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Systems Engineering
and
Where is Model Based Systems Engineering leading us?

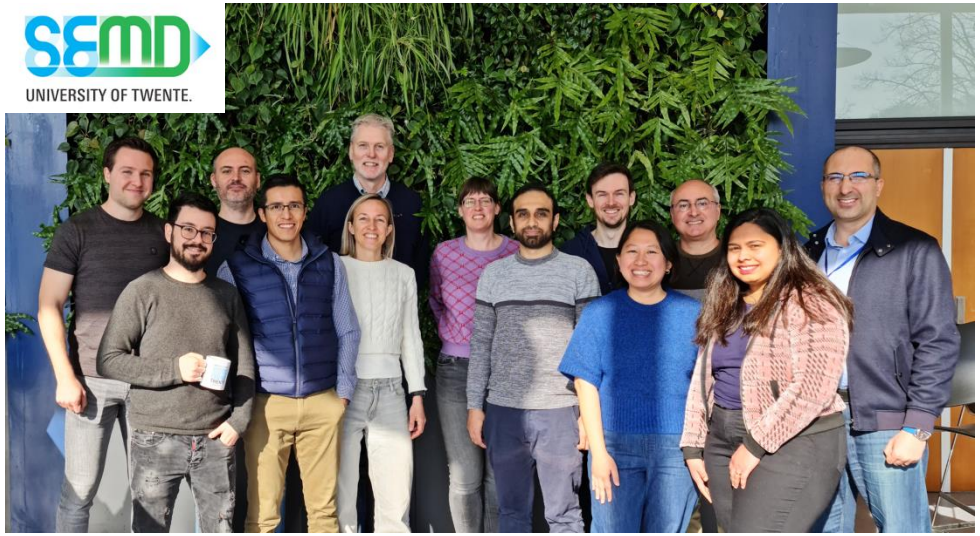
Maarten Bonnema

Inside Connect, Malaga, 20250904

SYSTEMS ENGINEERING & SEMD MULTIDISCIPLINARY DESIGN

Who is Maarten Bonnema

- Full Prof in Systems Engineering and Multidisciplinary Design - SEMD
- MSc in Electrical Engineering
- EngD in Technical Systems (Mechatronics & Mechanical Engineering)
- PhD in Systems Architecting
- Industrial Experience as Systems Engineer at ASML
- Collaboration with, and consulting for high-tech companies
- INCOSE Fellow
  (International Council On Systems Engineering)



What is Systems Engineering?

INCOSE definition:

"a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods."

https://www.incose.org/about-systems-engineering/system-and-se-definition/systems-engineering-definition, accessed 20230626

Noah's Ark, Roman Aquaducts & Road System

1960s: MIT course on SE by Arthur Hall

1966: USAF SE Handbook

1969: STD-499 Military Standard: SE Management

1990: National Council on Systems Engineering, renamed in 1995 INternational: INCOSE

1995: NASA SE Handbook

1996: The Art of Systems Architecting by Maier and Rechtin

1998: INCOSE SE Handbook v.1

2009: CNN Money calls Systems Engineer "the best job in the world"

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"…**the systems engineer resembles an architect**, who must generally have adequate substantive knowledge of building materials, construction methods, and so on, to ply his [or her] trade. Like architecture, **systems engineering is in some ways an art as well as a branch of engineering**. Thus, aesthetic criteria are appropriate for it also. For example, such essentially aesthetic ideas as **balance**, **proportion**, **proper relation of means to ends**, and **economy of means** are all relevant in a systems-engineering discussion."

Hendrick Bode in a 1967 report for the US House of Representatives

https://nap.nationalacademies.org/read/21281/chapter/6

What is Systems Engineering? – a practical description

1. The *System perspective*;
2. Separate the *what* and *how much*, from the *how*;
3. Focus on the *interfaces*;
4. *Uncertain* and *incomplete information* in taking far-reaching decisions;

- Relying on *Communication* in a context of *Multi-disciplinarity*.

1. The System Perspective:

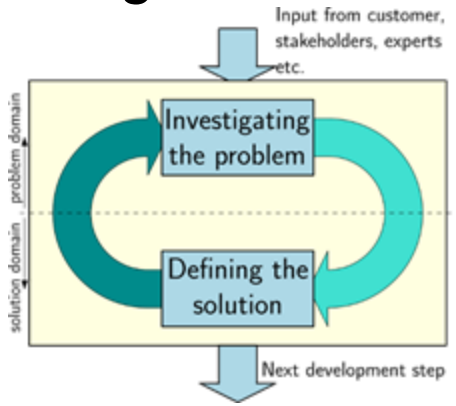
- Zooming in to relevant details
- Zooming out to the context and environment
- Zooming in and out in Hierarchy and Time

- One person's system is another person's subsystem

What is Systems Engineering? – a practical description

2. Separate the *what* and *how much*, from the *how*

- Fundamental to SE
- Distinguish the Function from the Solution
- Define what is good *enough*



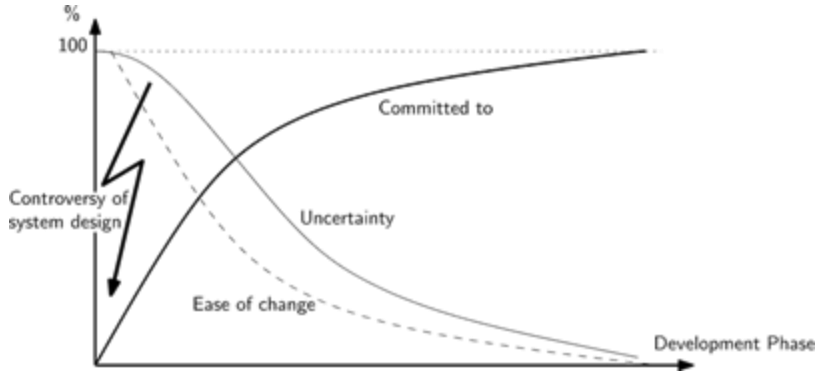
3. Focus on the *interfaces*

"There are two kinds of Systems Engineers: those that look at the interfaces and amateurs"

Robert Halligan - PPI

What is Systems Engineering? – a practical description

4. Uncertain and *incomplete information* in taking far-reaching decisions



"If a man will begin with certainties, he shall end in doubts; but if he will be content to begin with doubts he shall end in certainties"

Sir Francis Bacon

+ Relying on *Communication* in a context of *Multi-disciplinarity*

- Different disciplines use different languages
- Integration and consistency is not easily checked
- SE looks at the big picture and across disciplines

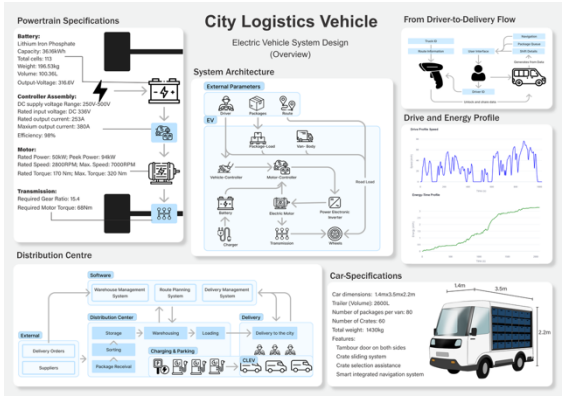
The SE uses many “simple” diagrams to acquire, manage and show very diverse types of information and knowledge

Picture source: Bonnema, G. M., K. T. Veenvliet and J. F. Broenink (2016). Systems Design and Engineering: facilitating multidisciplinary development projects. Boca Raton, FL, CRC Press.

Transition from “Paper & document based” to “Model based”

Paper & document based SE

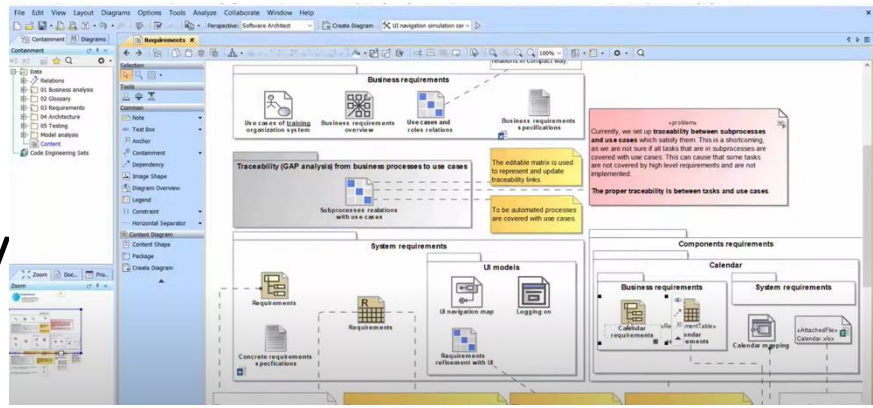
- The “truth” is in reviewed and accepted documents
- “baselines”
- Widespread use of pictures and diagrams (“model supported”)
- A3 Architecture Overviews help to focus



Students’ work, see https://www.mdpi.com/3457318

Model Based SE (MBSE)

- The “truth” is in an interlinked set of models
- Documents (snapshots) can be generated automatically
- Tooling essential to maintain consistency



Source https://www.keonys.com/catia-magic

MBSE

- Philosophy (Long&Scott: “thought process”)
- Method
- Tool(s)
- Facilitated by a language

INCOSE: MBSE is the “formalized application of modeling to support system requirements, design, analysis, verification and validation, beginning in the conceptual design phase and continuing throughout development and later life cycle phases”

- Language (e.g. SysML) and tool without method or philosophy is no SE
- Philosophy or method without tool and language is impractical and unstable

Long, D. and Z. Scott (2011). A Primer for Model-Based Systems Engineering. Blacksburg, VA, USA, Vitech Corporation.

INCOSE Wiki: https://incosewiki.info/Model_Based_Systems_Engineering/index.php?title=MBSE_Definitions retrieved 20250829

Promises of MBSE

2007

MBSE enhances the ability to capture, analyze, share, and manage the information associated with the complete specification of a product, resulting in the following benefits:

- Improved communications among the development stakeholders
- Increased ability to manage system complexity
- Improved product quality
- Enhanced knowledge capture and reuse
- Improved ability to teach and learn SE fundamentals

Friedenthal S, Griego R, Sampson M. INCOSE model based systems engineering (MBSE) initiative. Paper presented at INCOSE 2007 Symposium, San Diego, CA, USA, 2007. https://www.researchgate.net/publication/267687693_INCOSE_Model_Based_Systems_Engineering_MBSE_Initiative retrieved 20250829

2020

48 benefits claimed

- Improved system quality
- Increased rigor
- Increased traceability
- Reduce errors
- Reduce cost
- Reduce risk
- Improved risk analysis
- Improved system design
- Increased effectiveness
- Improved deliverable quality
- Better requirements generation
- Increased accuracy of estimates
- Improved predictive ability
- Better analysis capability
- Improved capability
- More stakeholder involvement
- Strengthened testing
- Reduce time
- Improved consistency
- Increased capacity for reuse
- Easy to make changes
- Reduce rework
- Reduce waste
- Increased productivity
- Increased efficiency
- Increased transparency
- Increased confidence
- Increased flexibility
- Better requirements management
- Ease of design customization
- Higher level of support for integration
- Increased uniformity
- Increased precision
- Early V&V
- Reduce ambiguity
- Higher-level support for automation
- Reduce burden of SE tasks
- Better manage complexity
- Improved system understanding
- Reduce effort
- Better data management/capture
- Better decision making
- Better accessibility of information
- Better knowledge management/capture
- Improved architecture
- Multiple viewpoints of model
- Better communication/ information sharing
- Improved collaboration

Henderson, K. and A. Salado (2021). "Value and benefits of model-based systems engineering (MBSE): Evidence from the literature." Systems Engineering **24(1): 51-66.**

Types of projects and MBSE suitability

Greenfield

Projects start (largely) from scratch

Each project can decide on its methodology and documentation approach

Common in space and defense

(Sequential) Brownfield

Projects create evolutionary changes to existing system designs

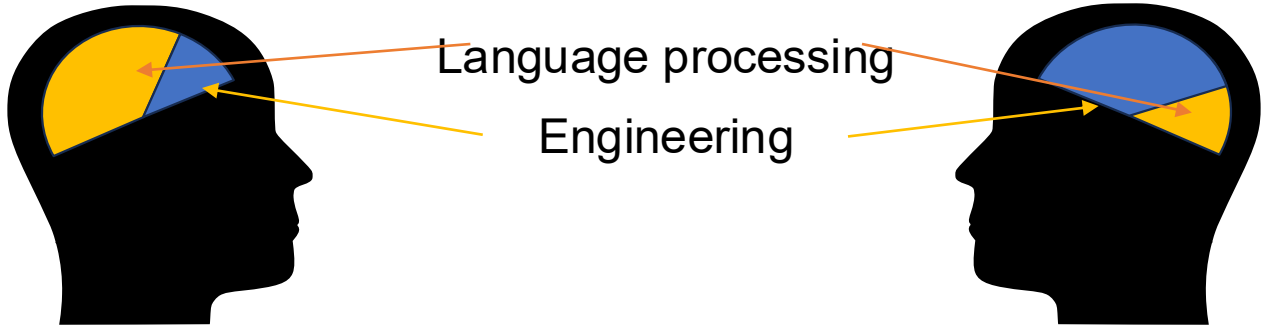
Documentation approach stable across many projects and generations

Common in High-Tech

Challenges of MBSE

- Large body of knowledge not coded in models (in particular relevant for sequential brownfield projects)
- Learning curve for tooling and language
- Cultural aspects
- Perceived value

- Actual *measured* value of MBSE unclear [Henderson&Salado]
- Proficiency in handling an abstract System Language
  - Inhibits communication to non-SE-ers
  - Mental load to handle the language

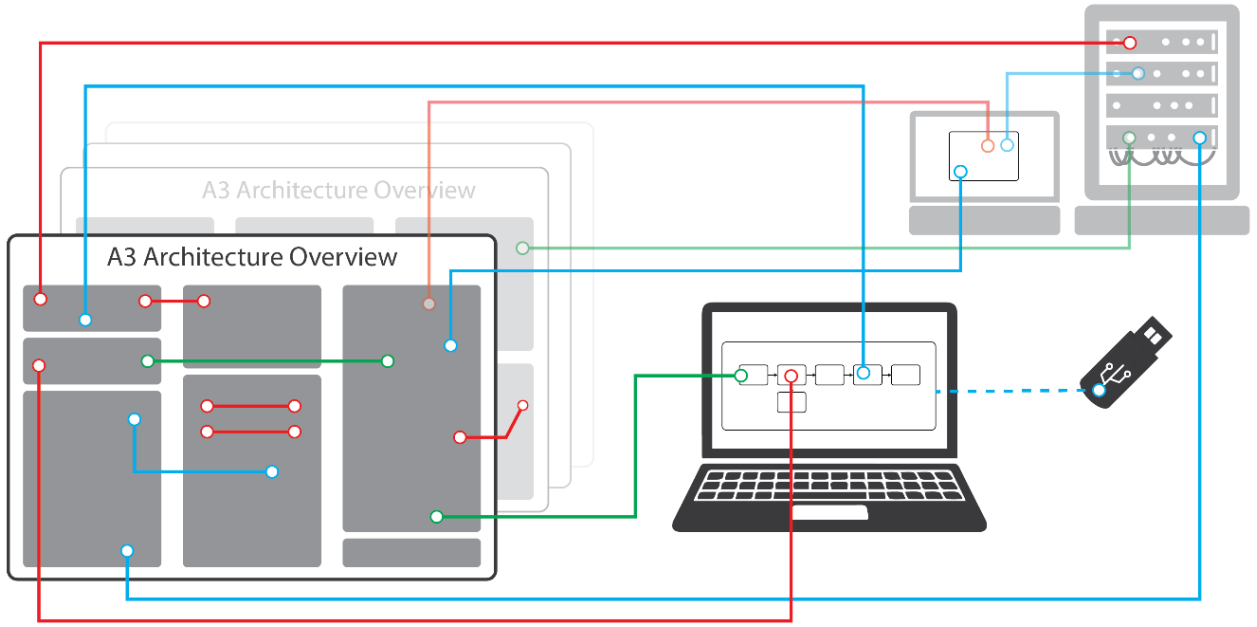


Huldt, T. and I. Stenius (2019). "State-of-practice survey of model-based systems engineering." Systems Engineering **22(2): 134-145.** <- Note that >70% of the respondents in the reported survey are from Aerospace and defense!

Henderson, K. and A. Salado (2021). "Value and benefits of model-based systems engineering (MBSE): Evidence from the literature." Systems Engineering **24(1): 51-66.**

Flavours and mixtures of Paper Based and MBSE

- From MBSE-approaches:
  - Formality
  - Error checking
  - Consistency checking
  - Single source of truth
- From paper-based approaches:
  - High info content
  - Facilitating communication
  - Tailored representations for discussions



Outlook

- Develop user-friendly tooling (ongoing)
- Bridge the gap between pictures and formal models
- Use AI to “mine” bodies of knowledge
- Teach SE to **all** engineering disciplines

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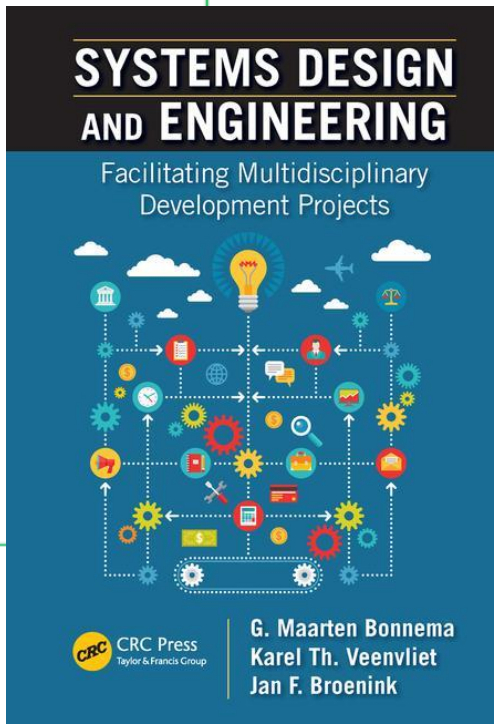
Thank you!

More information on www.utwente.nl/semd

SE in 45 minutes: https://tinyurl.com/SEin45min

Scan Me

SYSTEMS ENGINEERING & SEMD MULTIDISCIPLINARY DESIGN



The Vee-Model