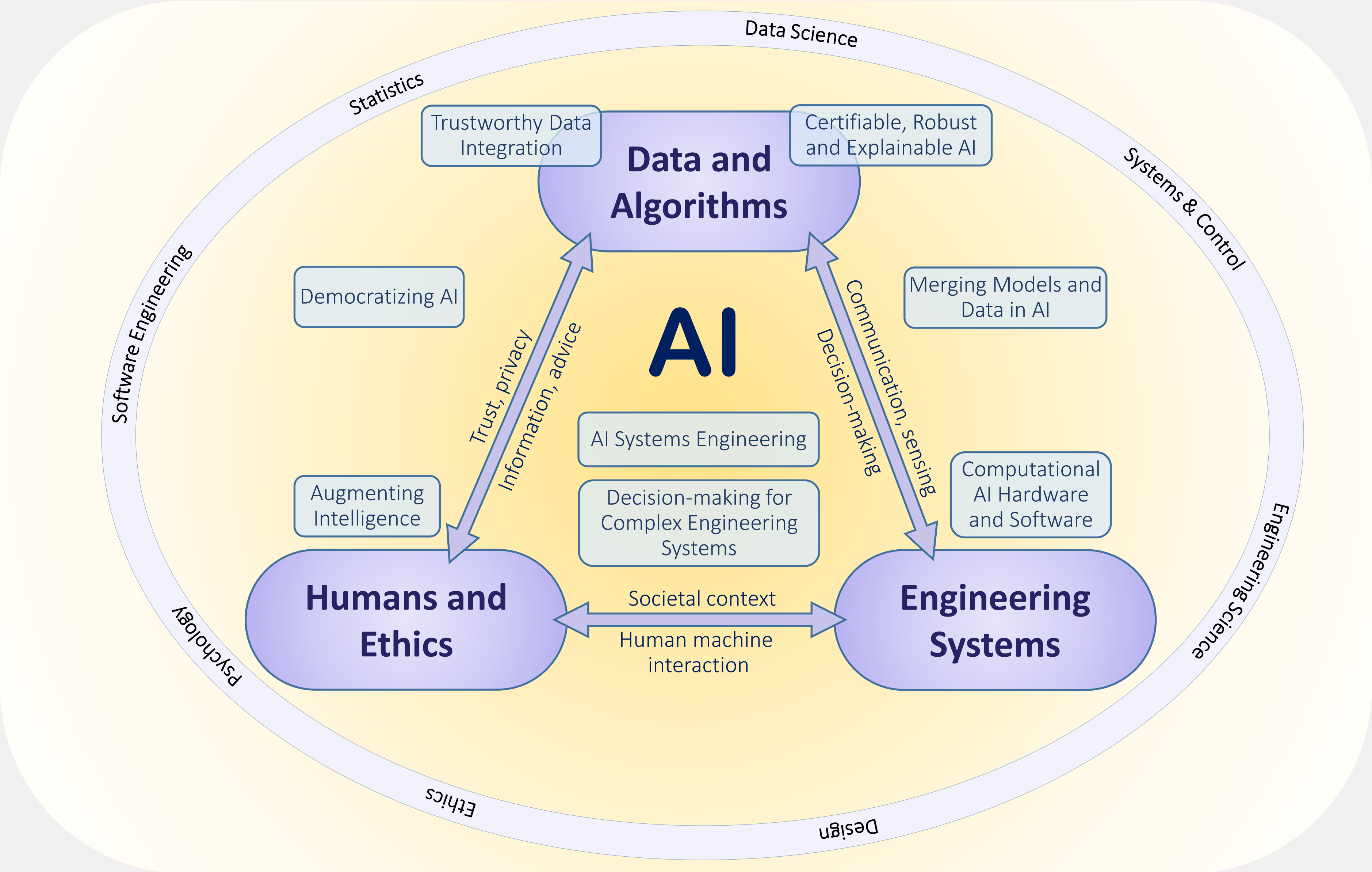
Time
A system evolves over time on an unpredictable and unforeseen path. Disruptive technologies or a combination of new insights can also lead to a revolution.

The **real world** - a mix of natural and man-made systems - is the context of grand challenges.

A **system** is an interconnected set of elements that are coherently organized, interact together and jointly achieve something.

Levels of aggregation support the understanding of the larger (complex) whole within which the question and the answer play. Zooming in and out, alternating different complementary views and exploring alternatives, supports the choice without exactly knowing.

Scientific Roadmap of Eindhoven AI Systems Institute




SECRET
SAUCE
?

Dutch design for high-tech equipment (1/2)

- Multidisciplinary, rooted in control technology and DDP
- Strong technological basis and orientation
- Detailed understanding of relevant physics
- Predictive modeling → model-based design
- Lumped parameter and back-of-the-envelope (DSL)
- Focus on essential functions and interactions
- Budgeting: errors, dynamic errors, other driving parameters, …
- Early prototypes (functional models)

Door Picture taken by User:Ellywa - Eigen werk, Publiek domein, https://commons.wikimedia.org/w/index.php?curid=19500

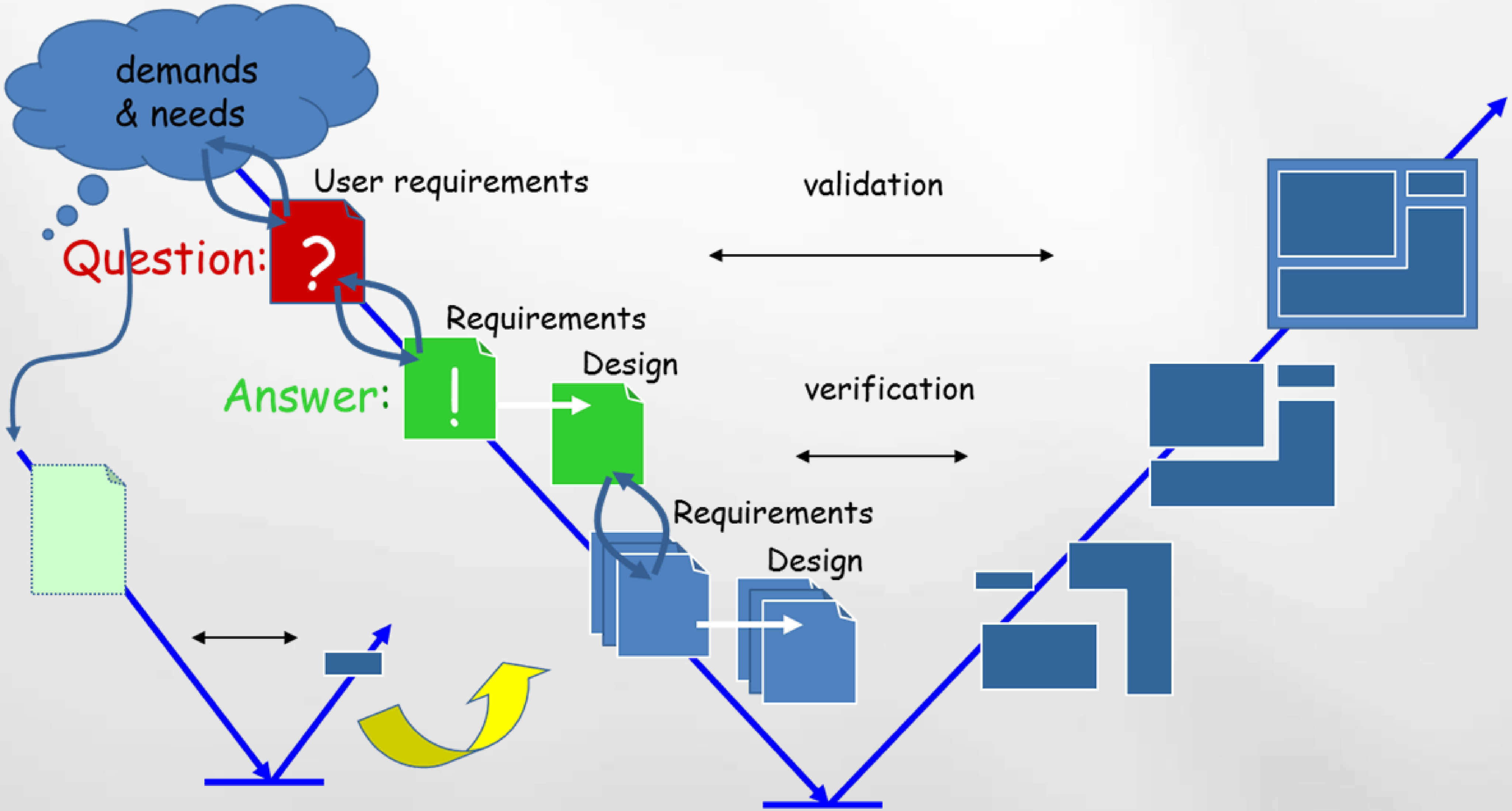
Dutch design for high-tech equipment (2/2)

- Purpose over manners (“bot”)
- Content over hierarchy (“informeel”)
- Challenge your assignment (“eigenwijs”)
- Challenge the processes (“kort door de bocht”)
- Challenge the status quo (“moet beter kunnen”)

https://www.adamsrecruitment.com/blog/2019/06/4-characteristics-of-a-modern-workforce

HTSC HIGH TECH SYSTEMS CENTER TU/e

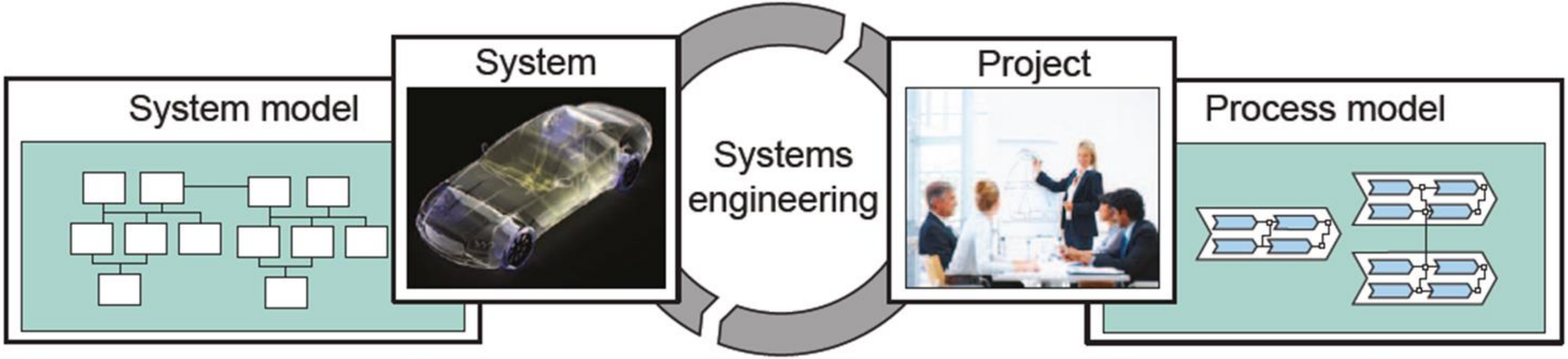
Systems Engineering



Philips CFT, SEM group, 2001, some additions

Systems Engineering

Heinz Nixdorf Institut + Fraunhofer IPT view



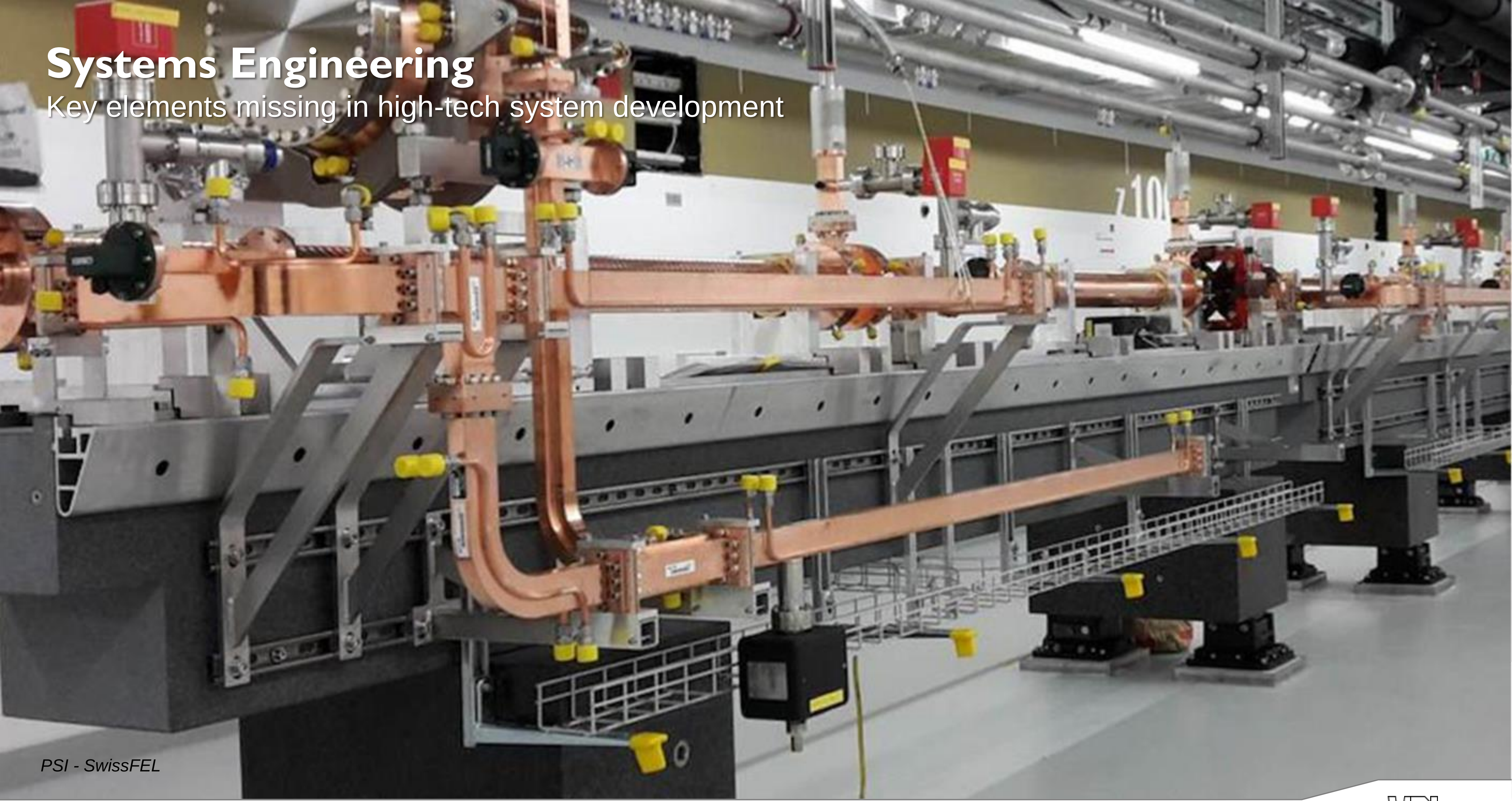
- Requirements
- System architecture
- Analysis, simulation
- Test, validation
- Optimisation
- ...

- Resources
- Stakeholder
- Activities
- Risks
- Costs, time
- ...

Figure 2-1: Joint analysis of system and project – the core aspects of SE

SYSTEMS ENGINEERING in industrial practice, Heinz Nixdorf, Fraunhofer IPT
https://www.iem.fraunhofer.de/content/dam/iem/de/documents/Studie%20Systems%20Engineering_englisch.pdf

Systems Engineering
Key elements missing in high-tech system development

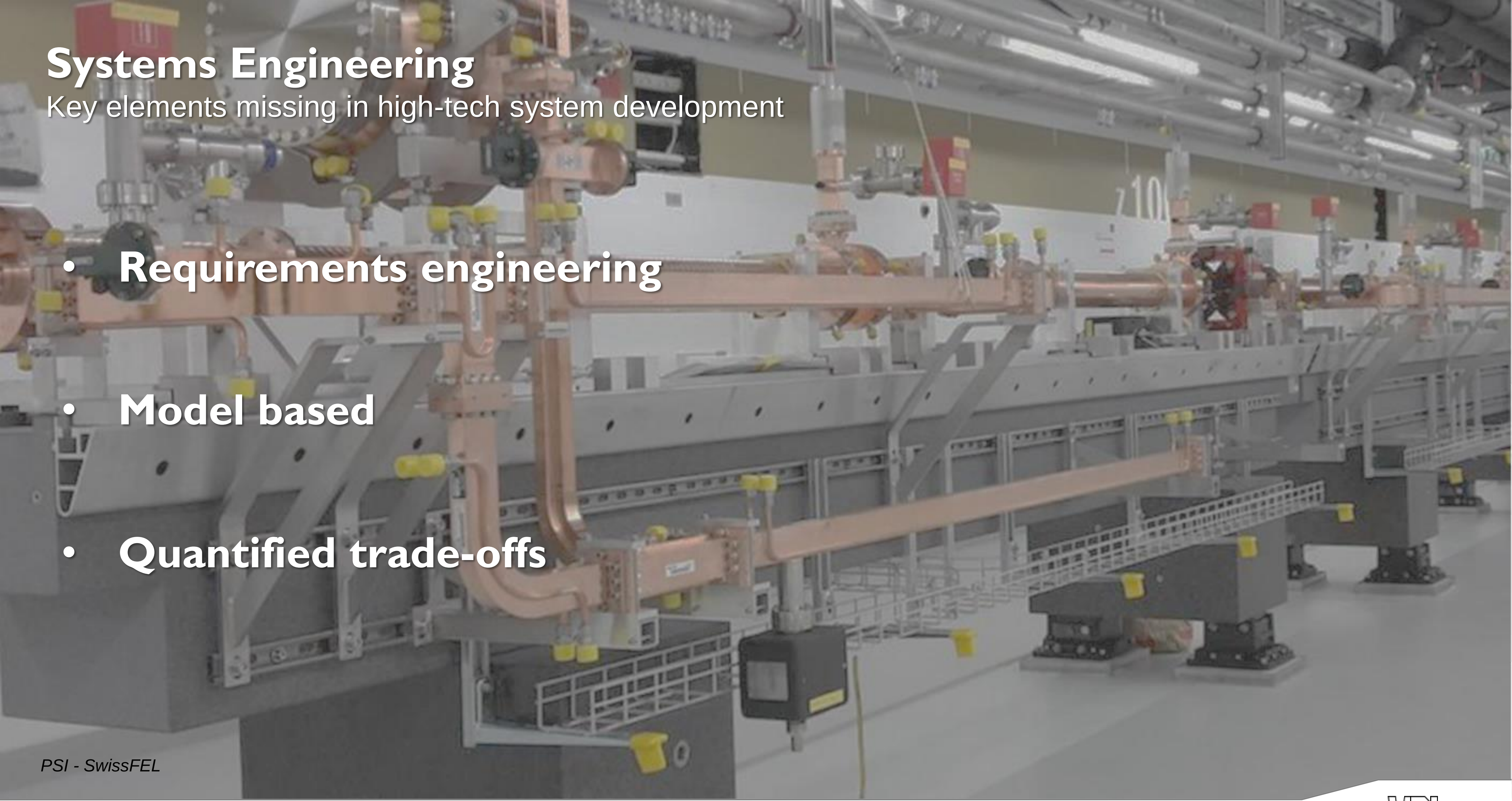


PSI - SwissFEL

Systems Engineering

Key elements missing in high-tech system development

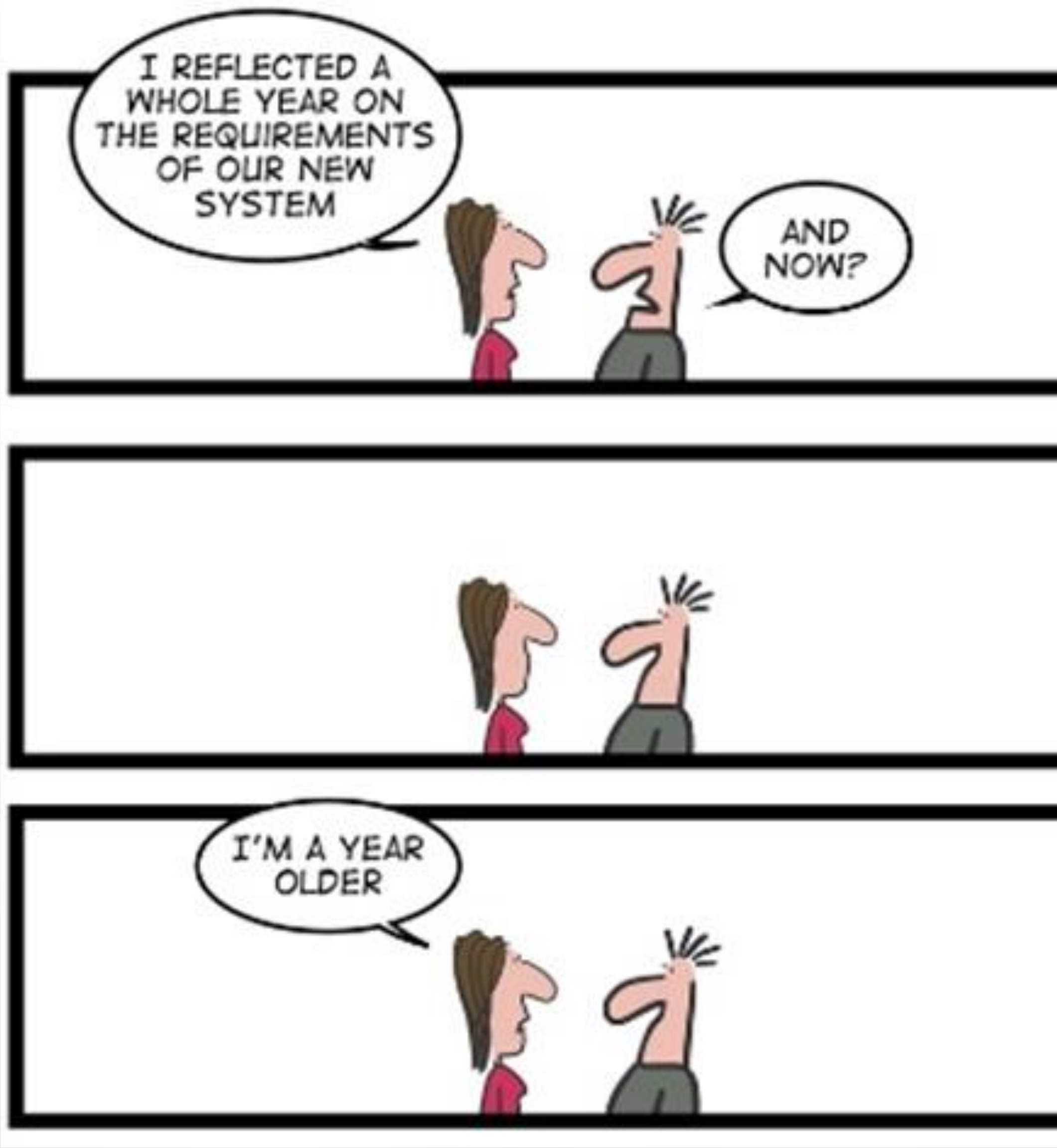
- **Requirements engineering**
- **Model based**
- **Quantified trade-offs**



PSI - SwissFEL

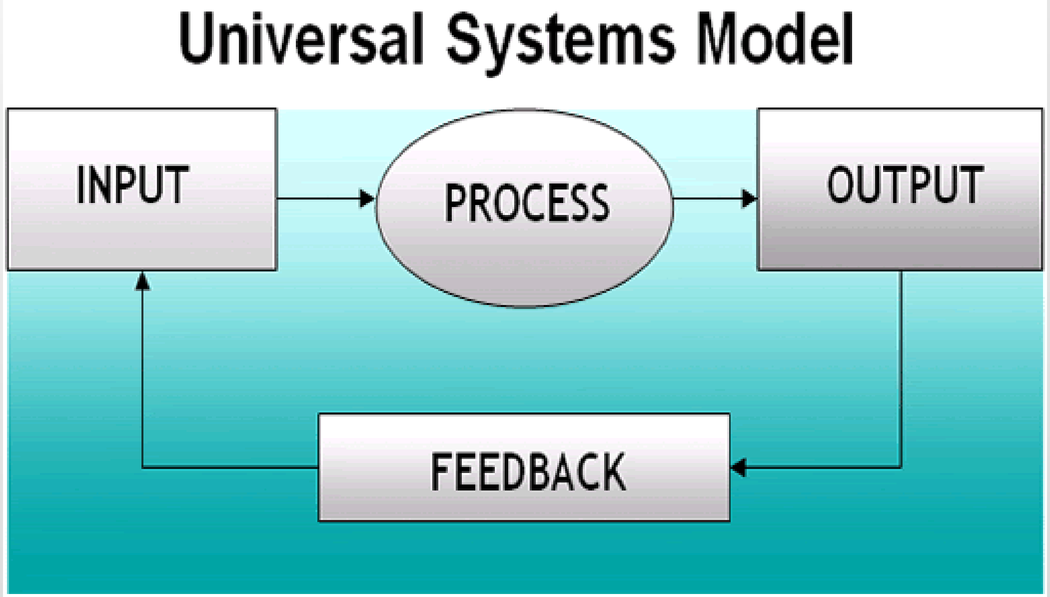
Requirements engineering

- Key to **effective** (and efficient) system development
- Requirements **model**, not just plain docs
- Need **version control**, baselining, traceability
- Basis for medical and other **certifications**
- **Flow-down** of requirements
- **Scenarios**
- **Alternative** concepts



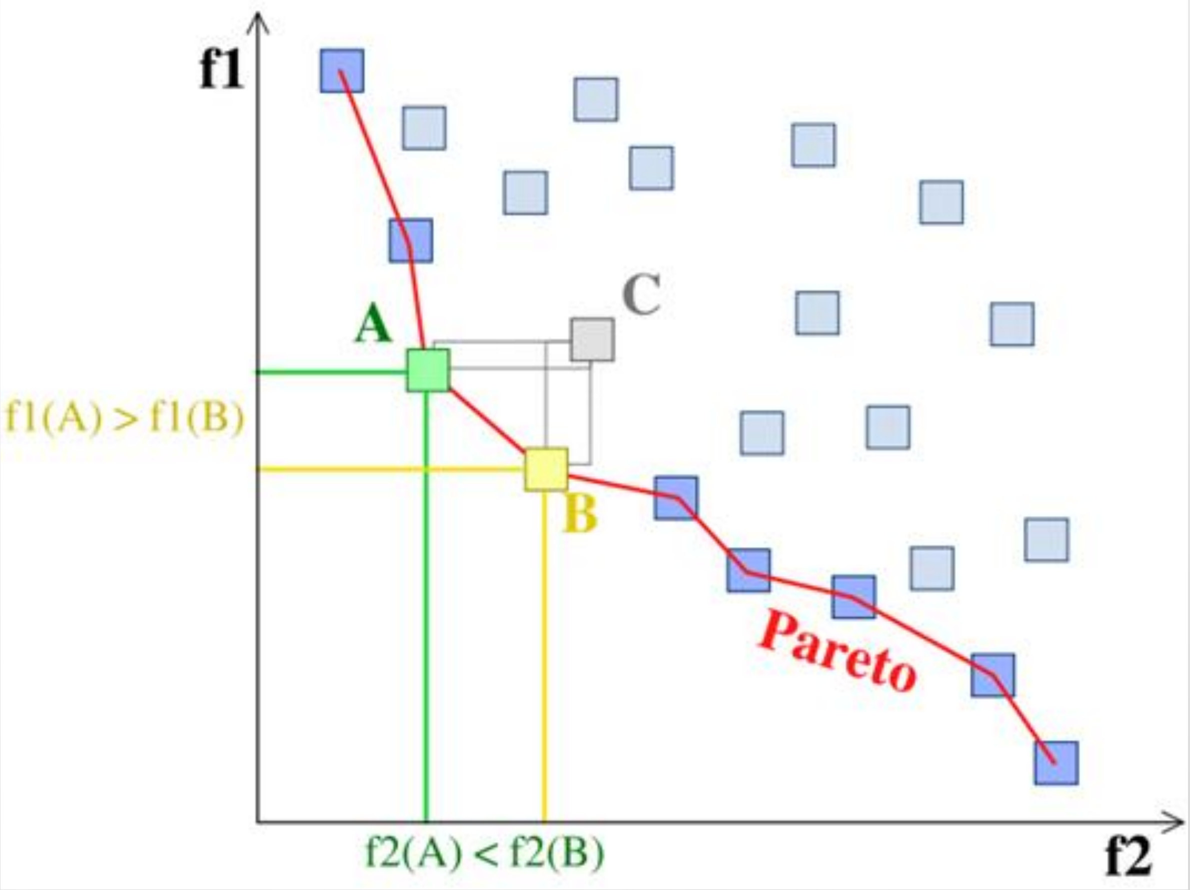
Model-based

- Models **instead of documents** (capture knowledge, drive development)
- No multi-multi, rather **co-evolving separate models**
- Baselining, version control, **configuration** management
- **Formal language** models can be treated as software
- **General modeling** should come back as course
- **Model-based SE** is gaining momentum
- Close gap between “**software & the others**”
- “Live” **models for reviews**
- “**Zoom in & out**” to deal with complexity



Quantified trade-off – synthesize and compromise

- Multi-parameter, multi-objective **optimization** for various concept alternatives
- **Formal methods** to deal with complexity
- Strong linkage to **requirements**
- Knowledge of (system level) **sensitivities**
- Cost of **future change**



Models in the driver seat?

Model-based Systems Engineering

- The formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases. (INCOSE, 2007)

Model-driven engineering

- A software development methodology that focuses on creating and exploiting domain models, which are conceptual models of all the topics related to a specific problem.

Simulation-driven design

- Simulation-driven design moves simulation much closer to the front end of the process. Engineering teams do not have to wait until they have completed a design for analysis and feedback. (ASME)

Simulation platforms

Modeling of wafer handler

A wide variety of tools is used for development & engineering

- Mechanics and dynamics – Siemens NX, ANSYS
- Dynamics and control – MATLAB and Simulink
- Supervisory control, logistics – (ESI) Concerto
- Heat & flow – ANSYS
- Mechanisms and dynamics – SimMechanics
- Electronics – Mentor
- Electro mechanics – ANSYS, Vector Fields, FEMM
- Particle flow, generation – special
- Vacuum – special

- Tolerance stacks – Excel
- Reliability – Excel
- Cost – Excel
- Bill of Material – Excel
- …

Evaluation of Conceptual Design Choices using Dependency Structure Matrix Methods, K.A. Meeuwsen, MSc thesis, 2019

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- Tolerance stacks – Excel
- Reliability – Excel
- Cost – Excel
- Bill of Material – Excel, TCE
- Requirements – Word
- Test plans, reports – Word
- Project planning – MS Projects, Excel, special
- Risk analysis – Excel
- PDM, ERP, CAD/CAM, CMM, …

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- PDM, ERP, CAD/CAM, CMM, …

- CAM programming – NX CAM, …
- Machining analysis – Vericut, …
- Dimensional metrology – Calypso, …
- 3D printing – Cura, others
- Machine learning – PyTorch, Tensorflow, …
- Statistics – Minitab, R, Python, Anaconda, …
- Structure – DSM

Evaluation of Conceptual Design Choices using Dependency Structure Matrix Methods, K.A. Meeuwsen, MSc thesis, 2019

Design Structure Matrix – the good ol' N^2 re-invented

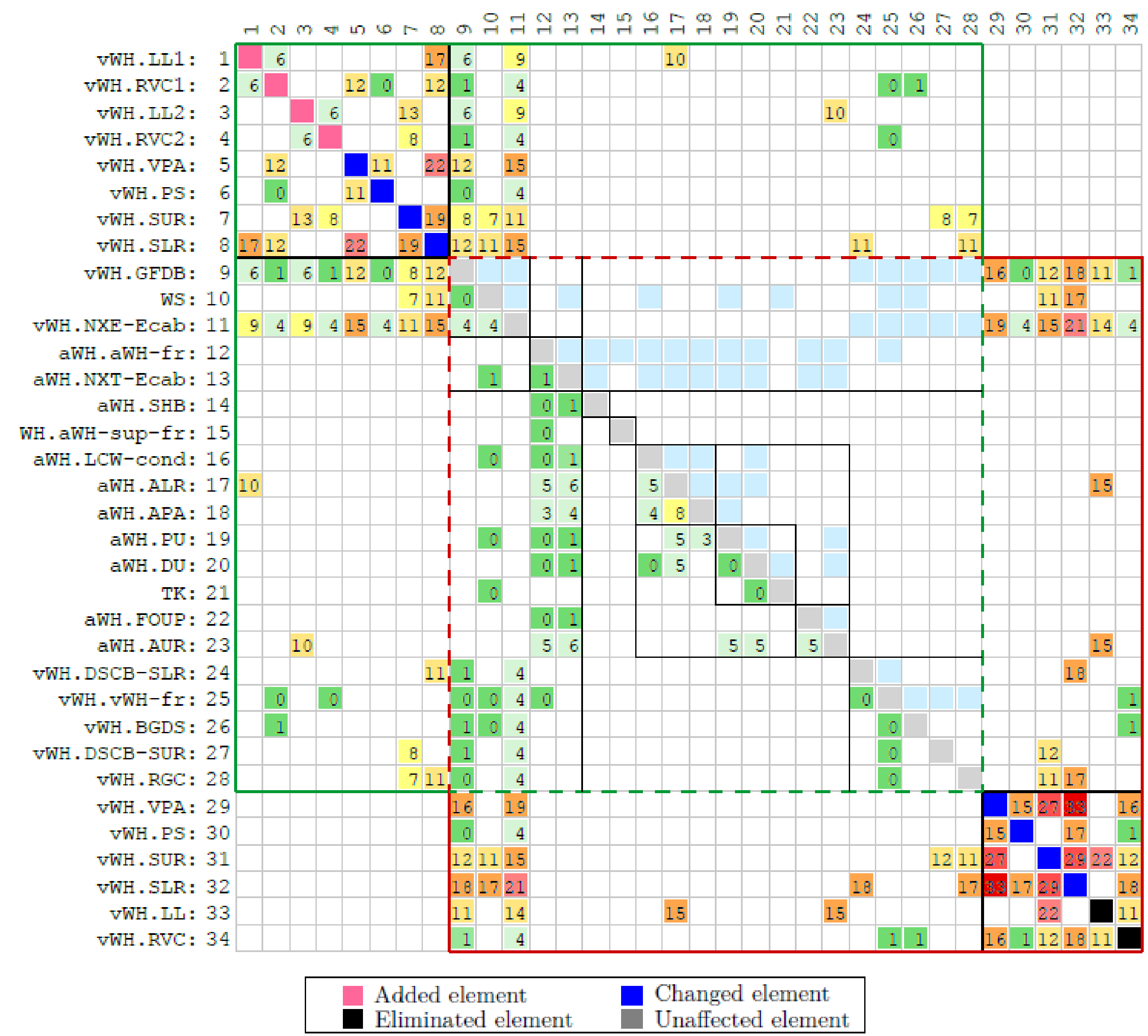


Figure 7.2: Availability impact CD-DSM, 3rd level of decomposition

Evaluation of Conceptual Des

The role of systems engineering

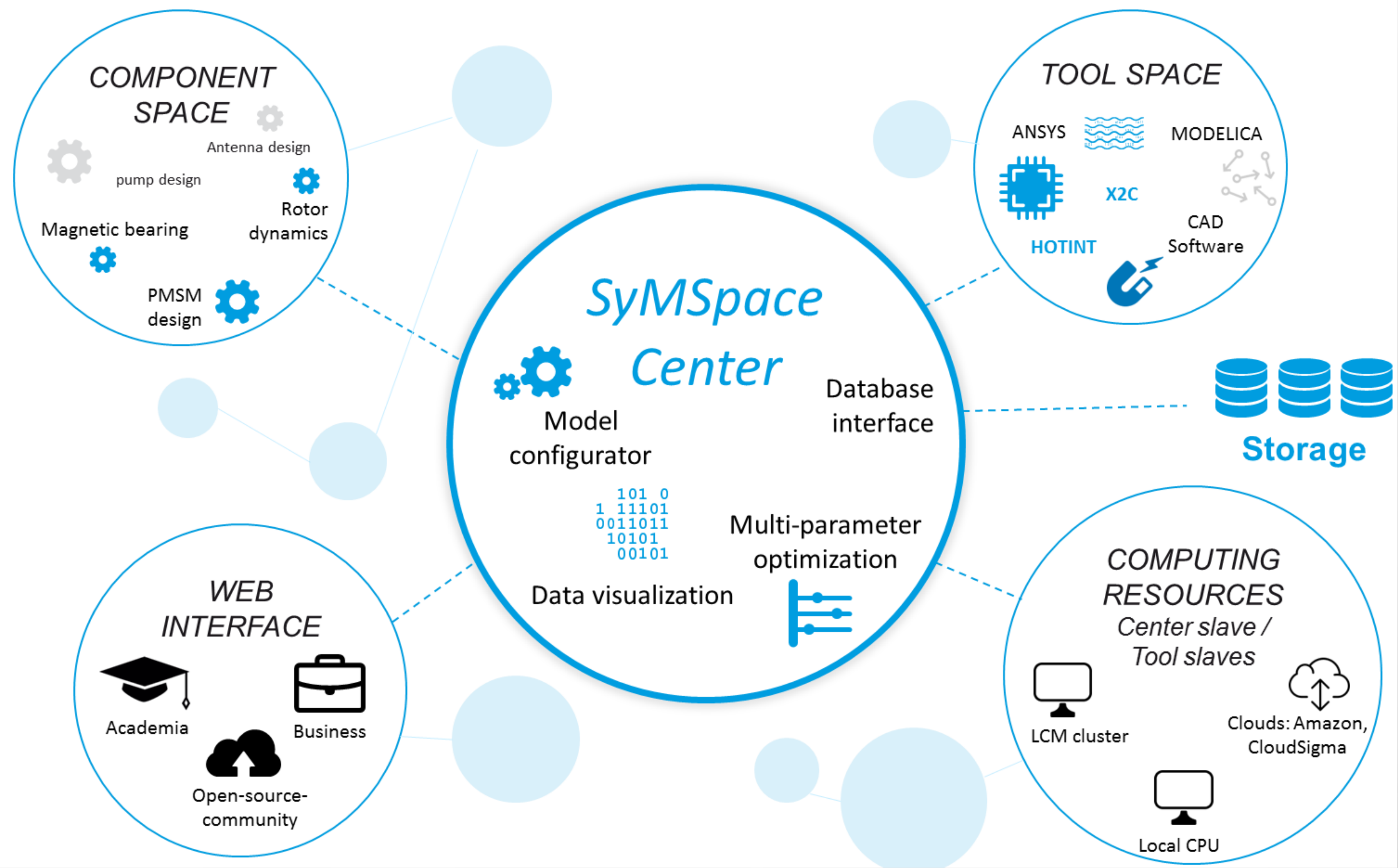
- SE drives the task – “divide and conquer”
  - Elicitate requirements, translate to specifications, structure
  - Break down the problem, define interfaces
  - Support trade-off analyses, decision making

- SE coordinates information – “broker” the relevant data
  - Single source of truth
  - Up-to-date, accessible, reviewed, available, traceable, baselined, …

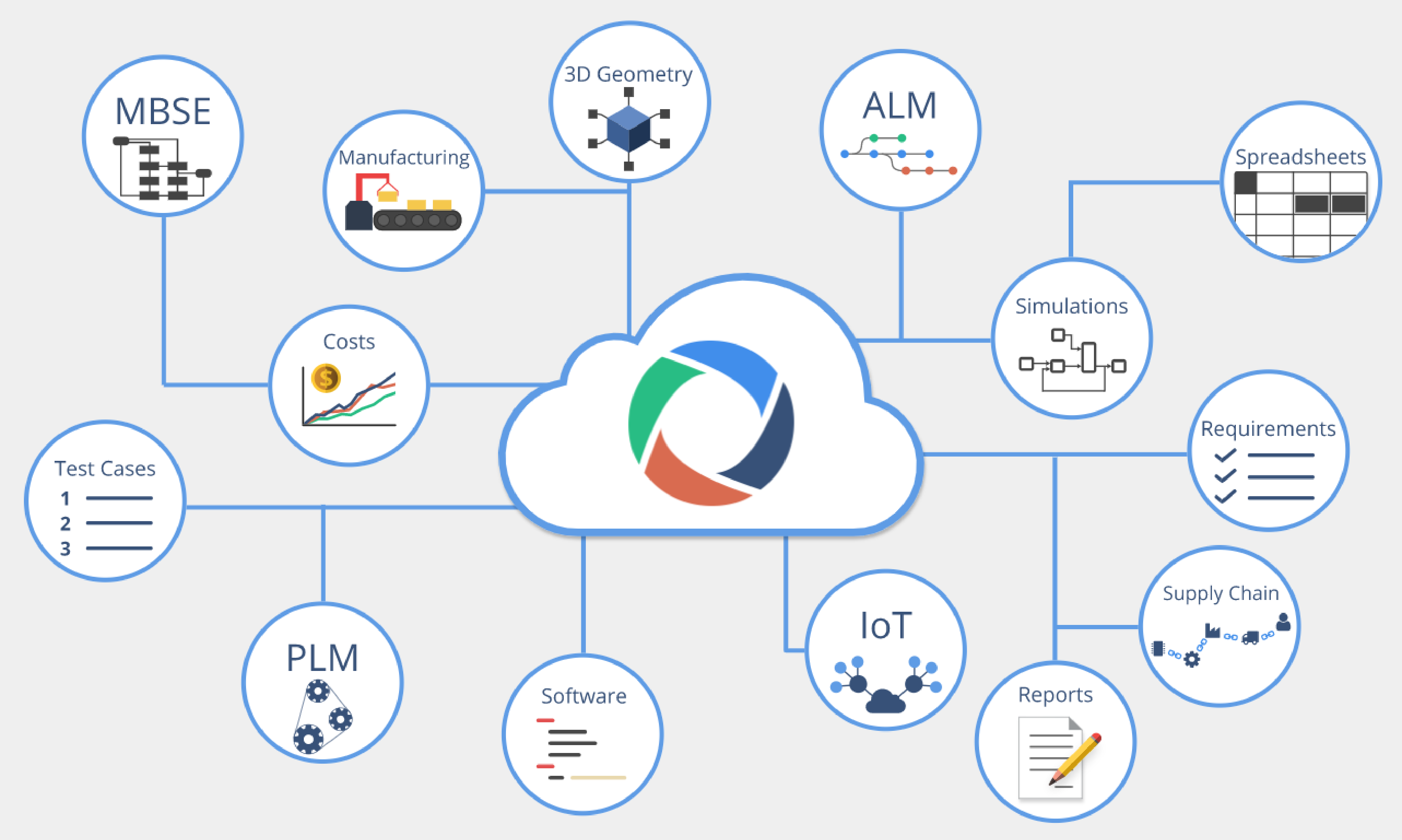
Challenges for engineering tools

- Multi-vendor – there is no one-stop-shop
- Multi-physics – different (physical, mechanical, electrical, chemical, …) aspects are modeled together
- Multi-model – not all aspects can be covered in one model
- Multi-stage – from early concept to end-of-life management
- Version-controlled
- Interoperable – exchange data between different tools, organizations (standards)
- Key is a domain-specific Information model
    - Digital version of Philips TPD standard
    - Extend with systems engineering information elements

Example of simulation tool integration



Another example: Open Services for Lifecycle collaboration



Conclusions

- Interoperability between tools – standards!
- Collaboration in the Netherlands, Brainport, Eindhoven
- Tools are essential for engineering
  - Model based development will be the norm (problems are complex and complicated)
  - Models are made and manipulated with tools
  - Information is managed by tools
- Call for action
  - Start using SE tools, enhancing interoperability, coordinate in the region
  - From description to behavior to generation of design and code → the end goal!