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Model based Systems Engineering (MBSE)

Missing Link in the digital Enterprise Strategy ?

Keynote to the MBSE Workshop

at the INCOSE Los Angeles International Workshop

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Welcome in a partially digital World

E Vido short 0114.mp4

Google Earth animation flowing from Europe to North America, on to California, Los Angeles and finally to the Marriott Conference Hotel

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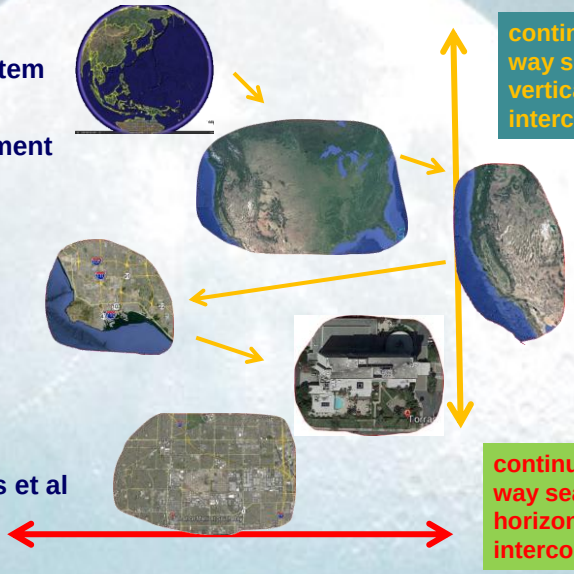
Google Earth - Model and Benchmark for MBSE?

- Holistic System
- System Element
- Subsystem
- Equipment
- Piece Part
- Plus Wiring Diagrammes et al



continuous two way seamless vertical interconnects

continuous two way seamless horizontal interconnects

Note: Mark Sampson's famous car diagramme sends a similar message

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Outline

- A bit of History
- The emerging digital World
- The Systems Engineering World – in Context
- MBSE – Status and Future
- Summary and „Take Aways"

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Systems Engineering Roots

- SE has been practiced for centuries – so has Project Mgt
- From simple constructions to complex operations involving hundreds and thousands of specialists
- Architects, ship builders, water managers were early SEs/PMs





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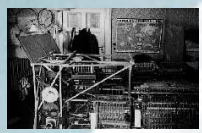
SE Tools - Capability Steps since the 1930s



First freely programmable Computer by "Zuse" 1938

Slide Rules and Pocket Computers - Engineers working Tools since 50s

"back of the envelope" calculations are forever

Early 1960s computer

Early 1980s IBM PC

Modern PCs & Laptops with enormous capabilities

Networks of interlinked Computers with seemingly infinite Capabilities

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Emerging Digital World

- Remember the paperless office idea?

Credit: EADS Astrium, “ages ago”

- Some real examples from our emerging “Digital World”
  - Engineering Analysis and Design
  - Concurrent Engineering in Space
  - Manufacturing & Automation
  - Transport Logistics
  - Germany’s “Industrie 4.0”
  - The Earth

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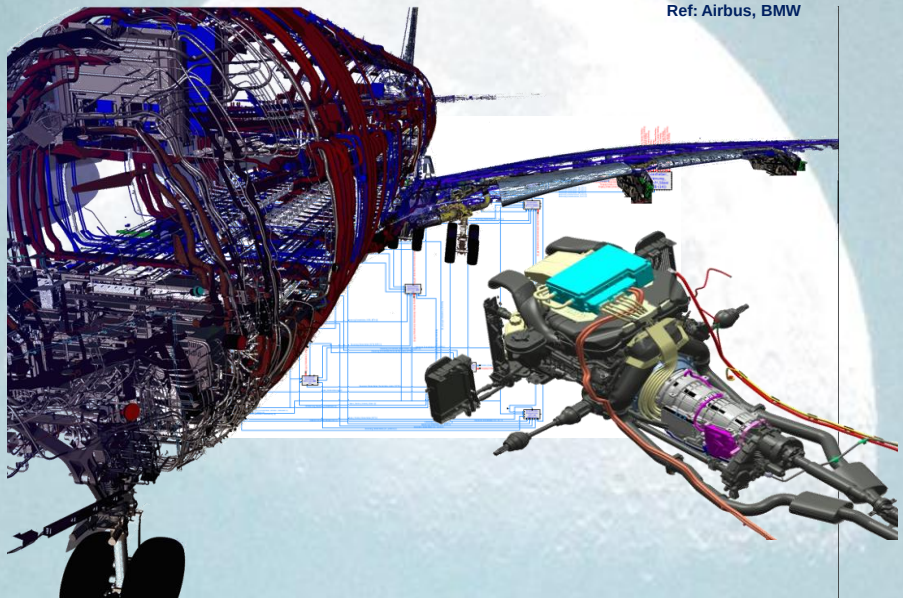
Engineering Design
Domain and Bottom-up Models, CAD

Ref: Airbus, BMW



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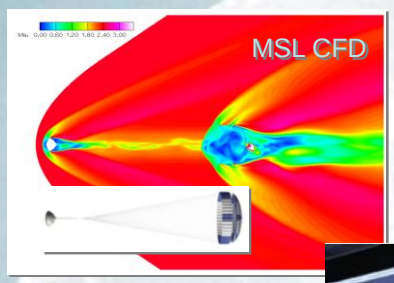
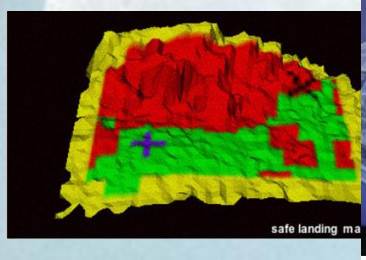
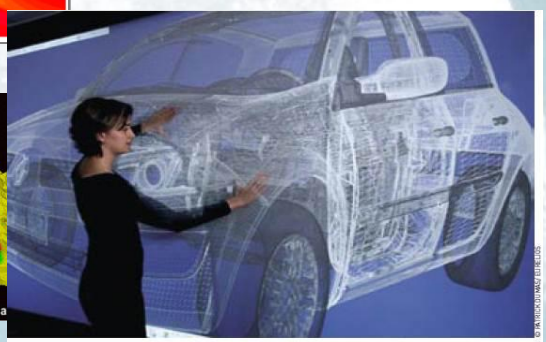
Domain and Bottoms-up Models

Ref: JPL, AFIS/Renault







Revolutions and Transformations take Time
Example CAD History

- Idea goes back to 1957; solid modeling/wireframes and first vendor tools offered 1980s
- Unmet expectations and frustrations all along!
- Initial focus on aircraft and automobiles, today most all industry sectors
- Real breakthrough only late 1990s

→ Ambitions of CAD vendors are to evolve towards more encompassing SE capabilities

Example Space: Early System Level Modeling
Concurrent Conceptual Design Facilities in JPL, Industry, ESA
From Paper to interlinked PCs - a big Improvement in Process Technology

Is this MBSE? Yes, the first „integrated“ step of MBSE

Ref: ESA CdF facility

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Example "Automated" Manufacturing and Process Contol

"Digitization" in Transition




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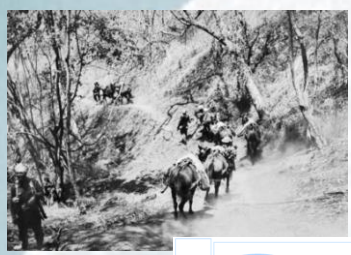
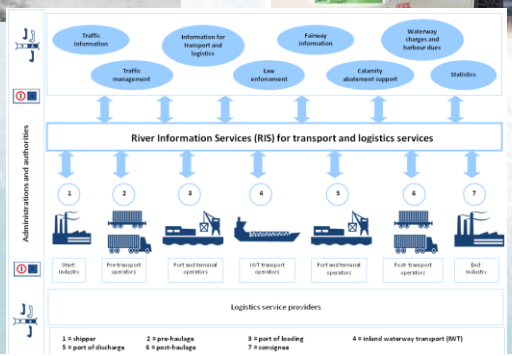
Example: Todays Logistics World

From Mules to Global Digital Networks and Supply Chains



Ref: Industry 4.0, Fraunhofer Gesellschaft

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Example: German Industry 4.0

Industry, Government and Research Institutes cooperation to create a Nationwide digital Business Base

Premise: "Not every enterprise has a digital business model, but every enterprise will have to become digital"

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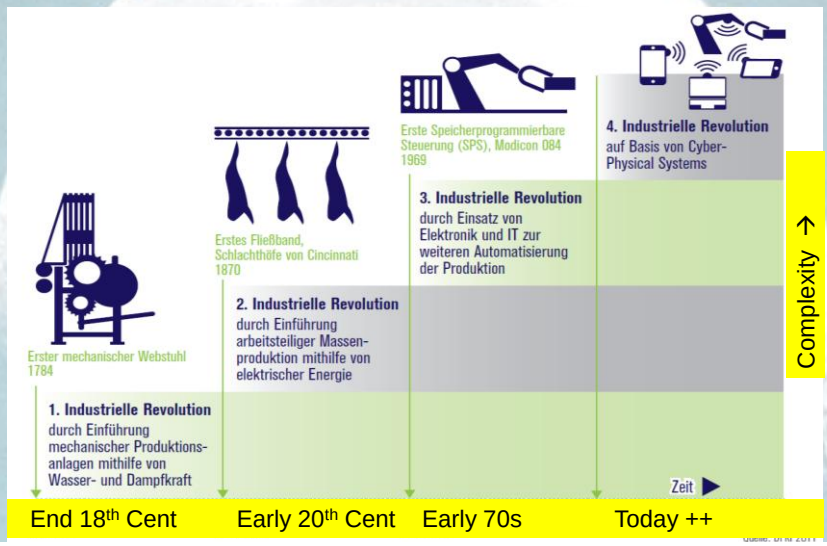
The four Stages of the Industrial Revolution



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Internet of Things and Services –

The Buzzword is "smart"

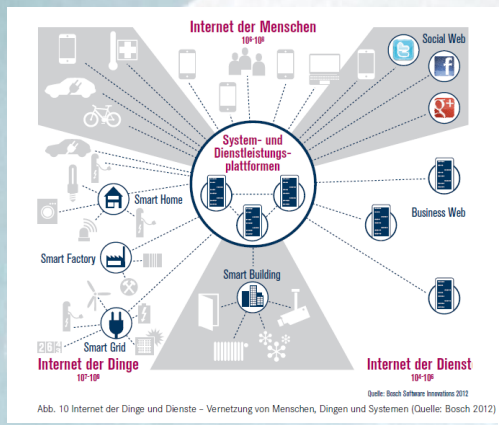

Abb. 10 Internet der Dinge und Dienste – Vernetzung von Menschen, Dingen und Systemen (Quelle: Bosch 2012)

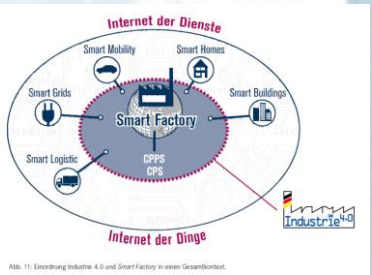

Abb. 11: Einordnung Industrie 4.0 und *Smart Factory* in einen Gesamtkontext.

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Which Enterprise Functions will be affected by the digital Transformation?

(an incidental organigramme)

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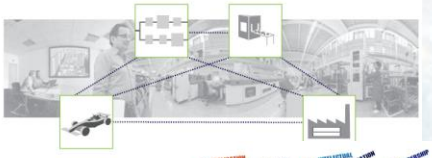
Does SE play any Role in this Transformation?

Source: "Industrie 4.0" – Siemens Corporation

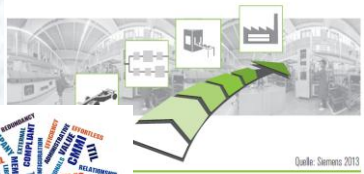
Today: elaborate interfaces between supporting IT systems

Umfangreiche Schnittstellen zwischen unterstützenden IT-Systemen



Tomorrow: seamless Systems Engineering accross the entire value chain

Durchgängiges System-Engineering über die gesamte Wertschöpfungskette



Quelle: Siemens 2013

→ "digitization" is affecting most all parameters of day to day business operations

→ Enterprise functions will become digital almost all the way!

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The digital Transformation is all encompassing

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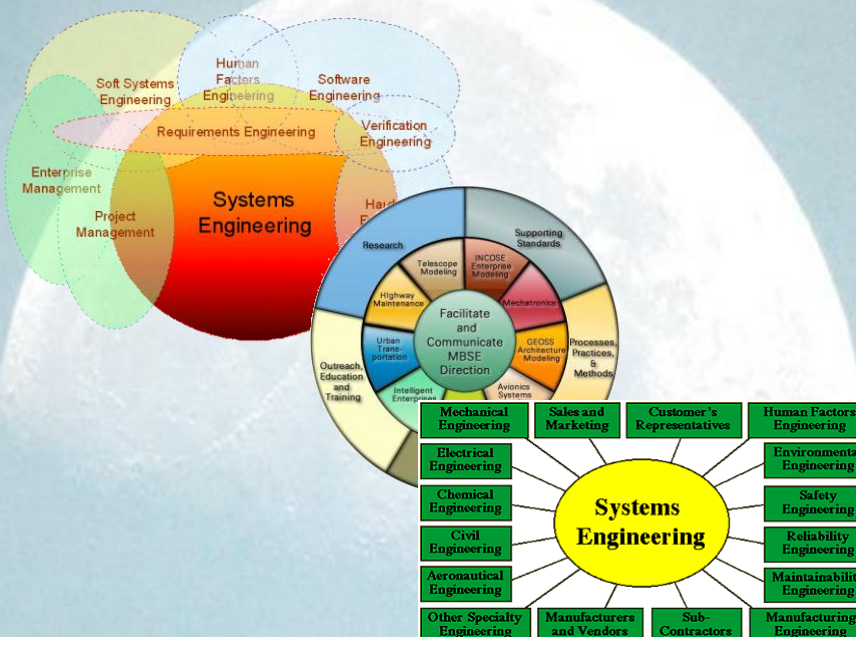
SE in the Center of the Universe



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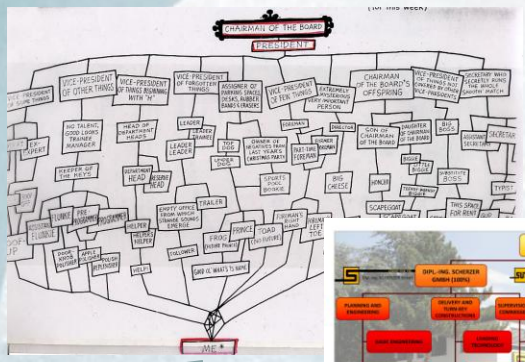
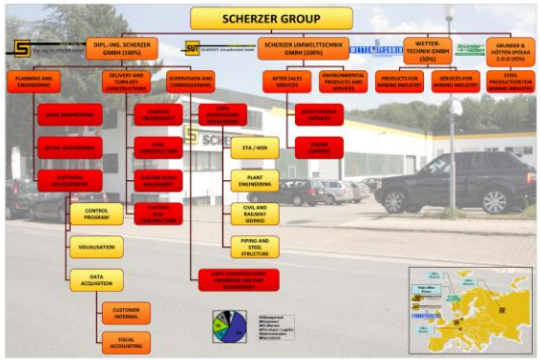
SE in Reality – far behind Programme/Project Management in Recognition (incidental Organigrammes)



The lonely SE



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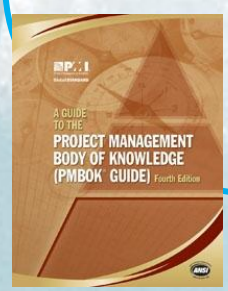
There are many PM – SE Overlaps

How well are they aligned?

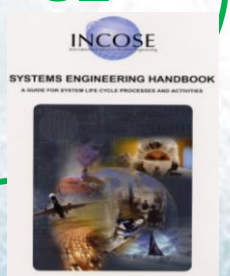
PM



Examples

- Stakeholder Needs/ Requirements
- Project Scope/Interfaces
- Cost & Schedule (lean)
- Technology Selection
- Risk Assessment/Mitigat
- Project Processes applic/tailoring

SE



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„End-to-End“ SE deals with many Variables

- Performance & scope
- Cost and Schedules
- Procurement and subcontracting
- Technology assessments
- Human factors
- Risk evaluations and mitigation
- Environment and other regulations
- etc etc

Above variables contain a mix of “hard” engineering and “soft” social and economics based parameters, all of which imply “gut-feel “judgments and decisions

These in turn make up day-to-day life of senior SEs (and PMs) in a challenging mix of “science and art”

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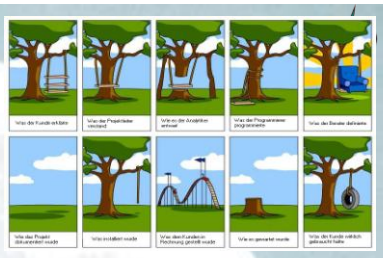
Example Requirements Engineering



- requirements are derived from expressed & assumed customer or market demands

- need be traded against stakeholder needs - technical, economic, social, environmental, feel and touch, looks, etc

- need analysis of different verification and validation means

- and be subjected to risk evaluations, time to market, cultural differences of market regions, etc etc

→ freezing requirements along the life-cycle and at which level of depth is subject to large differences in industry! Freezing them too early or too late can make big differences in time, quality and cost

→ implies both science and art!

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Example Cost Engineering

- Cost estimates are based upon technical and programmatic descriptions at any given moment – they can never be better than the prevailing technical and programmatic project baselines
- Data bases with archived cost of past projects, cost per kg of hardware, or lines of software code are helpful, but need SE and PM judgements and project tailored adaptations for validation
- Reducing or de-risking cost takes many system analyses, design and/or process changes, technology assessments, discussions with stakeholders etc etc

→ More art than science

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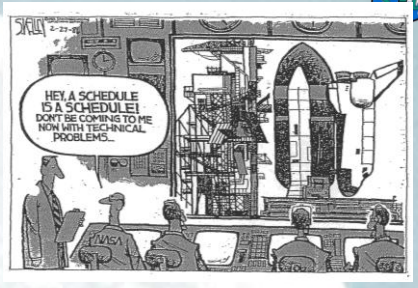
Example Schedule Engineering



Can you "calculate" how long a specific test will take? Which problems will occur and how long it will take to fix them?

Can you "calculate" how long the qualification of a new technology might take?

Can you "calculate" how long it will take to "integrate" a complex R&D project containing multiple suppliers and process variables?

→ More art than science

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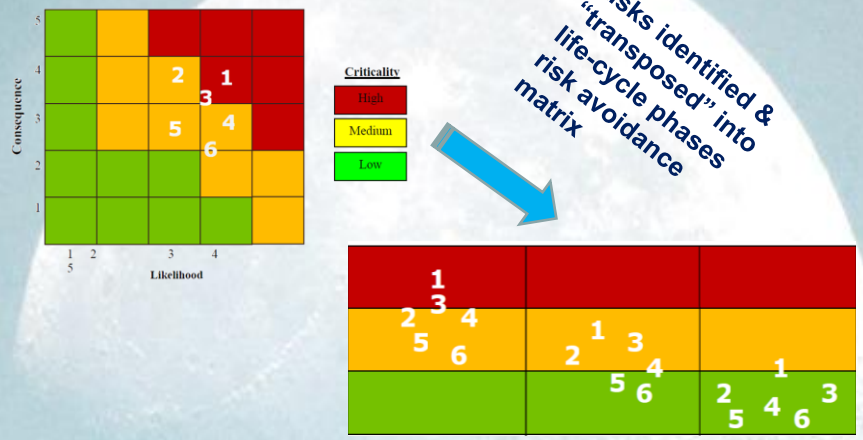
Example Risk Identification and Mitigation



Can anyone "calculate" the many steps it can take to convert an early risk matrix into a "all under control" type of solution?

→ lots of art and science

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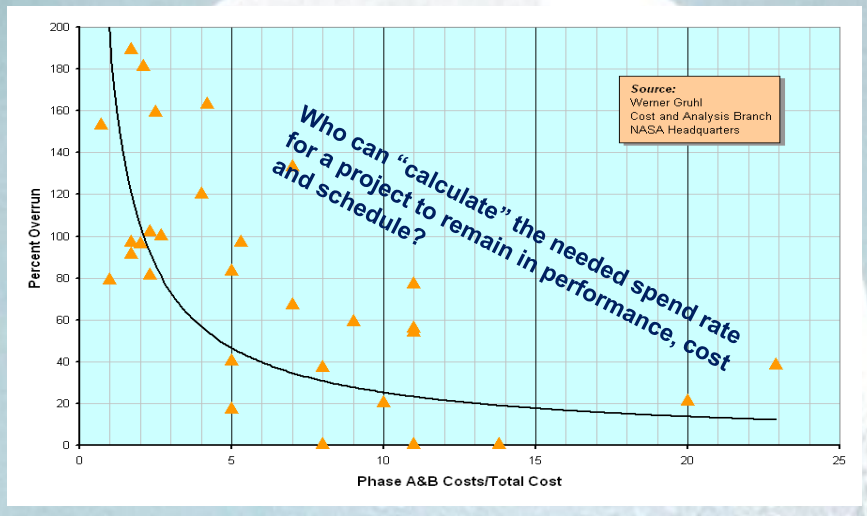
Example: How much upfront Investment?



→ Lots of science and art

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…or "calculate" the Human Failures that can occur during any Project at any Time?

→ Lots of art with some science

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Lessons and Implications for MBSE

- SE deals with many variables and specialized disciplines. Some are physics based hard engineering, others are soft economics, social, human or environmental based. Much of it is about leadership and decision making and combines "science and art"
- SE is akin to and strongly interdependent with PM

→ MBSE must eventually find solutions to cope with above through an approach to interact with many other models in the digital enterprise network

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MBSE – Definition Attempts

“Model-based systems engineering (MBSE) is 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 SE Vision 2020

More pragmatic:
“MBSE translates physics, functional, economics and social based (project) data into interrelated digital model representations”

Beware:

- *The product of an arithmetical computation is the answer to an equation; it is not the solution to a problem*
- *Confusing the model with reality is like sitting in a restaurant and proceeding to eat the menu*

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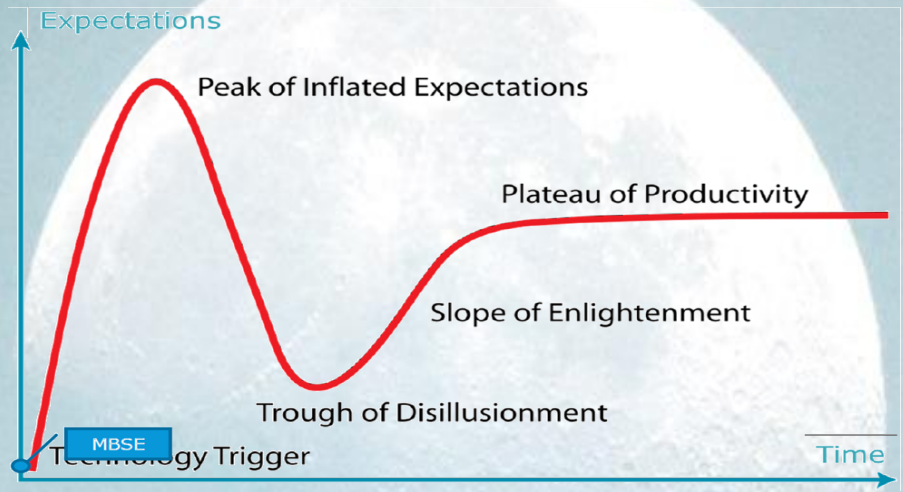
Where is MBSE on the Hype Curve?

Ref: K. Hjortnaes, ESA/ESTEC



→ Can two examples from automotive and space answer the question?

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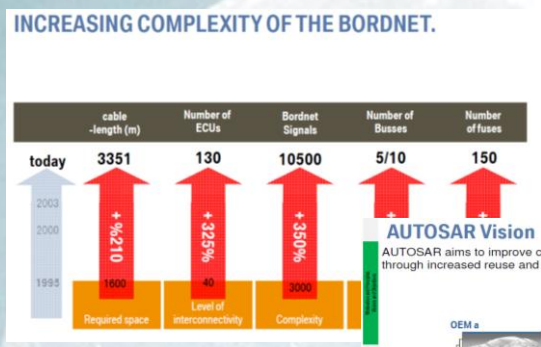
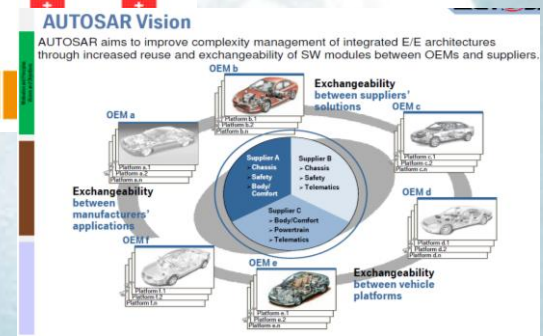
Example Automotive Industry

Ref: BMW Group, Dr. M. Tietze and Autosar Consortium





→ Is this MBSE or subsystem engineering? Architecting & modeling highly complex avionics for two million + automobiles is MBSE!

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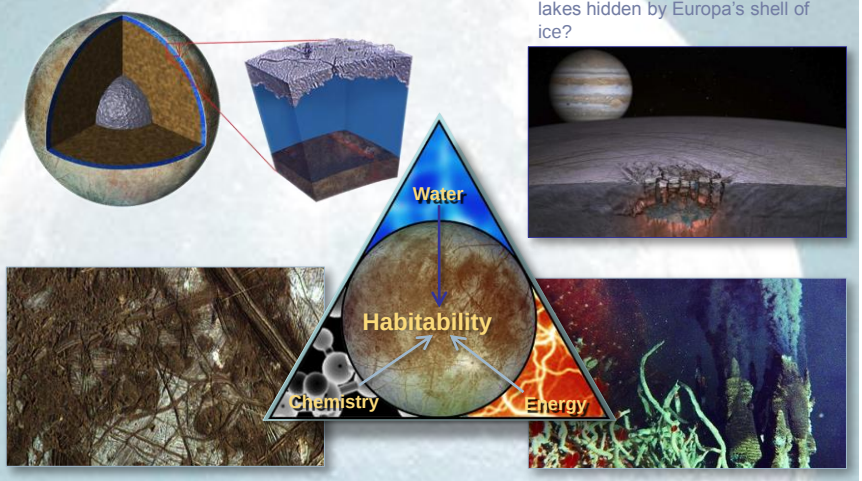
Example JPL Europa Clipper Mission

Ref: Todd Bayer and Brian Cooke, NASA JPL

Water: Are a global ocean and lakes hidden by Europa's shell of ice?



Chemistry: Do red surface deposits contain organics from below?

Energy: Can surface oxidants provide energy for metabolism?

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Example JPL Europa Clipper - MBSE **Benefits so far**

Ref: Todd Bayer and Brian Cooke, NASA JPL

- **More efficient and accurate communication of technical information within project and among disciplines**
  - Not limited by foreseeable levels of increasing system complexity
  - Easily integrated with existing discipline tools (MBSE is the *keystone* for full Model Based Engineering)
- **Greater re-use and evolution of our system designs**
  - 3 full mission studies in the time it usually takes for 1 or 2
  - 5 parallel configurations maintained
- **More consistent, controllable generation of system metrics and normalization of risk assessment**
  - Identical automated analyses are applied to all configurations and versions
- **More efficient generation of project documentation**
  - Ensuring consistency of documentation by drawing from same system model
- **A better bridge from college education to project best practices**
  - Recent graduates are arriving with knowledge of and expectation of using MBSE methods
- **More complete capture of expert knowledge, lessons learned, principles**
  - These things can be "baked in" to the system model

→ a more detached view on MBSE status follows

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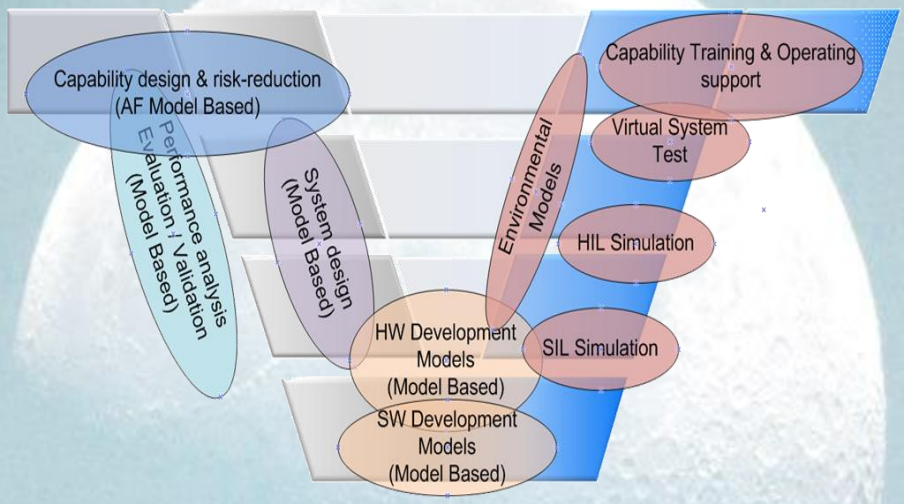
A Functions oriented View of the Vee - Example

Ref: Airbus Defence and Space Company, S. Ackva



→ We need many different models to characterize a system and support SE during the life-cycle. How can we make them fit together?

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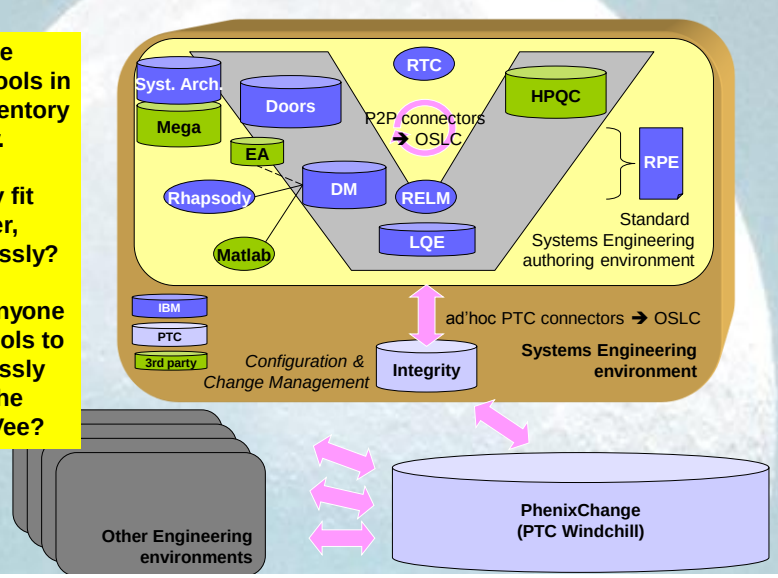
A Tools oriented View of the Vee - Example

Ref: Airbus Defense and Space Company, F Autran

We have many tools in our inventory already.

Do they fit together, seamlessly?

Does anyone have tools to seamlessly cover the entire Vee?



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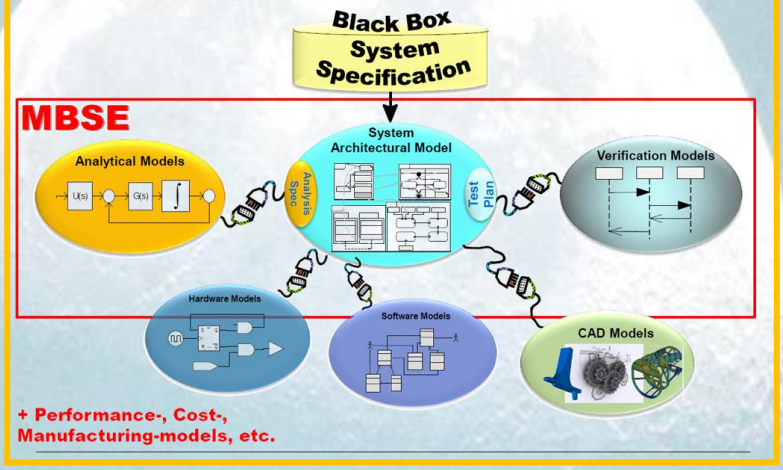
MBSE is: Connections and Interdependencies

Ref.: Airbus Defense and Space Company, H. Klenk, with modifications

Connection to many Enterprise Functions and Models

Connection of discipline specific models



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Today's MBSE Status in Summary

- Lots of pilot studies with mostly promising results
- Potentially replacing docs and enhancing continuity during life-cycle phase transitions
- Growing executives recognition of MBSE potential
- Limited MBSE trained workforces
- Many specialized and non seamless, non plug and play SE tools confuse not only executives
- Little recognition that MBSE is a key element of future "digital enterprises"

As summed up by the INCOSE Vision 2025:

> Model-based systems engineering has grown in popularity as a way to deal with the limitations of document-based approaches, but is still in an early stage of maturity similar to the early days of CAD/CAE.

…. and the future of MBSE?

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MBSE must blend/interact with many Things

- Blend different stakeholder views (engineering, production, maintenance/servicing, cost/profitability, market needs & opportunities, time-to-market, product launch, management, etc)
- Interact with other enterprise tools and databases (eg business, specialist, design, production, logistics, supply chain, PLM) in a seamless plug and play manner
- Ensure match to different use cases, sustainability, et al

→ deal with science and art components of complex systems by also providing decision analysis support to PMs and other policy/decision makers beyond SE

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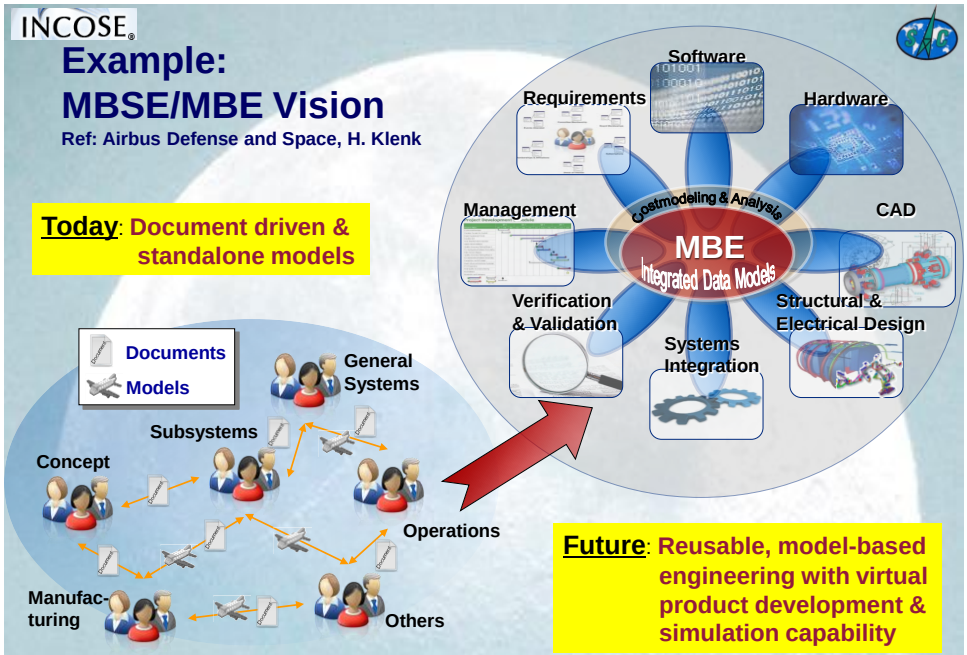
Example: MBSE/MBE Vision

Ref: Airbus Defense and Space, H. Klenk

Today: Document driven & standalone models



Future: Reusable, model-based engineering with virtual product development & simulation capability

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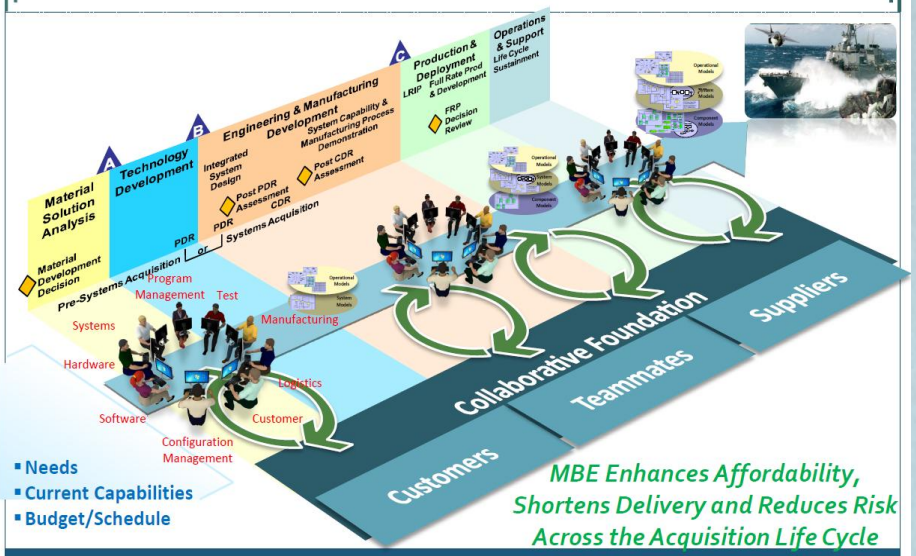
MBE To-Be State

Source: NDIA MBE Final Report dated February 2011



- Needs
- Current Capabilities
- Budget/Schedule

MBE Enhances Affordability, Shortens Delivery and Reduces Risk Across the Acquisition Life Cycle

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Virtual Engineering and MBSE – Symbiosis awaiting Realization in many Fields

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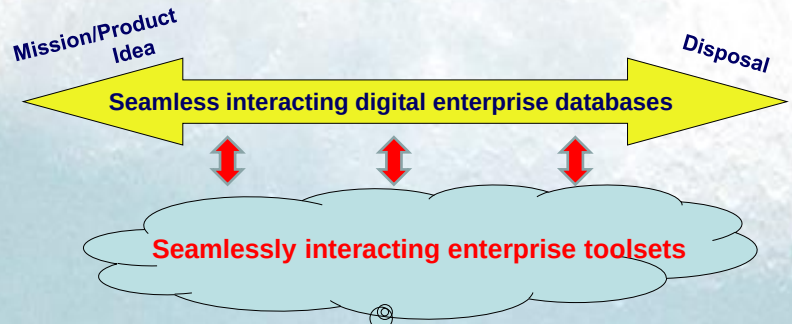
MBSE Long-Term Objectives

- Integration/correlation of many different insular solutions from related fields into coherent plug and play SE capability interacting with other digital enterprise functions and models
- Supporting IT infrastructure advancements, together with PLM and others, as seamless elements - a la Google Earth!

→ A thorny path with incremental steps for years to come!



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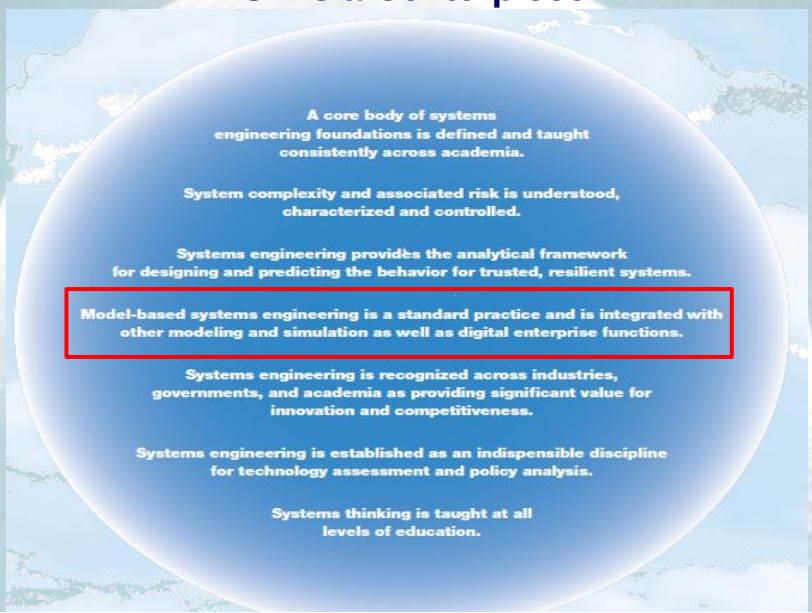
INCOSE Vision 2025 – 7 SE Grand Challenges
MBSE is a Centerpiece



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Where will MBSE be in some 10 Years?

Reference: INCOSE Vision 2025

Formal systems modeling is standard practice for specifying, analyzing, designing, and verifying systems, and is fully integrated with other engineering models. System models are adapted to the application domain, and include a broad spectrum of models for representing all aspects of systems. The use of internet-driven knowledge representation and immersive technologies enable highly efficient and shared human understanding of systems in a virtual environment that span the full life cycle from concept through development, manufacturing, operations, and support.

→ **But it will also have to be well integrated/related to the digital enterprise environments around it**

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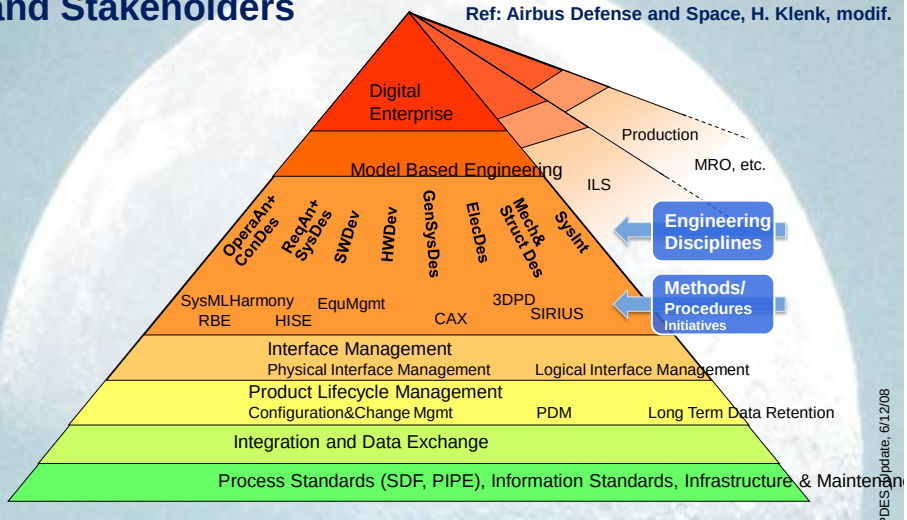
Digital Enterprise Hierarchies have many Layers and Stakeholders

Ref: Airbus Defense and Space, H. Klenk, modif.



Pyramid provides overview of the many elements of a MBE/MBSE strategy

based upon PDES update, 6/12/08

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Conclusions on MBSE

- MBSE has lots of potential - there is no question about its future, only about the best way forward and the pace of the "systems revolution in the making"
- MBSE needs to be embedded and correlated with other related digital enterprise functions, tools and databases and successively address science and art elements of SE
- MBSE will be helped by rapid IT advances, like cloud computing, query and reasoning technologies, smart visualizations and virtualizations, game industry advances and the "Internet of Things"

→ Near-term MBSE transition objectives:

1. from software and tools push to SE demand
2. towards seamlessly interacting tools and databases, better visualizations and emerging digital enterprise architectures

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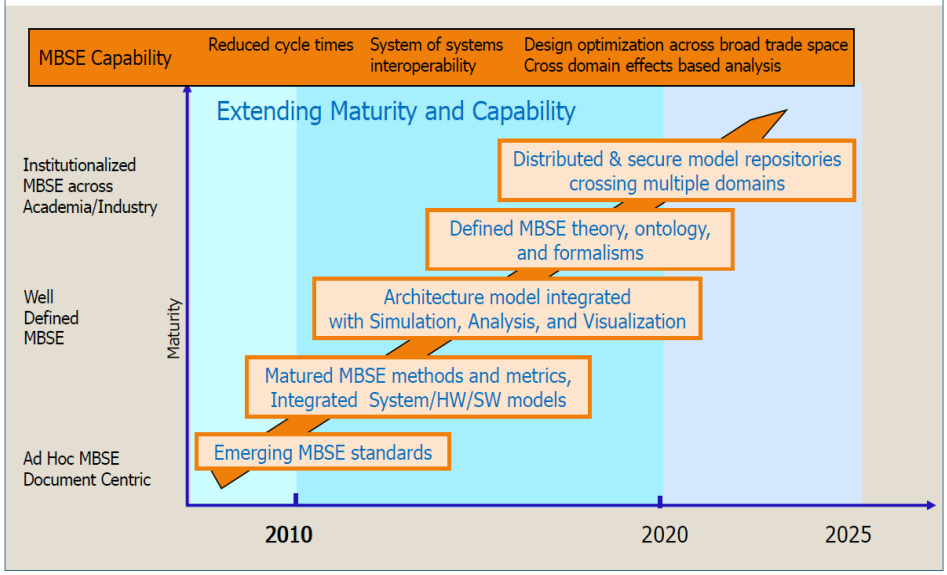
Outline

- A bit of History
- The emerging digital World
- The Systems Engineering World – in Context
- MBSE – Status and Future
- Summary and „Take Aways"

INCOSE MBSE Roadmap



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Conclusions and Take-aways (1 of 3)

- **Advances in the transformation of enterprises to become digital are breathtaking – a major revolution driven by IT advances, efficiency and competitiveness goals at global and local scale; transformation will affect all functions, including SE and PM**
- **MBSE will become "integrated/interrelated" with other functions of the digital enterprise, especially engineering, PM/PLM, supply chain management, manufacturing**
- **SE and PM are crucial and highly interdependent "horizontal" enterprise functions and technical integration/project drivers! Efficiency and competitivity demands will eventually force them to better align approaches and tools**

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Conclusions and Take-aways (2 of 3)

- MBSE has made enormous strides during past 5 years – still, it is only a beginning; years of hard work ahead
- MBSE will advance first and fast along the "hard" (physics based) engineering elements, but will have to successively face integration/interaction with the more "soft" (human, economics and social/environmental based) elements of systems
- MBSE must strive to become seamless in terms of vertical and horizontal navigation between different system levels and across system constituents → Google Earth benchmark!
- Better visualizations are vital for accelerating MBSE acceptance by executives and "established" SEs

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Conclusions and Take-aways (3 of 3)

- Final breakthrough for MBSE will come through product quality and efficiency advances enhancing enterprise competitiveness and by proving it can better manage complexity
- Which path forward will be most successful to create a more integrated seamless plug and play MBSE capability is open:
  - the bottoms-up push by vendors enlarging their analysis and design tool capabilities to successively include more SE elements, or
  - The top down approaches by OEMs/Primes who create their own system frameworks and integrate bottoms-up vendor tools as they become available and fit in
- MBSE is on an acceleration path and will become the norm for System Engineers in "complex product" enterprises by the turn of the decade

Without doubt: "The Future of Enterprises and of SE are Model-based"

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Let's come back to our Google Model of MBSE Two final Questions

- When someone would have told you some 20 years ago that you can have the digital Earth on your Laptop and that you can navigate seamless from the holistic system Earth to your own house and onwards to your neighbors garden, your local theater, or your cottage in Alaska

  What would you have replied?

- Can you in turn believe that MBSE will enable you in some 10 years to navigate from your system "automobile or spacecraft " seamlessly down to brakes, switches, thrusters or valves and give you all relevant technical, functional, economics, environmental and social information to review or modify?

  What will you reply now?

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Is MBSE indeed the missing link in the digital Enterprise Strategy ?

May be not the missing one, but certainly an important link in the digital chain of modern Enterprises!

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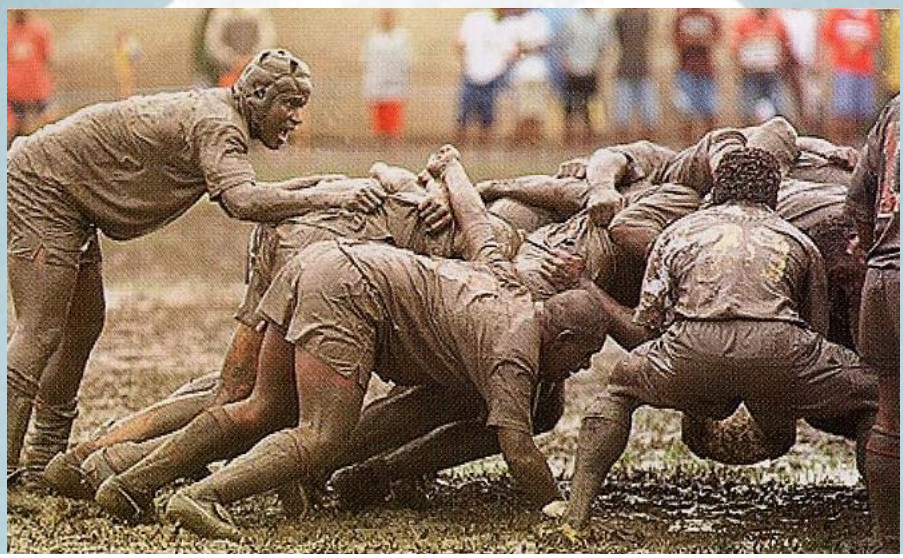
Remember SE is all about Teamwork and Leadership



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Genuine Compliments to Mark and Sandy for pushing so hard on this MBSE front

Without the Insights and Initiatives of the two of you MBSE would not have come this far

Many Thanks