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V1.2.5

Life Cycle Management: Evolving Challenges and Emerging Solutions

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ICTT System Sciences

Understand your systems.™

Is this your "tomorrow", or a distant future?

From "The Hardware Renaissance Arrives: A New Dawn for Gadgets", *The Wall Street Journal*, March 23, 2015:

"Recently, as I gazed into the prototype of a smart breast pump, I had a vision of the future. I saw an age in which new products—actual, physical electronics products—will go from idea to store shelves in a matter of months. A future in which warehouses and distribution centers cease to exist, because factories produce finished goods from raw materials on demand, and they never stop moving through the supply chain. *Only it turns out all of this is possible today*. The "hardware renaissance" that began in Silicon Valley in just the last five years, born of rapid prototyping technologies, has become something much larger and more important. It has been a sea change in every stage of producing physical objects, from idea to manufacturing to selling at retail . . ."

-- Christopher Mims, *The Wall Street Journal*, p B1,6, March 23, 2015

-- emphasis added

Abstract

Shrinking innovation cycles and rising complexity raise challenges throughout the life cycles of the products and systems that teams manage. A spectrum of remarkably predictable problems has repeatedly surfaced across diverse industries, as enterprises, their products and services, their customers and suppliers, and the global economy have wrestled with more complex and rapidly-changing systems.

It has been said that “All Innovation Is Innovation of Systems”. The powerful paradigm behind this view brings a family of new solution methods and tools, increasingly supported by scientific foundations. Implications of these solutions are far-reaching, as they impact technical teams, product and market strategists, production and support processes, leadership at all levels, and the integrated infrastructure of information, processes, and tools.

Product Lifecycle Management (PLM) methods and systems play critical, high-value roles in this emerging integrated framework, which is itself a system, with its own life cycle. The same underlying methods that improve management of products and services can be used to organize the framework of in which PLM systems are implemented, integrated, and evolved.

This talk will include examples, including a project currently underway with IPLI.

Contents

- Life cycles are embedded in innovation
- All innovation is innovation of systems
- Life cycle processes *vs*. life cycle information
- Explicit representation, IP, and the Model Based Economy
- Systems for learning from experience
- Agility in life cycle management
- Information system roles
- The importance of community; roles for IPLI & partners
- Example IPLI collaboration
- Challenges & opportunities—conclusion
- Discussion
- Attachments, references

Life Cycle Management: Evolving Challenges and Emerging Solutions

- The life cycles of products, services, and other systems offer challenges and opportunities in competitive markets and institutions.
- This talk is to stimulate awareness and discussion of the systemic challenges and solution opportunities for Product Life Cycle Management (PLM).
- We will spotlight some underlying issues not always emphasized in "pure PLM" conversations.

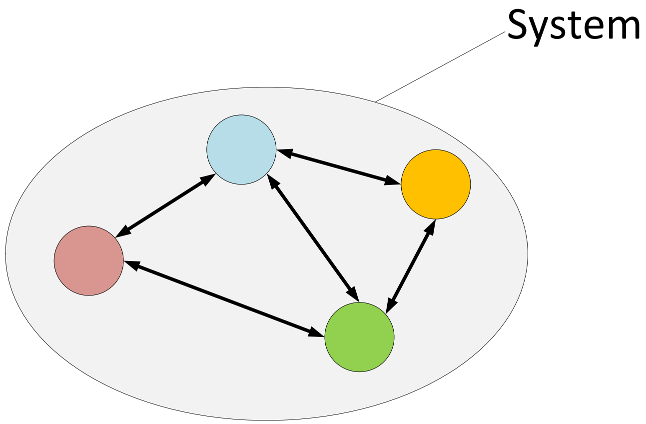
Life cycles are embedded in innovation

For purposes of this discussion:

- Life cycles of products & other systems will mean either--
  - A single instance of such an entity, from the time it is fabricated until it is destroyed, or . . .
  - A product line, product model type, family or class of products or technologies, from conception through use and eventual withdrawal.
- Innovation of products & other systems:
  - Realization of improved value by stakeholder;
  - This view emphasizes full delivery of benefit, not just ideation or invention.
  - Innovations may be small and incremental, or large and disruptive.

All innovation is innovation of <u>systems</u>

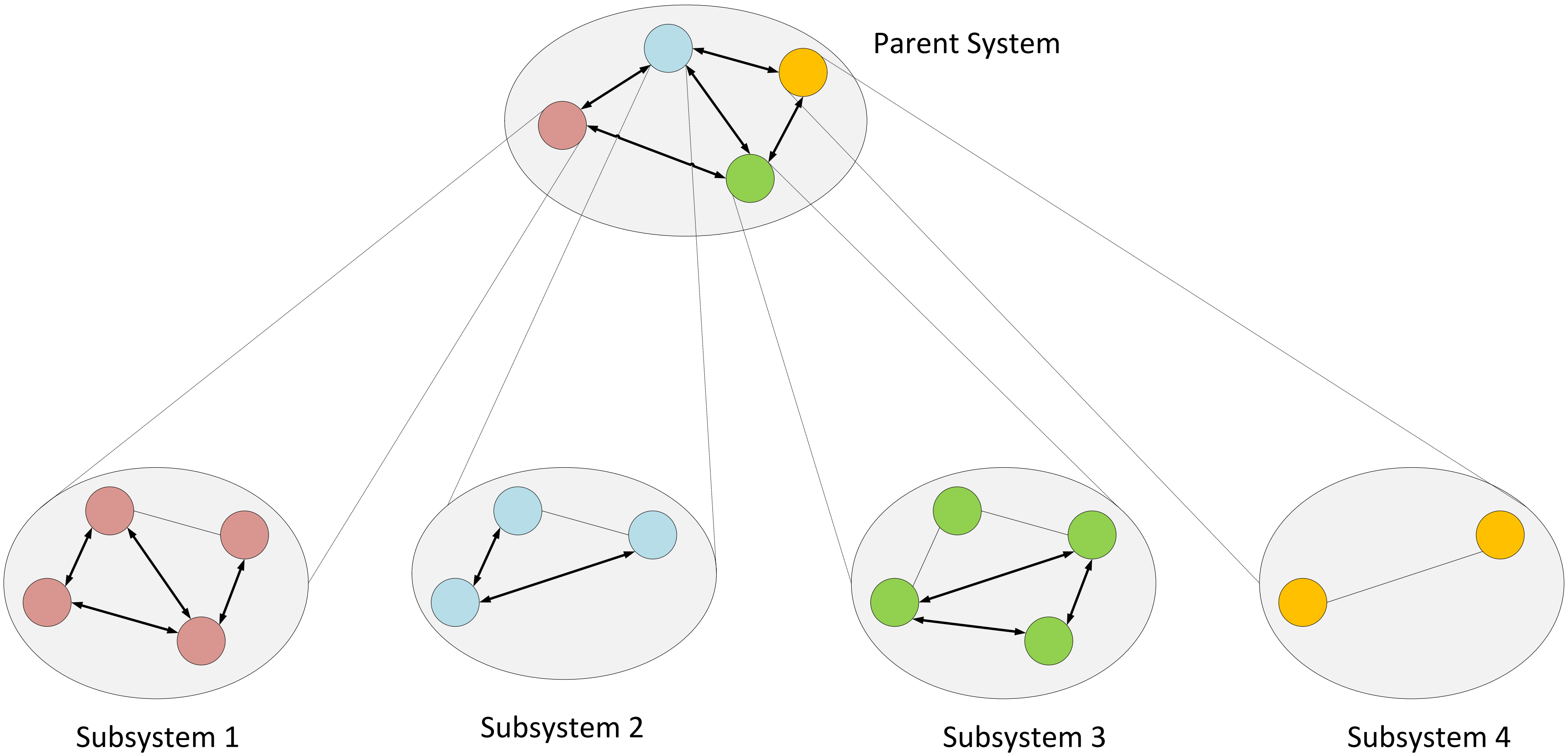
- A <u>system</u> is a set of interacting components:



- By <u>interact</u>, we mean the components exchange force, energy, mass, or information with each other, thereby changing each other’s states.
- By <u>state</u>, we mean the condition of a component that influences its future interactions.
- <u>*All the physical laws discovered by the hard sciences*</u> are expressed in terms of these interactions!

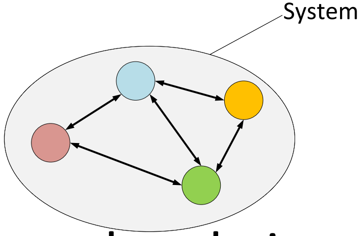
All innovation is innovation of <u>systems</u>

- A component can itself be another system, called a <u>subsystem</u>:



All innovation is innovation of systems

- By the System Phenomenon we mean:
  - The behavior a system as a whole exhibits emerges from its component interactions, not simply a listing of its component properties:



  - That emergent behavior may be obvious or unexpected, and may be highly valuable or detrimental to human stakeholders.
  - It is also the immediate origin for all observed discipline-specific phenomena of physics, chemistry, mechanics, biology, electromagnetics, thermodynamics, etc.

- Examples:
  - Vehicle stability, aircraft dynamics, cooked food taste, satellite receiver performance, manufacturing line quality, distribution system capacity, drug efficacy, business team performance, engine emissions, machine safety, equipment corrosion resistance, power train losses, nanostructure toxicity, cardiovascular health, medical instrument accuracy, enterprise cyber security.

So what? Why is this important to our discussion?

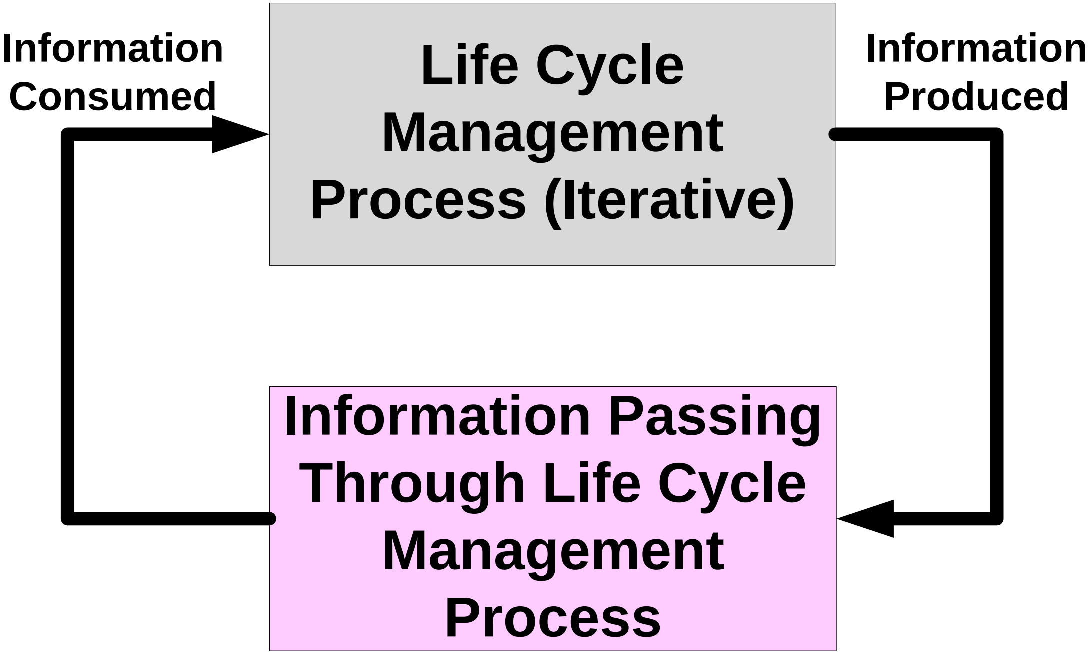
- What's the connection to PLM?
- Many, if not all, of the challenges and opportunities of managing life cycles arise from the Systemic nature of:
  - The managed systems (products, services, others)
  - The systems that manufacture or produce them
  - The systems that distribute and service them
  - The systems of innovation that improve them
  - Including the PLM Systems, themselves!
- A well-known set of predictable, system-based challenges can be learned and addressed.
- Powerful methods and tools for understanding and managing these systems exist.

So what? Why is this important to our discussion?

- Even though these subjects are critical to PLM . . .
- Because they are more recently recognized as emerging, they are not always explicitly covered by typical PLM conversations—whether as formal standards or more informal attention:
  - Some of what we’ll discuss is in the form of certain standards-based information not specific to PLM, and …
  - Some is emerging in literature and practice, not yet visible as formal standards.

Life cycle <u>processes</u> vs. life cycle <u>information</u>

- First, key points about the <u>processes</u> of PLM;
- Second, recognition that the nature of the PLM <u>information</u> is shifting, in a way even more fundamental than <u>process</u>:



Information Consumed

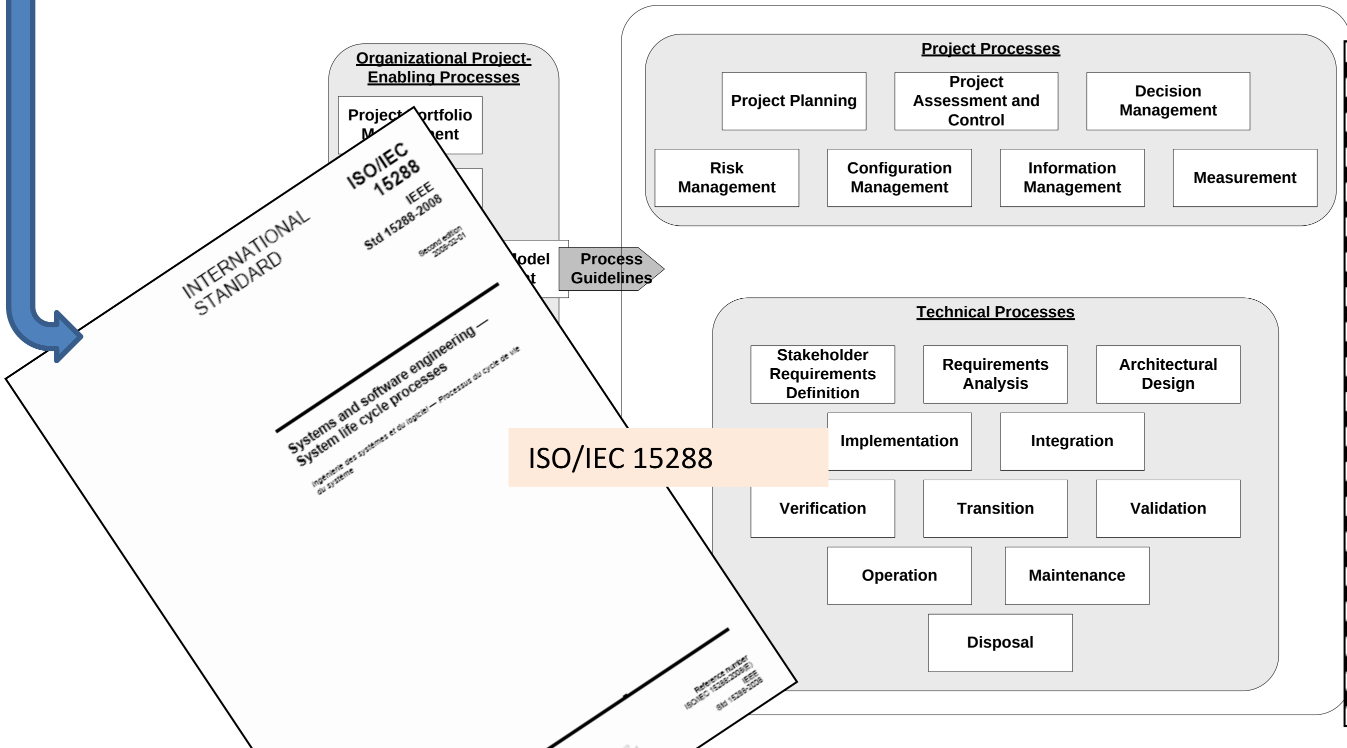
Life Cycle Management Process (Iterative)

Information Produced

Information Passing Through Life Cycle Management Process

Life cycle processes vs. life cycle information

- Enterprises and standards bodies have lots of procedural guides to their work, including those about life cycles:
  - International Standards (consider ISO 15288, also ISO TR24748)
  - Professional Society and Trade Group Publications
  - Enterprise-specific processes and procedures



INTERNATIONAL STANDARD

ISO/IEC 15288

IEEE Std 15288-2008

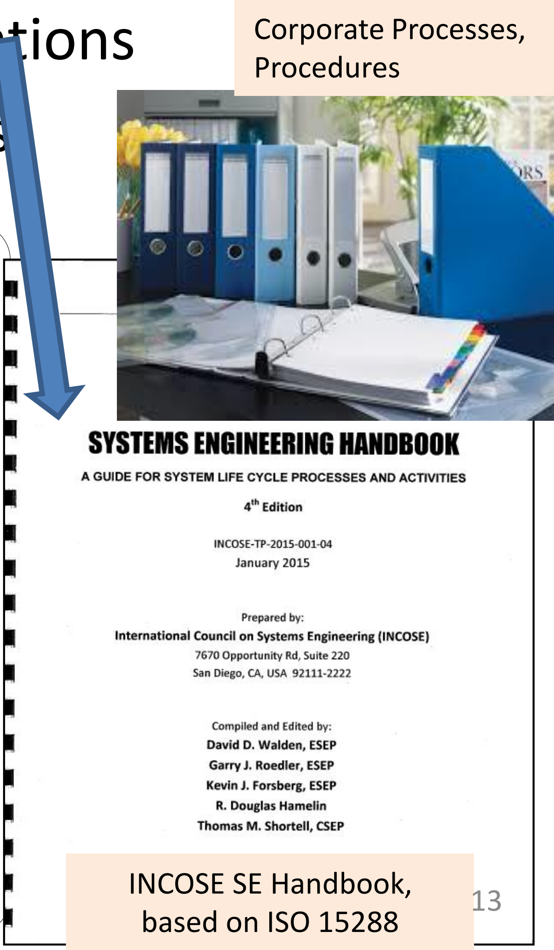
Second edition 2008-02-01

Systems and software engineering — System life cycle processes

Ingénierie des systèmes et du logiciel — Processus du cycle de vie du système

Reference number ISO/IEC 15288:2008(E)
IEEE Std 15288-2008

ISO/IEC 15288



Corporate Processes, Procedures

SYSTEMS ENGINEERING HANDBOOK

A GUIDE FOR SYSTEM LIFE CYCLE PROCESSES AND ACTIVITIES

4th Edition

INCOSE-TP-2015-001-04
January 2015

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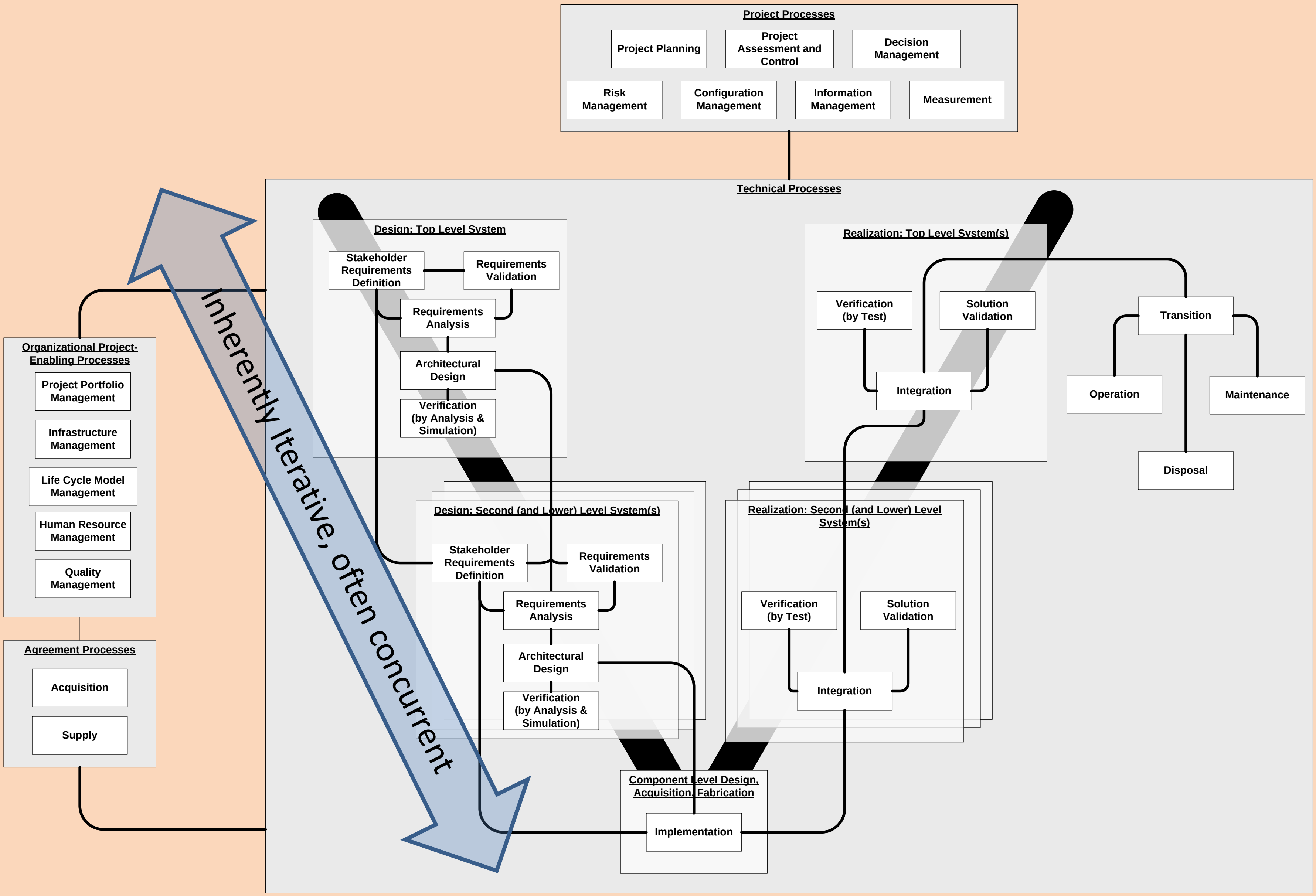
INCOSE SE Handbook, based on ISO 15288

Logical Architecture View of ISO 15288 Life Cycle Management Processes



Project Processes
- Project Planning
- Project Assessment and Control
- Decision Management
- Risk Management
- Configuration Management
- Information Management
- Measurement

Technical Processes

Design: Top Level System
- Stakeholder Requirements Definition
- Requirements Validation
- Requirements Analysis
- Architectural Design
- Verification (by Analysis & Simulation)

Realization: Top Level System(s)
- Verification (by Test)
- Solution Validation
- Integration

- Transition
- Operation
- Maintenance
- Disposal

Design: Second (and Lower) Level System(s)
- Stakeholder Requirements Definition
- Requirements Validation
- Requirements Analysis
- Architectural Design
- Verification (by Analysis & Simulation)

Realization: Second (and Lower) Level System(s)
- Verification (by Test)
- Solution Validation
- Integration

Component Level Design, Acquisition, Fabrication
- Implementation

Organizational Project-Enabling Processes
- Project Portfolio Management
- Infrastructure Management
- Life Cycle Model Management
- Human Resource Management
- Quality Management

Agreement Processes
- Acquisition
- Supply

Inherently Iterative, often concurrent

Current version: 2008. A new 2014/5 draft standard has passed balloting and will be published as a standard in 2015.

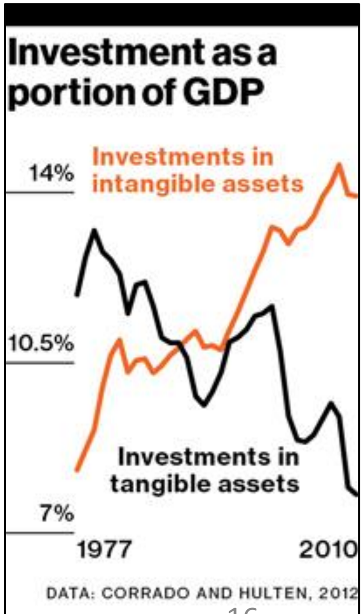
Life cycle processes vs. life cycle information

The rise of Model-Based Engineering, Model-Based Design, and Model-Based Systems Engineering (MBSE):

- Structure of system representation is moving from models of business data in the traditional database modeling sense to STEM models of the real systems they describe, in the sense of science and engineering of those systems.
- This changes the focus from (what is a ‘good’ business information model?) to (what is the actual science-based representation of the engineered system?).
- Amounts to a shift from subjective opinion to objective science—shifting from document prose to ‘models’.
- A key question, from science: What is the smallest model of a system, for purposes of understanding (or life cycle managing) it?
- This question can define the System Configuration Space, to be tracked by a future PLM schema.
- It is within that space that the iterative PLM Process moves candidate systems through System Configuration Space.

Explicit representation, IP, and the rise of the Model-Based Economy

- A central theme of this talk is the movement to explicit representation of systems with ‘models’ sufficient to actually manage their life cycles
- Key evidence for the power behind this movement:
  - Explicit models of physical interactions are the basis for describing virtually all the laws discovered by the physical sciences—including well known product problems.
  - Once unlocked by the rise of STEM, human innovation supported by these representations has powered 300 years of dramatic human progress.
  - Annual US capital investment in intangible intellectual property, compared to capital investment in hard assets, recently reached the cross-over point: annual IP investment is now larger than bricks and mortar.
  - We are moving to the Model-Based Economy.
  - S*Patterns can be financially capitalized, under FASB.

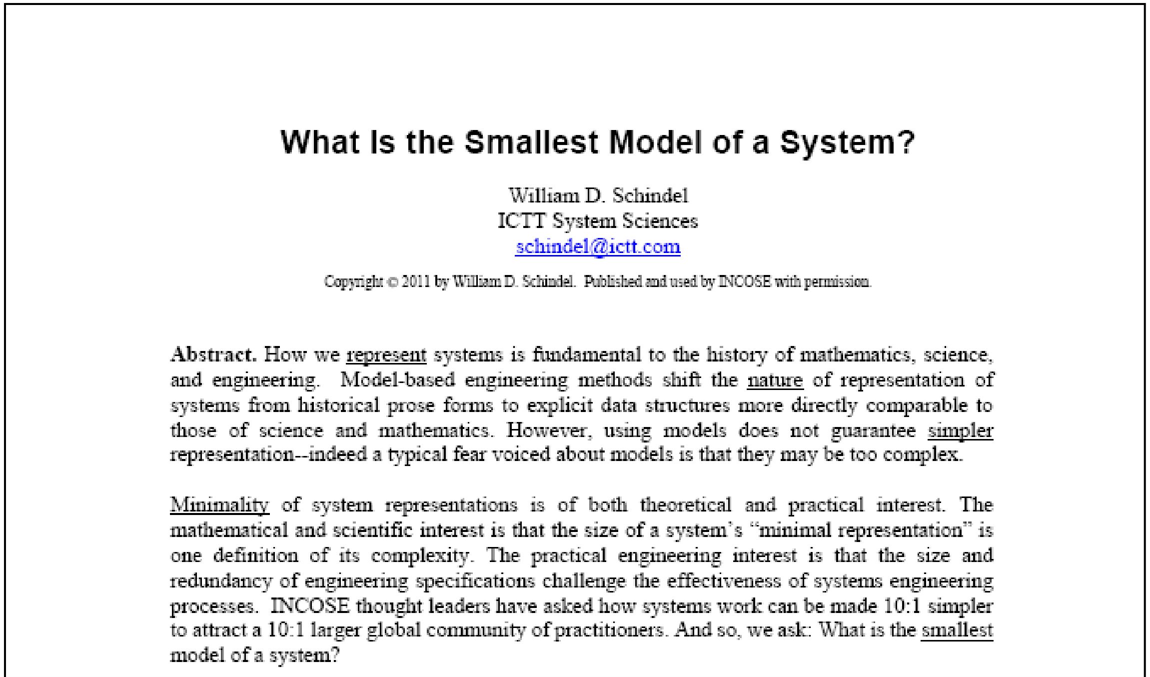

Investment as a portion of GDP

DATA: CORRADO AND HULTEN, 2012

- However, because we are living in the middle of this change, it is not so well understood:
  - The majority of all representation of systems, even in automation databases, continues to be based on “data models” that are other than the explicit model representation of the smallest explicit model necessary for life cycle management.
- We can’t fool Mother Nature:
  - The underlying nature of systems will continue to challenge life cycle management until this reality is understood and represented explicitly.
- A simple and widely-observed example of this impact is the cross-functional physical interaction of real delivered systems that span enterprise functional silos: product design, manufacturing, distribution, service and support.
  - These receive relatively tortured attention because the simple physical interactions evident almost immediately in deployed systems are not explicitly represented in life cycle management representations of the implemented systems.

Explicit representation, IP, and the rise of the Model-Based Economy

- Based on decades of testing and refinement, our best understanding of the smallest model of a system necessary for the purposes of science, engineering, and life cycle management is the S*Metamodel:



What Is the Smallest Model of a System?

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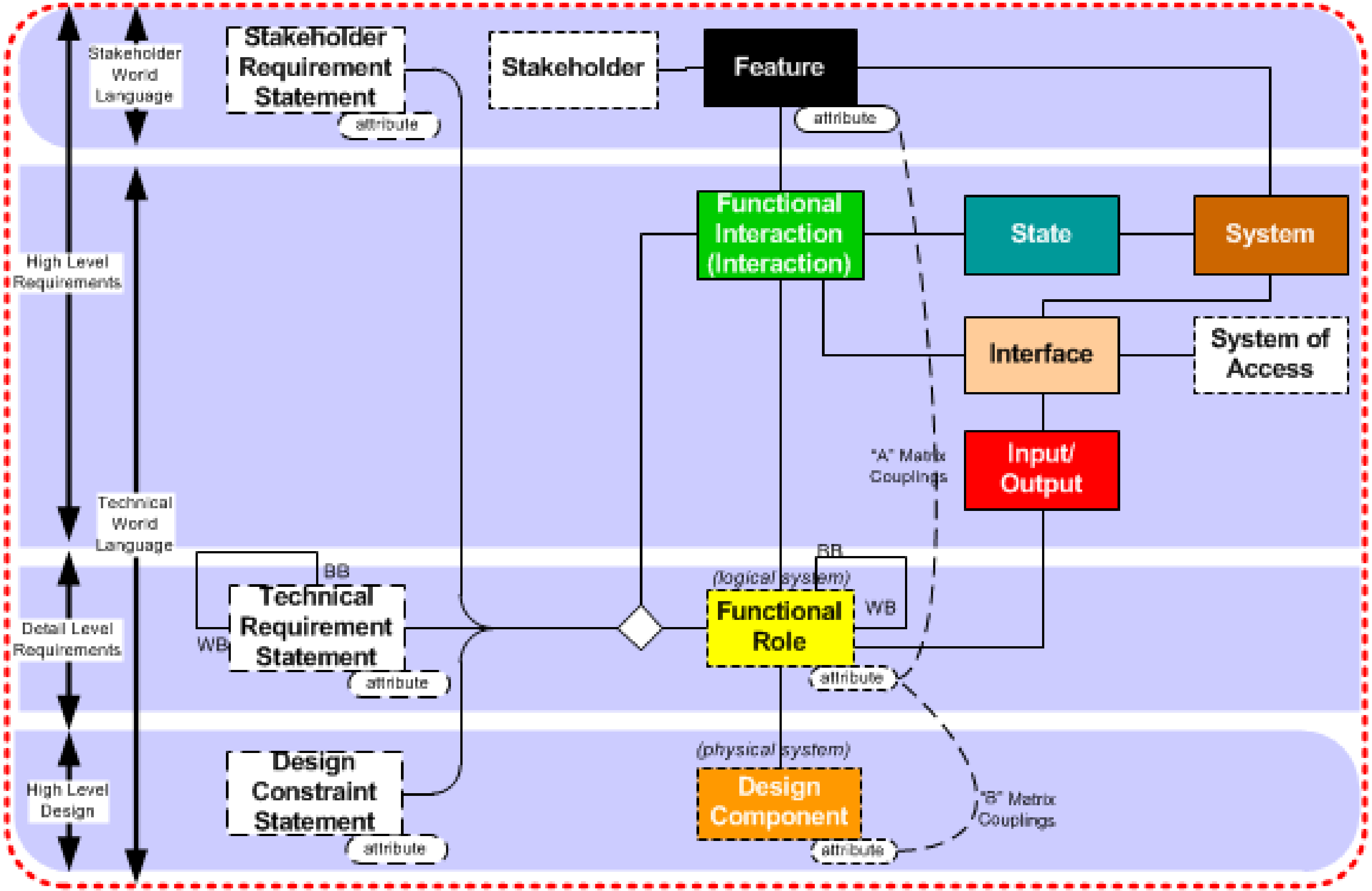
Abstract. How we represent systems is fundamental to the history of mathematics, science, and engineering. Model-based engineering methods shift the nature of representation of systems from historical prose forms to explicit data structures more directly comparable to those of science and mathematics. However, using models does not guarantee simpler representation--indeed a typical fear voiced about models is that they may be too complex.

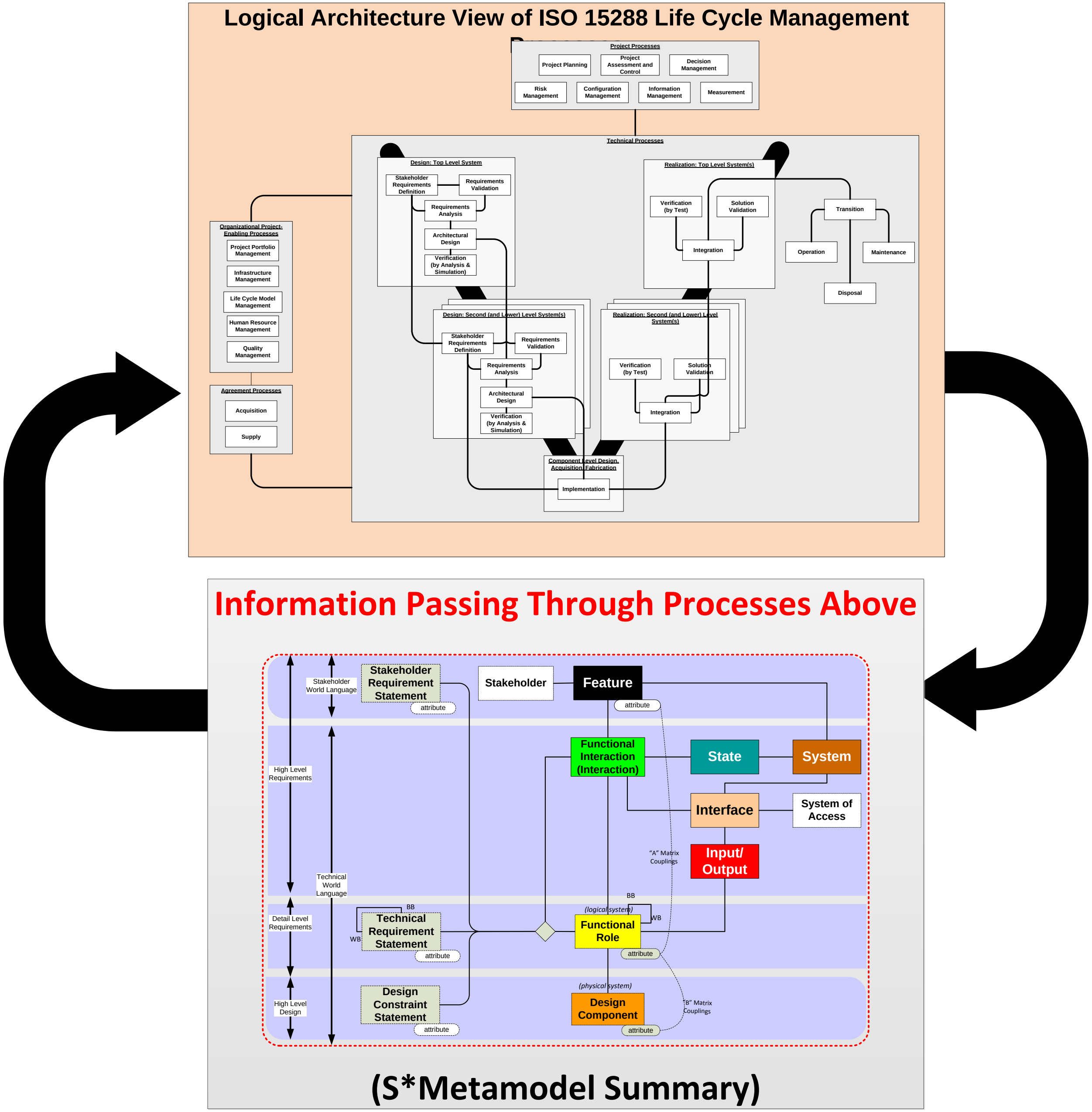
Minimality of system representations is of both theoretical and practical interest. The mathematical and scientific interest is that the size of a system's "minimal representation" is one definition of its complexity. The practical engineering interest is that the size and redundancy of engineering specifications challenge the effectiveness of systems engineering processes. INCOSE thought leaders have asked how systems work can be made 10:1 simpler to attract a 10:1 larger global community of practitioners. And so, we ask: What is the smallest model of a system?

Extract from the S*Metamodel



S*Metamodel = smallest model necessary for purposes of science, engineering, life cycle management

Life cycle processes vs. life cycle information



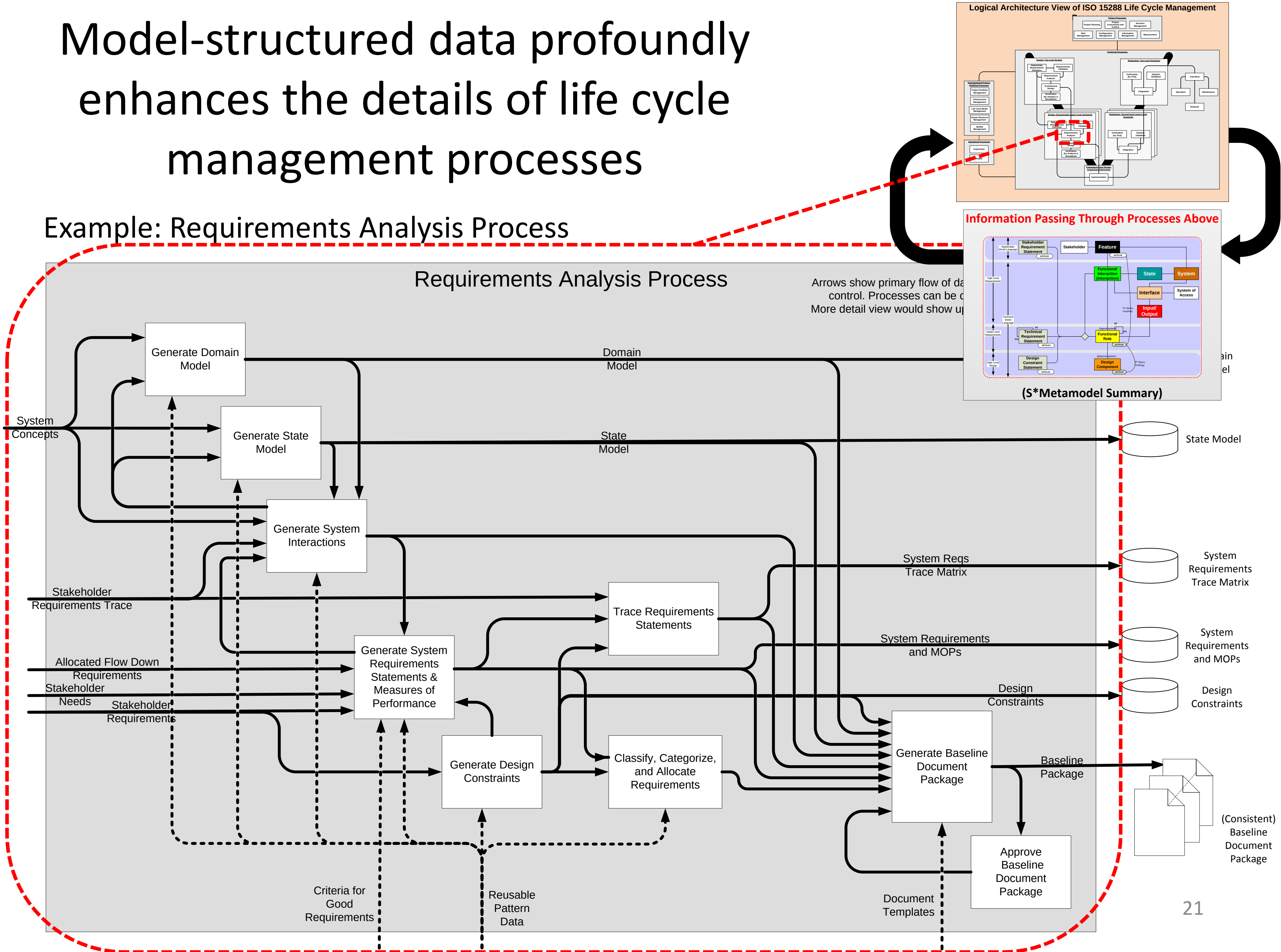
Logical Architecture View of ISO 15288 Life Cycle Management

Information Passing Through Processes Above

(S*Metamodel Summary)

Model-structured data profoundly enhances the details of life cycle management processes

Example: Requirements Analysis Process



Logical Architecture View of ISO 15288 Life Cycle Management

Information Passing Through Processes Above

(S*Metamodel Summary)

Requirements Analysis Process

Arrows show primary flow of da
control. Processes can be c
More detail view would show up

A simple example

- Manufactured Oil Filter Product Line Family

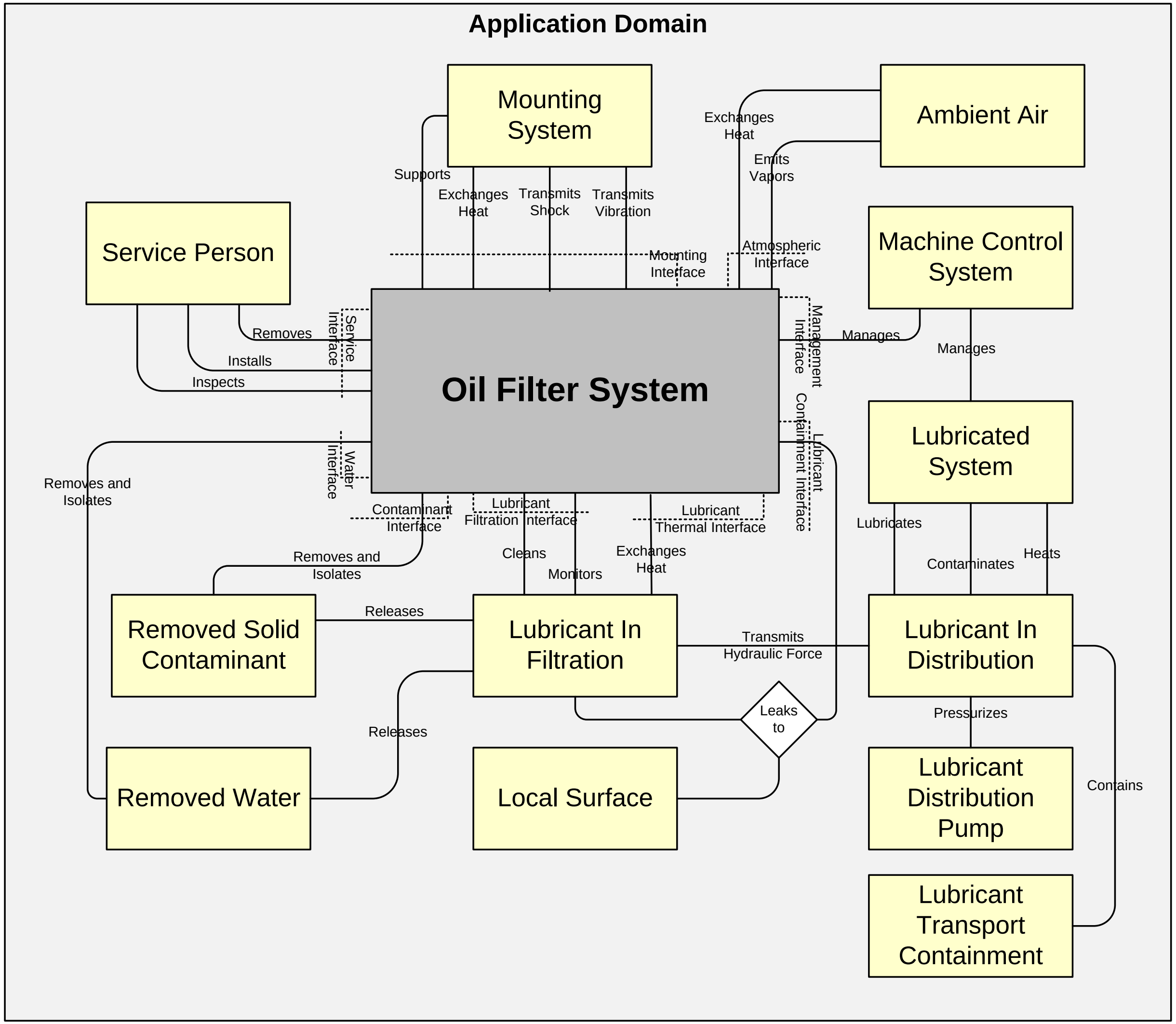
and

- Oil Filter Manufacturing System

Functional Requirements are all captured as models of physical Interactions with its environment . . .

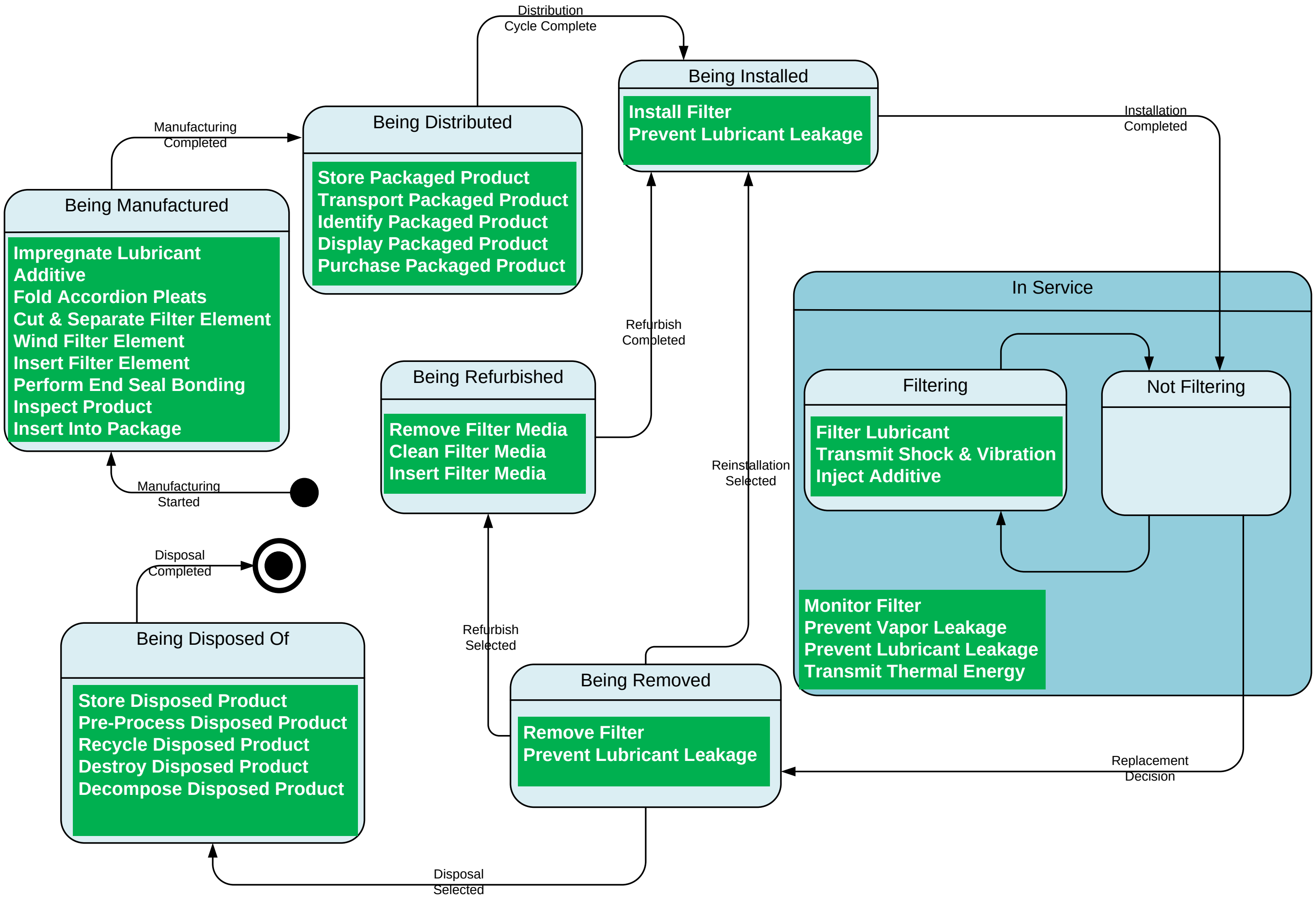
Oil Filter Product Line Family

- Using explicit modeling language databases, the interactions of the product are captured and manifest all the functional requirements.



Life Cycle of an Oil Filter Product Instance

- Using explicit modeling language databases, the interactions of the product are captured and manifest all the functional requirements.



Manufacturing Started

Being Manufactured

Impregnate Lubricant Additive
Fold Accordion Pleats
Cut & Separate Filter Element
Wind Filter Element
Insert Filter Element
Perform End Seal Bonding
Inspect Product
Insert Into Package

Manufacturing Completed

Being Distributed

Store Packaged Product
Transport Packaged Product
Identify Packaged Product
Display Packaged Product
Purchase Packaged Product

Distribution Cycle Complete

Being Installed

Install Filter
Prevent Lubricant Leakage

Installation Completed

In Service

Filtering

Filter Lubricant
Transmit Shock & Vibration
Inject Additive

Not Filtering

Monitor Filter
Prevent Vapor Leakage
Prevent Lubricant Leakage
Transmit Thermal Energy

Replacement Decision

Being Removed

Remove Filter
Prevent Lubricant Leakage

Reinstallation Selected

Refurbish Selected

Being Refurbished

Remove Filter Media
Clean Filter Media
Insert Filter Media

Refurbish Completed

Disposal Selected

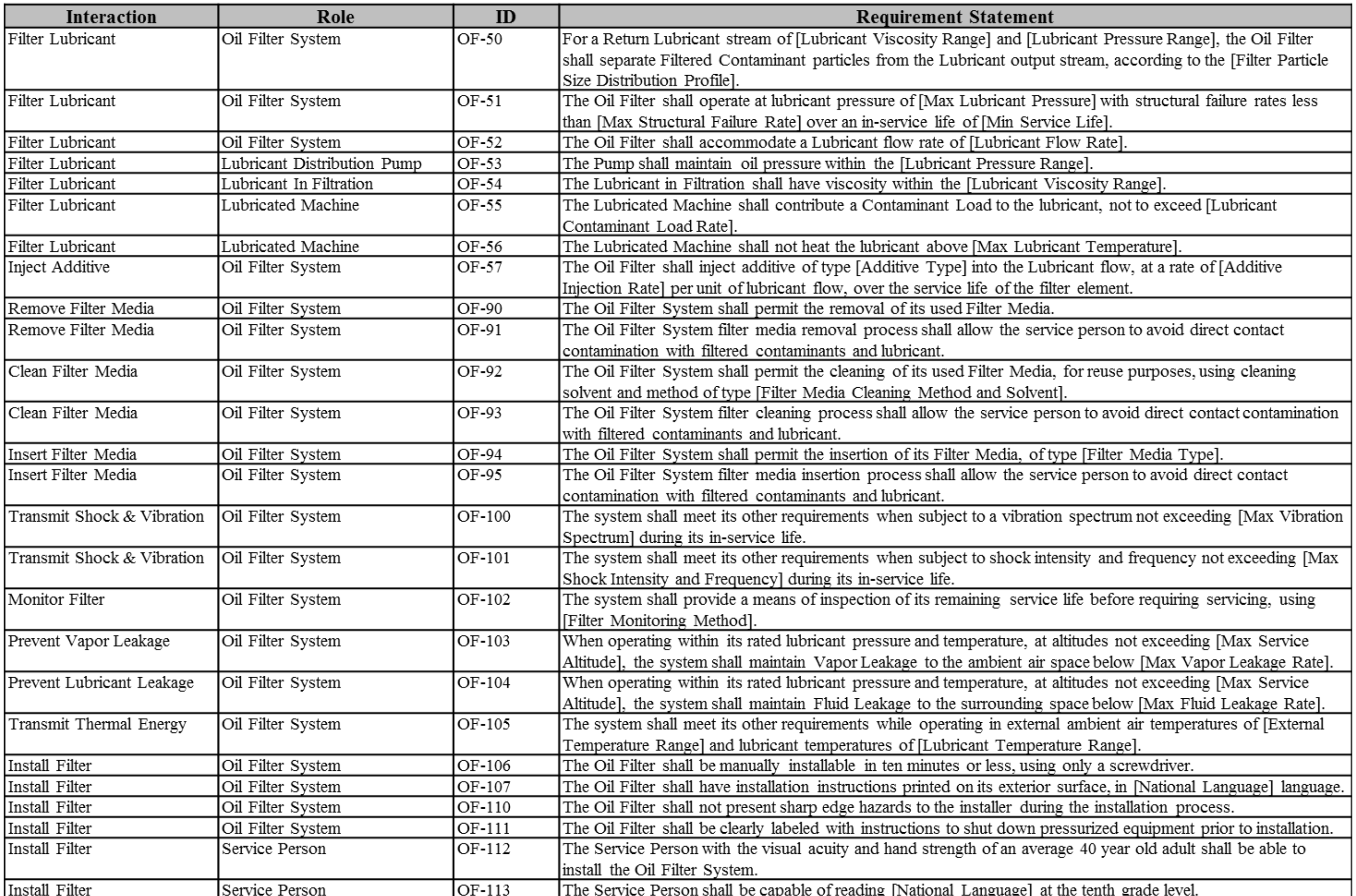
Being Disposed Of

Store Disposed Product
Pre-Process Disposed Product
Recycle Disposed Product
Destroy Disposed Product
Decompose Disposed Product

Disposal Completed

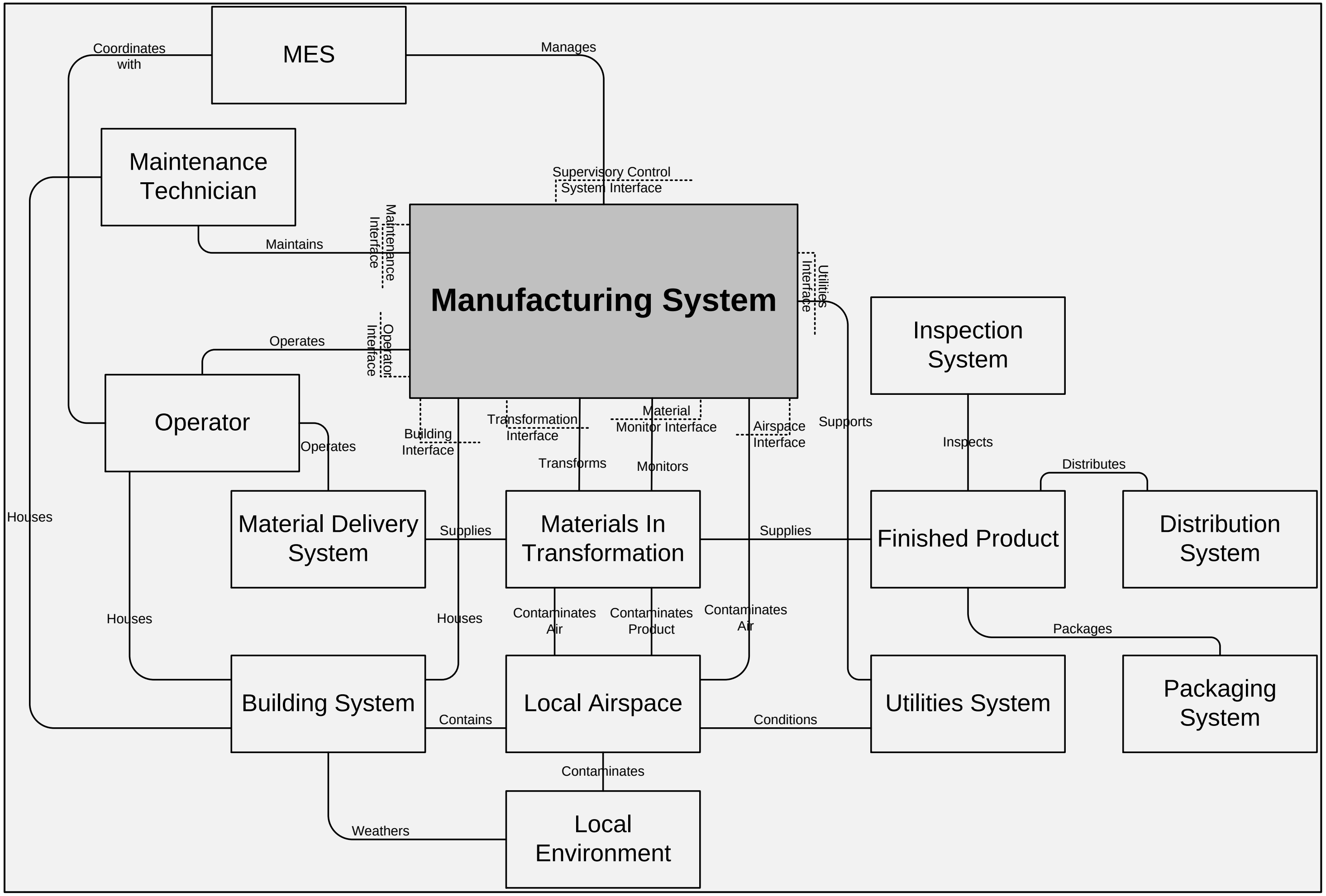
Product Requirements Extract

- Using explicit modeling language databases, the interactions of the product are captured and manifest all the functional requirements.

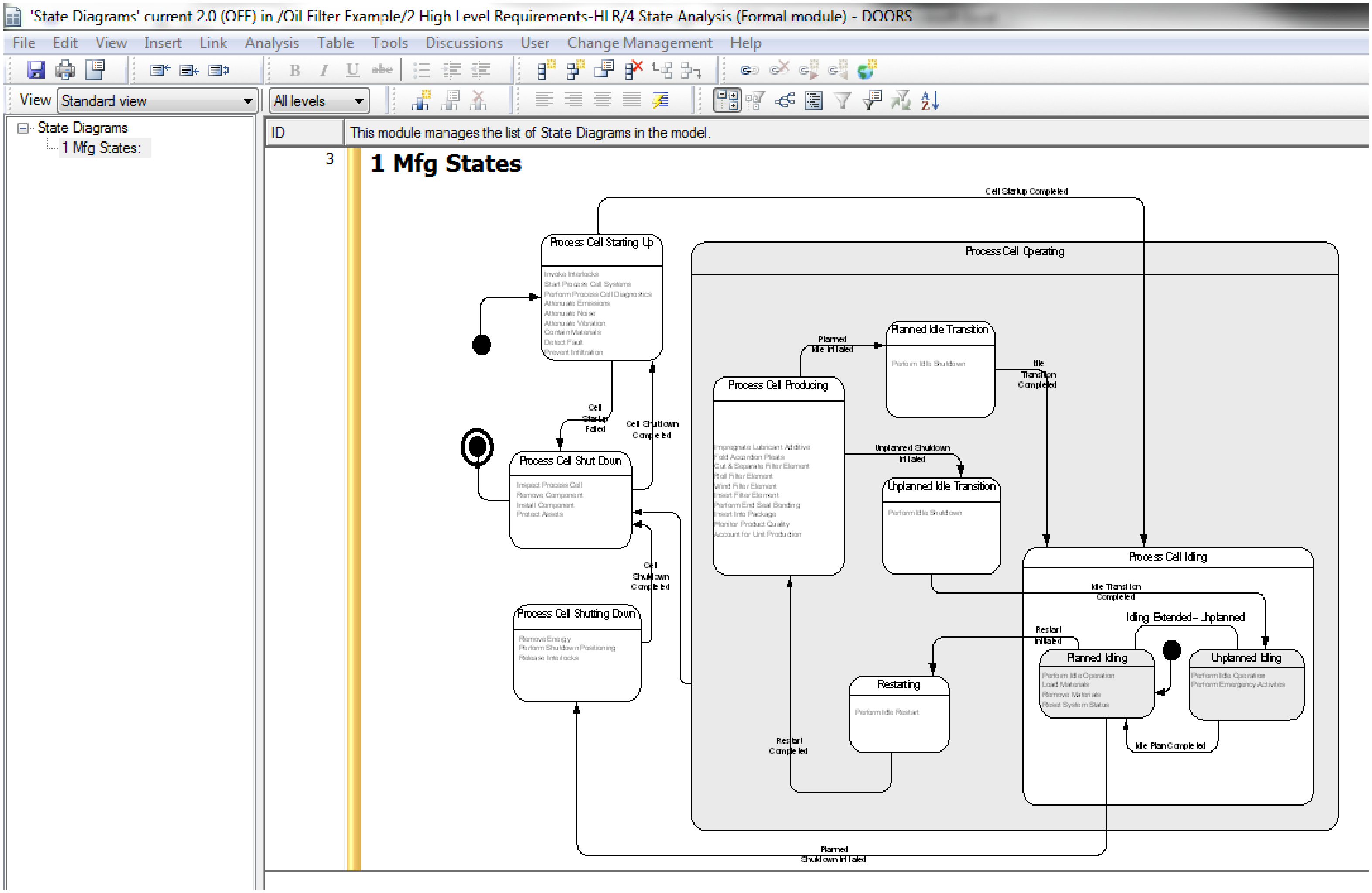


Interaction	Role	ID	Requirement Statement
Filter Lubricant	Oil Filter System	OF-50	For a Return Lubricant stream of [Lubricant Viscosity Range] and [Lubricant Pressure Range], the Oil Filter shall separate Filtered Contaminant particles from the Lubricant output stream, according to the [Filter Particle Size Distribution Profile].
Filter Lubricant	Oil Filter System	OF-51	The Oil Filter shall operate at lubricant pressure of [Max Lubricant Pressure] with structural failure rates less than [Max Structural Failure Rate] over an in-service life of [Min Service Life].
Filter Lubricant	Oil Filter System	OF-52	The Oil Filter shall accommodate a Lubricant flow rate of [Lubricant Flow Rate].
Filter Lubricant	Lubricant Distribution Pump	OF-53	The Pump shall maintain oil pressure within the [Lubricant Pressure Range].
Filter Lubricant	Lubricant In Filtration	OF-54	The Lubricant in Filtration shall have viscosity within the [Lubricant Viscosity Range].
Filter Lubricant	Lubricated Machine	OF-55	The Lubricated Machine shall contribute a Contaminant Load to the lubricant, not to exceed [Lubricant Contaminant Load Rate].
Filter Lubricant	Lubricated Machine	OF-56	The Lubricated Machine shall not heat the lubricant above [Max Lubricant Temperature].
Inject Additive	Oil Filter System	OF-57	The Oil Filter shall inject additive of type [Additive Type] into the Lubricant flow, at a rate of [Additive Injection Rate] per unit of lubricant flow, over the service life of the filter element.
Remove Filter Media	Oil Filter System	OF-90	The Oil Filter System shall permit the removal of its used Filter Media.
Remove Filter Media	Oil Filter System	OF-91	The Oil Filter System filter media removal process shall allow the service person to avoid direct contact contamination with filtered contaminants and lubricant.
Clean Filter Media	Oil Filter System	OF-92	The Oil Filter System shall permit the cleaning of its used Filter Media, for reuse purposes, using cleaning solvent and method of type [Filter Media Cleaning Method and Solvent].
Clean Filter Media	Oil Filter System	OF-93	The Oil Filter System filter cleaning process shall allow the service person to avoid direct contact contamination with filtered contaminants and lubricant.
Insert Filter Media	Oil Filter System	OF-94	The Oil Filter System shall permit the insertion of its Filter Media, of type [Filter Media Type].
Insert Filter Media	Oil Filter System	OF-95	The Oil Filter System filter media insertion process shall allow the service person to avoid direct contact contamination with filtered contaminants and lubricant.
Transmit Shock & Vibration	Oil Filter System	OF-100	The system shall meet its other requirements when subject to a vibration spectrum not exceeding [Max Vibration Spectrum] during its in-service life.
Transmit Shock & Vibration	Oil Filter System	OF-101	The system shall meet its other requirements when subject to shock intensity and frequency not exceeding [Max Shock Intensity and Frequency] during its in-service life.
Monitor Filter	Oil Filter System	OF-102	The system shall provide a means of inspection of its remaining service life before requiring servicing, using [Filter Monitoring Method].
Prevent Vapor Leakage	Oil Filter System	OF-103	When operating within its rated lubricant pressure and temperature, at altitudes not exceeding [Max Service Altitude], the system shall maintain Vapor Leakage to the ambient air space below [Max Vapor Leakage Rate].
Prevent Lubricant Leakage	Oil Filter System	OF-104	When operating within its rated lubricant pressure and temperature, at altitudes not exceeding [Max Service Altitude], the system shall maintain Fluid Leakage to the surrounding space below [Max Fluid Leakage Rate].
Transmit Thermal Energy	Oil Filter System	OF-105	The system shall meet its other requirements while operating in external ambient air temperatures of [External Temperature Range] and lubricant temperatures of [Lubricant Temperature Range].
Install Filter	Oil Filter System	OF-106	The Oil Filter shall be manually installable in ten minutes or less, using only a screwdriver.
Install Filter	Oil Filter System	OF-107	The Oil Filter shall have installation instructions printed on its exterior surface, in [National Language] language.
Install Filter	Oil Filter System	OF-110	The Oil Filter shall not present sharp edge hazards to the installer during the installation process.
Install Filter	Oil Filter System	OF-111	The Oil Filter shall be clearly labeled with instructions to shut down pressurized equipment prior to installation.
Install Filter	Service Person	OF-112	The Service Person with the visual acuity and hand strength of an average 40 year old adult shall be able to install the Oil Filter System.
Install Filter	Service Person	OF-113	The Service Person shall be capable of reading [National Language] at the tenth grade level.

This also applies to the related Manufacturing System



This also applies to the related Manufacturing System



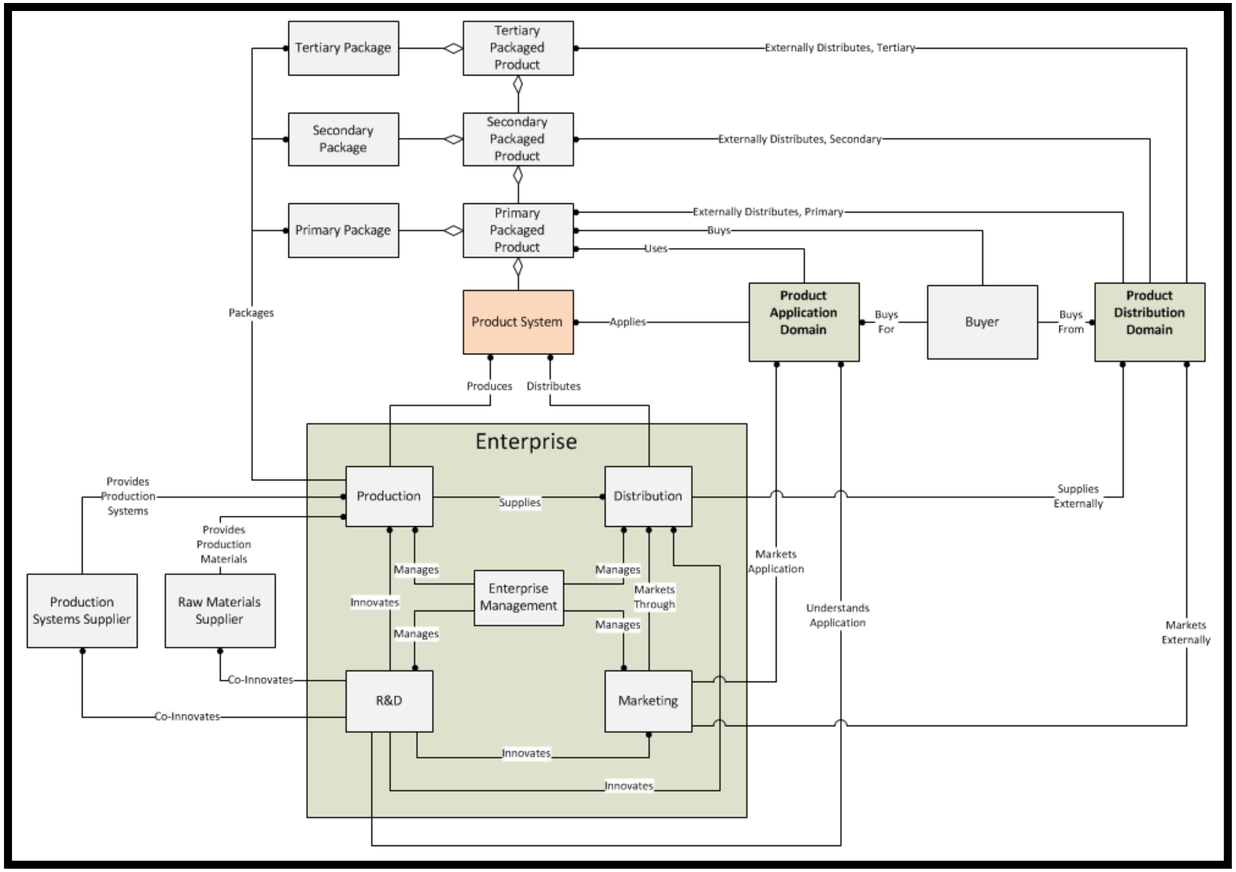
'State Diagrams' current 2.0 (OFE) in /Oil Filter Example/2 High Level Requirements-HLR/4 State Analysis (Formal module) - DOORS

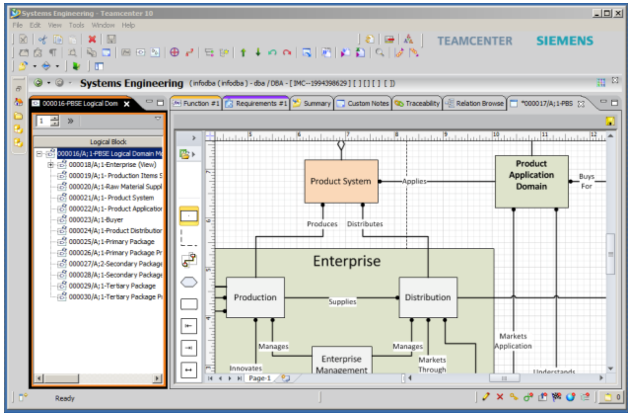
This module manages the list of State Diagrams in the model.

3 **1 Mfg States**

Even More Important:
The Higher Level Enterprise Model

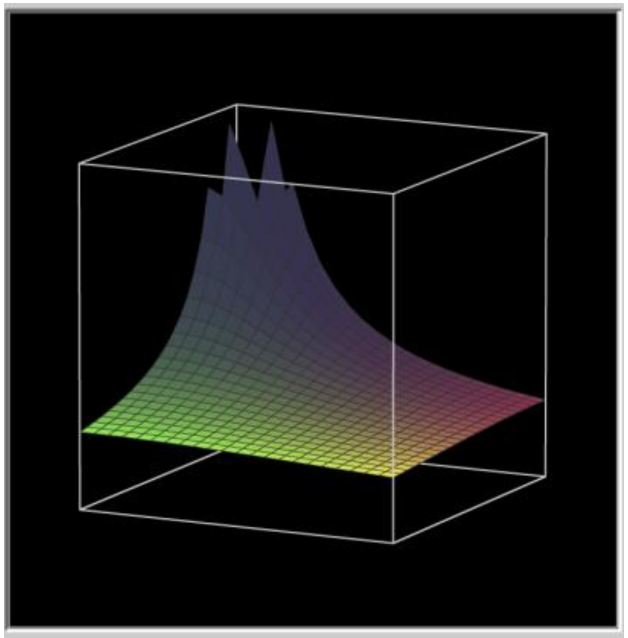
- Reveals interactions crossing functional "silos", and the requirements for collaboration:





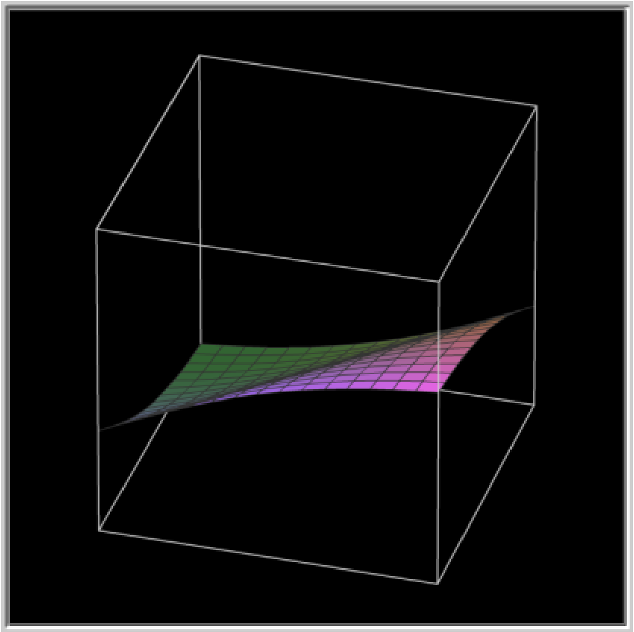
Even More Important:
The Higher Level Enterprise Model

- Drives all the way down to detailed cross-functional inter-dependencies:



Oil Filter manufacturing throughput as a function of Heat Time and Spray Time:

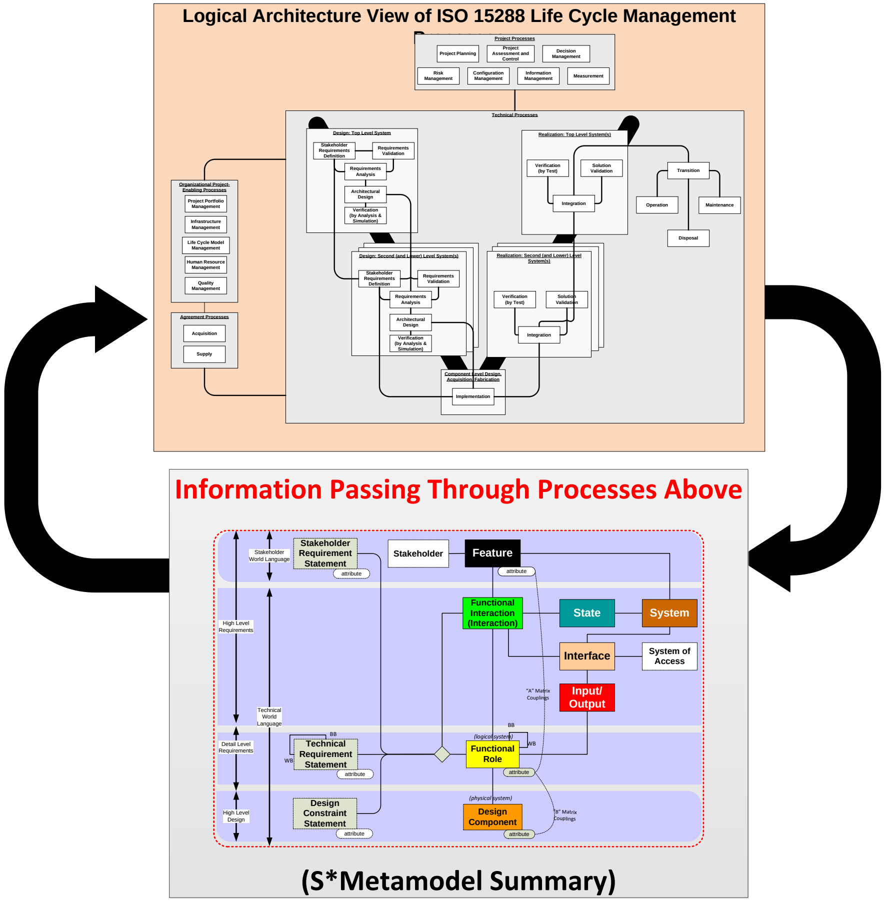
- X-Axis (Horizontal 1): Heat Time
- Y-Axis (Horizontal 2): Spray Time
- Z-Axis (Vertical): Unit Throughput



Oil Filter Additive Life as a function of Heat Time and Spray Time

- X-Axis (Horizontal 1): Heat Time
- Y-Axis (Horizontal 2): Spray Time
- Z-Axis (Vertical): Additive Life

Systems for learning from experience



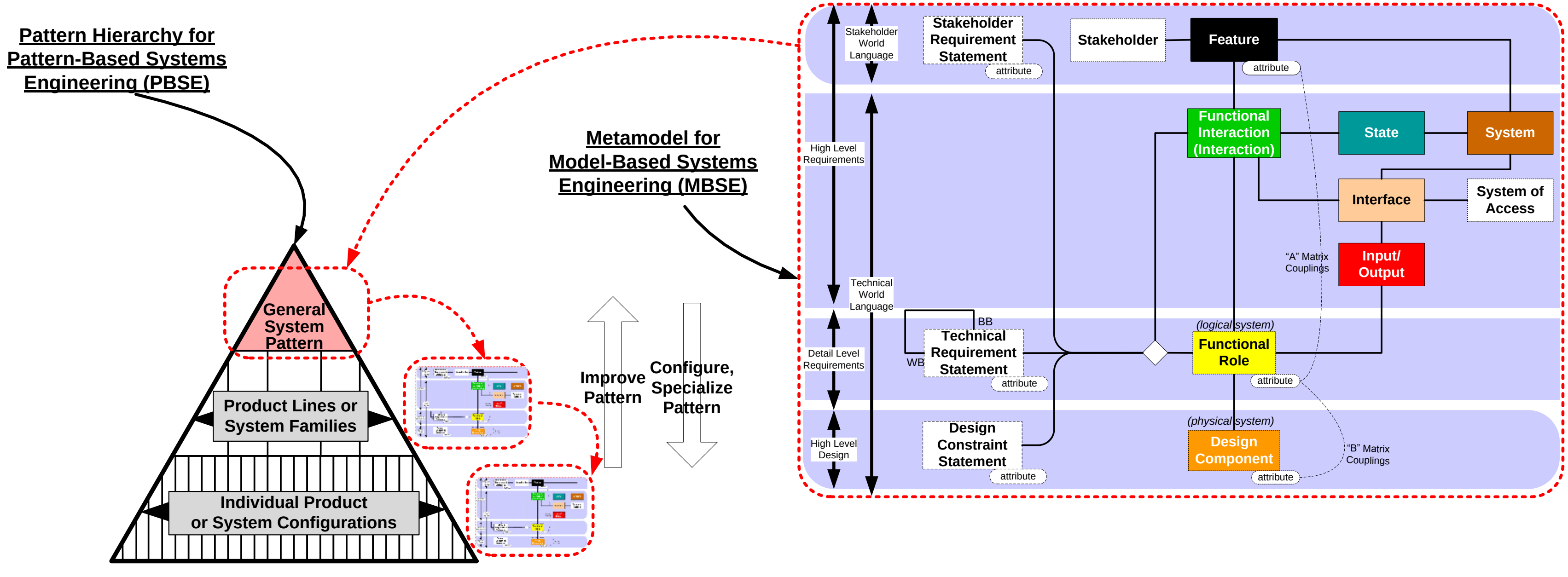
- Learning what is known about general life cycle management practices:
  - Use what is already known about life cycle management processes that apply in principle for all types of systems (e.g., ISO15288).
  - This includes systems-originating challenges and opportunities inherent to the nature of those processes.
- But what about future lessons . . .

Systems for learning from experience

- Learning and agility about your own enterprise and its offerings, markets.
- How will you manage:
  - What is learned about the configuration of those processes to your individual enterprise and business units—including the life cycle management processes and systems employed.
  - What is learned about your enterprise's products and services—including the dynamic and uncertain environment in which they are challenged to survive.
- To think about these, you should think about:
  - Pattern-Based Systems Engineering (PBSE) , and
  - Agile Systems Engineering Life Cycle Management . . .

Pattern-Based Systems Engineering

- S*Patterns are S*Models describing families of systems, product lines, platforms, or otherwise similar systems.
- S*Patterns are reusable and configurable, and the focus of the INCOSE/OMG MBSE Initiative Patterns Challenge Team.
- In the traditions of 300 years of science, S*Patterns are used to dynamically accumulate and apply what we learn about our systems: products, manufacturing, distribution, service, development.

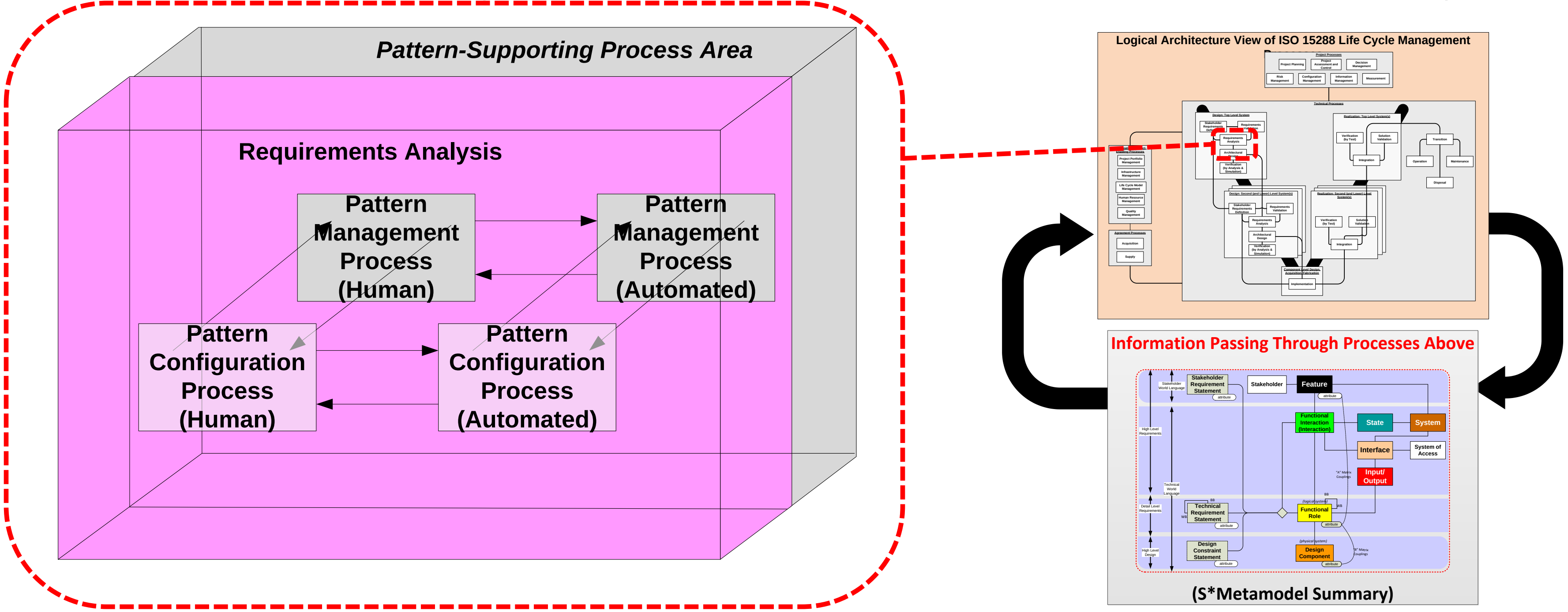


Pattern Class Hierarchy

Agility in Life Cycle Management

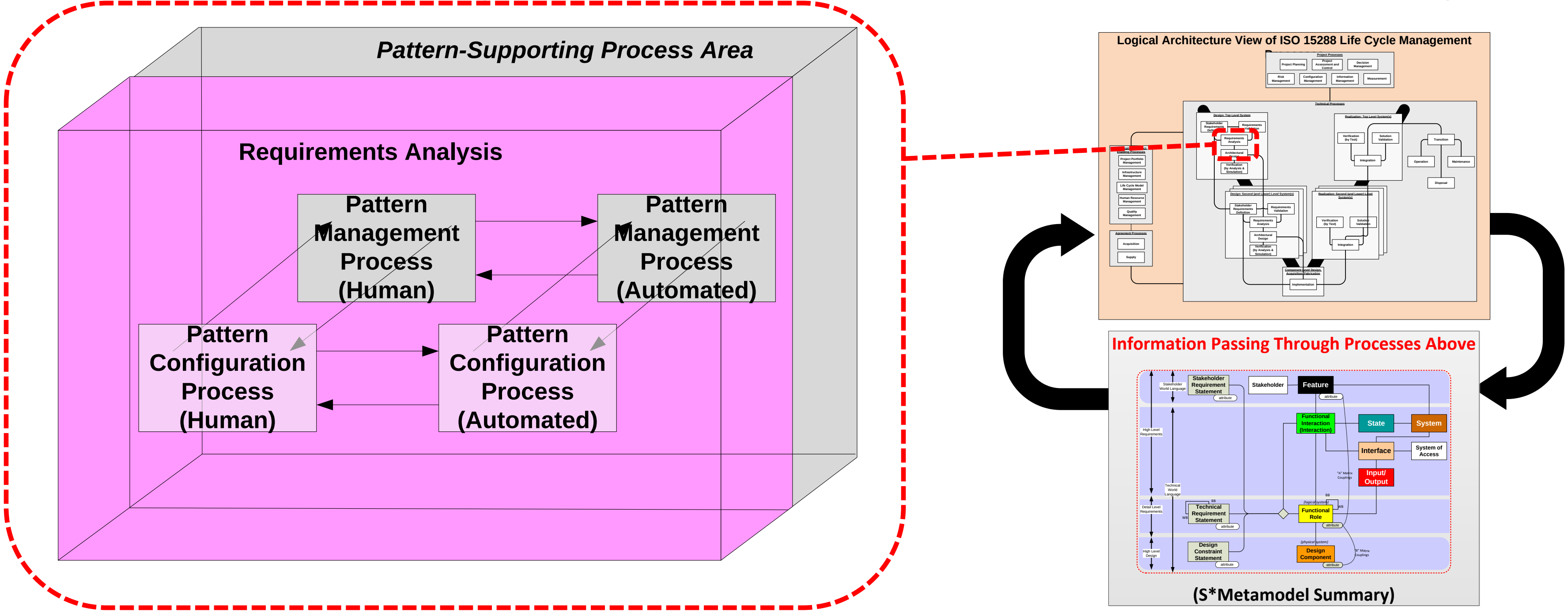
- The International Council on Systems Engineering (INCOSE) www.incose.org is the 25 year old global parent professional society concerned with the discipline of systems engineering across all domains: automotive, aerospace, health care, consumer products, advanced manufacturing, telecommunications, etc.
- INCOSE has begun a global 2015-16 project, the Agile Systems Engineering Life Cycle Model (ASELCM) Project.
- A community project of enterprises and institutions across the U.S. and Europe, to explore and report the current state of the art in the practice of agility across the life cycle of systems, in dynamic and uncertain environments.
- Based on exploratory workshops / clinics to be held at participating enterprises across the U.S. and Europe during 2015 – 2016.
- The result will include publication of the Agile System Engineering Life Cycle Management Pattern, as an input to the next update to ISO15288.
- You or your organization can participate in this project, as a visiting clinician or a visited workshop site.
- See http://www.parshift.com/ASELCM/Home.html

Information system roles, across the life cycle



- Each of the Life Cycle Management Processes has potential roles for humans and info systems.
- The introduction of model-based (MBSE) data structures opens the door for integration of a wide range of model-oriented tools, integrated by a common fabric.
- Merely using PLM information technology not a guarantee of MBSE model coverage, unless managed.

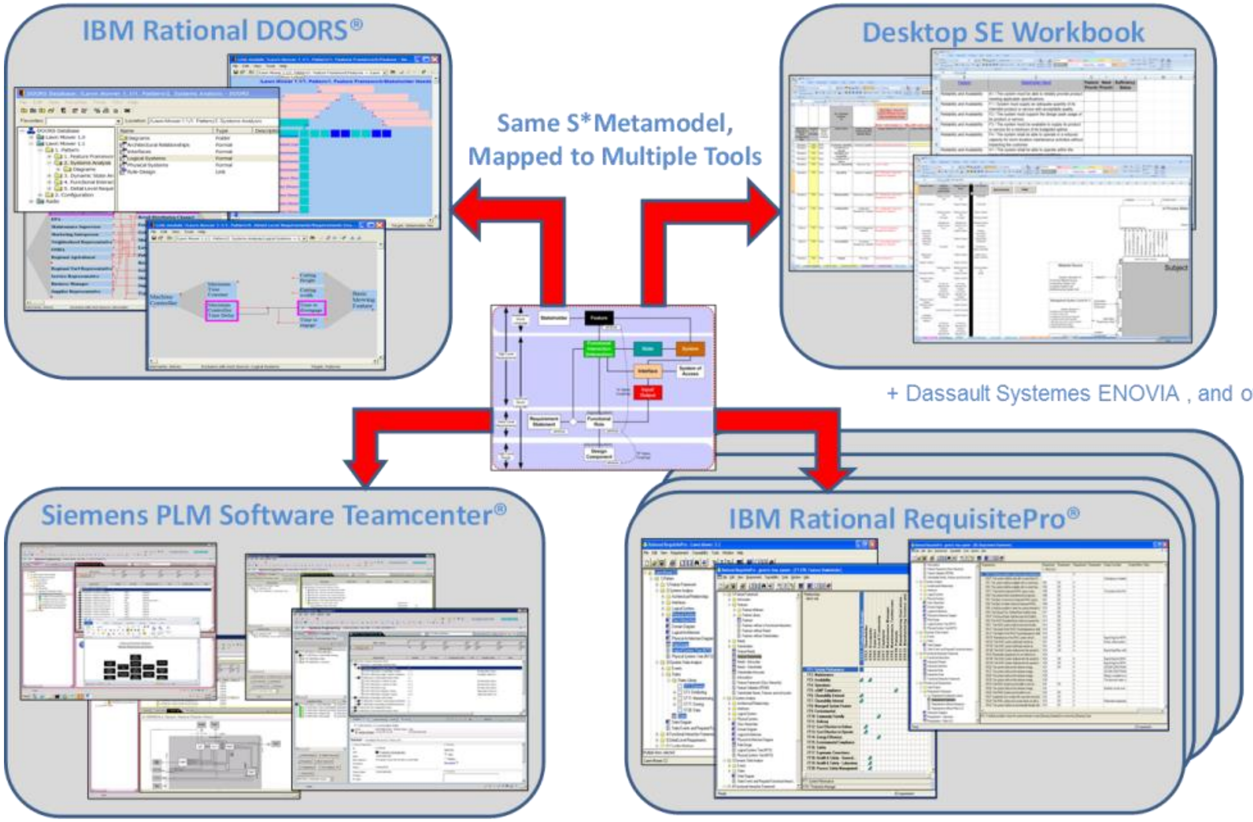
Information system roles, across the life cycle



- The introduction of pattern-based (PBSE) data structures opens the door for machine-assisted platform and product line management.
- PLM suppliers increasingly reach out to this integration opportunity through not only more functionality, but also integration gateways and integration technologies (e.g., OSLC).
- A common federated conceptual reference model (S*Metamodel) further enables this vision.
- Critical priority sequence of planning: Information first, then Process, then Automation—all as a system.

Existing PLM systems and other tools are S*capable

- The S*Metamodel has been mapped to a diverse range of PLM information systems, engineering tools, and databases, using their built-in schema capabilities.
- Substantially all the contemporary systems are capable of this representation.
- Examples: Has been mapped into Siemens Team Center, IBM/Rational DOORS, Requisite Pro, Dassault Systemes ENOVIA, Sparx Enterprise Architect, others.

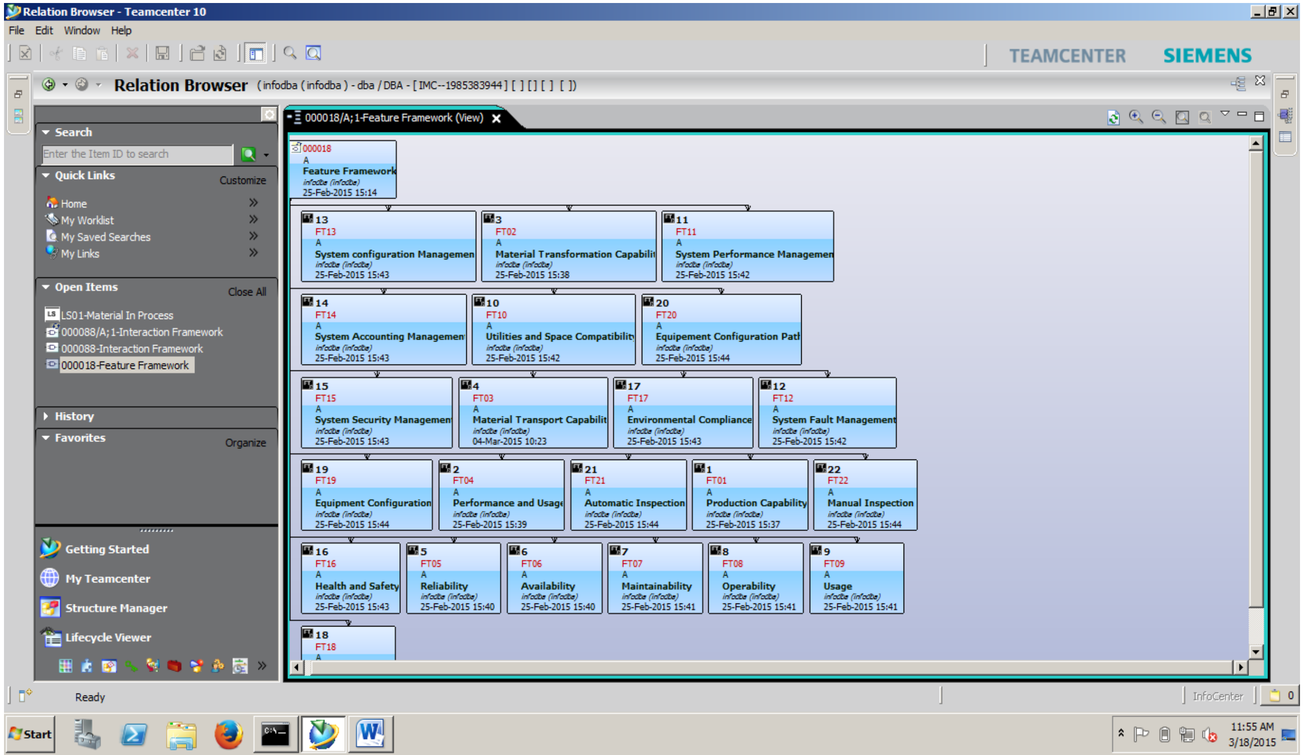


The importance of community; roles for IPLI & partners

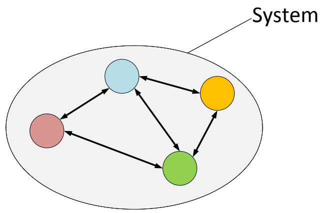
- As summarized here, this is a time of significant change in the foundations of innovative life cycle management, from concept through production, distribution, utilization and support.
- During such times of change, learning from others and working together become more important to the success of organizations and individuals.
- A consortium such as IPLI enhances the community needed to more effectively learn and advance together.
- Example: Agile methods have taught us how important it is to experiment. The IPLI consortium provides a way to plan and share those experiments, improving the leverage of these learning efforts.

Example IPLI collaboration

- One such recently-started collaboration with IPLI was undertaken by ICTT System Sciences:
  - Evaluation of a third party commercial PLM system ability to leverage model-based representation of generalized manufacturing systems, configurable to different process types and products.
  - Participation by graduate student and faculty members of IPLI.



Challenges & opportunities--conclusions



1. As complexity and rate of change increase, the <u>systems</u> nature of products and their enabling systems (e.g., innovation, production, distribution, support) brings both new challenges and opportunities to managing life cycles.
2. Effective <u>representation</u> of systems is at the heart of 300 years of revolutionary success that innovation has brought to humanity.
3. Emerging advances in Model-Based Systems Engineering (MBSE) support that more powerful representation of systems, bringing it into line with earlier science-supported engineering disciplines (e.g., mechanics, chemistry, electronics).
4. Contemporary PLM information systems can be directed to use those explicit model-based representations, if they are arranged to do so.
5. In dynamic or uncertain environments, agility across the life cycle is enhanced by explicit model-based representation of systems, as the means of capturing explicit learning and exploiting it.
6. Simply installing information technology does not guarantee success--the priority planning order is underlying information first, life cycle process second, and automation third.
7. During a time of advance and change in these areas, community and partnership provide effective means of better understanding and exploiting this landscape.

Discussion

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Speaker:

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Bill Schindel is co-lead of two global industry teams: (1) the System Patterns Challenge Team, part of the Model-Based Systems Engineering (MBSE) Initiative of the International Council on Systems Engineering (INCOSE), and (2) the INCOSE Agile Systems Engineering Life Cycle Model Project. His forty-year engineering career has included aerospace engineering with IBM Federal Systems, teaching engineering and mathematics at Rose-Hulman Institute of Technology, founding and leading a supplier of telecom carrier network control systems for the public network, and leading ICTT System Sciences, a systems engineering enterprise that has pioneered Pattern-Based Systems Engineering methods for transforming the productivity of the innovation process in medicine and health care, advanced manufacturing, aerospace, automotive, and consumer products. Bill is also president of the Crossroads of America (Indiana) chapter of INCOSE.

Attachments

(see also References for more sources)

“Interactions: Making the Heart of Systems Visible”, INCOSE Great Lakes Conference on Systems Engineering, 2013.

“Requirements Statements Are Transfer Functions: An Insight from Model-Based Systems Engineering”, *Proceedings of INCOSE 2005 International Symposium*, (2005).

“Accelerating MBSE Impacts Across the Enterprise: Model-Based S*Pattern”, to appear in *Proc. of INCOSE International Symposium IS2015*, Seattle, July, 2015.

“Abbreviated Systematica Glossary”, ICTT System Sciences, P3125, V4.2.2, 2013.

References

Representing Systems:

1. W. Schindel, “Requirements statements are transfer functions: An insight from model-based systems engineering”, *Proceedings of INCOSE 2005 International Symposium*, (2005).
2. W. Schindel, “What Is the Smallest Model of a System?”, *Proc. of the INCOSE 2011 International Symposium*, International Council on Systems Engineering (2011).
3. W. Schindel, “Interactions: Making the Heart of Systems Visible”, INCOSE Great Lakes Conference on Systems Engineering, 2013..
4. W. Schindel, “Maps or Itineraries? A Systems Engineering Insight from Ancient Navigators”, INCOSE Great Lakes Regional Conference, October, 2014.
5. W. Schindel, “System Life Cycle Trajectories: Tracking Innovation Paths Using System DNA”, INCOSE Great Lakes Regional Conference, October, 2014.
6. “Abbreviated Systematica Glossary”, ICTT System Sciences, P3125, V4.2.2, 2013.

Patterns; Pattern-Based Systems Engineering:

7. W. Schindel, “Pattern-Based Systems Engineering: An Extension of Model-Based SE”, INCOSE IS2005 Tutorial TIES 4, (2005).
8. J. Bradley, M. Hughes, and W. Schindel, “Optimizing Delivery of Global Pharmaceutical Packaging Solutions, Using Systems Engineering Patterns” Proceedings of the INCOSE 2010 International Symposium (2010).
9. W. Schindel, and V. Smith, “Results of applying a families-of-systems approach to systems engineering of product line families”, SAE International, Technical Report 2002-01-3086 (2002).

(Continued) ***Patterns; Pattern-Based Systems Engineering***

10. W. Schindel, “The Impact of ‘Dark Patterns’ On Uncertainty: Enhancing Adaptability In The Systems World”, INCOSE Great Lakes 2011 Conference, Dearborn, MI, 2011.
11. J. Sherey, “Capitalizing on Systems Engineering”, INCOSE IS2006, July, 2006.
12. W. Schindel, “Integrating Materials, Process, & Product Portfolios: Lessons from Pattern-Based Systems Engineering”, *Proc. of Society for the Advancement of Material and Process Engineering, 2012.*
13. Kahneman, D., *Thinking, Fast and Slow*, Farrar, Straus and Giroux, Publishers, 2011, ISBN-10: 0374275637.
14. Lewis, Michael, *Moneyball: The Art of Winning an Unfair Game*, Norton, New York, 2004.
15. W. Schindel, “Introduction to Pattern-Based Systems Engineering (PBSE)”, INCOSE Finger Lakes Chapter Webinar, April 26, 2012.
16. T. Peterson and W. Schindel, “Pattern-Based Systems Engineering: Leveraging Model-Based Systems Engineering for Cyber-Physical Systems”, NDIA GVSETS Conference, August, 2014.
17. Bill Schindel, Troy Peterson, “Introduction to Pattern-Based Systems Engineering (PBSE): Leveraging MBSE Techniques”, in Proc. of INCOSE 2013 Great Lakes Regional Conference on Systems Engineering, Tutorial, October, 2013.
18. W. Schindel, S. Sanyal, J. Sherey, S. Lewis, “Accelerating MBSE Impacts Across the Enterprise: Model-Based S*Pattern”, to appear in Proc. of INCOSE International Symposium IS2015, Seattle, July, 2015.
19. INCOSE Patterns Challenge Team, “PBSE Methodology Summary”, 2015
20. INCOSE Patterns Challenge Team web site: http://www.omgwiki.org/MBSE/doku.php?id=mbse:patterns:patterns

***Systems Engineering in Innovation*:**

21. W. Schindel, “Innovation as Emergence: Hybrid Agent Enablers for Evolutionary Competence” in *Complex Adaptive Systems*, Volume 1, Cihan H. Dagli, Editor in Chief, Elsevier, 2011
22. W. Schindel, S. Peffers, J. Hanson, J. Ahmed, W. Kline, “All Innovation is Innovation of Systems : An Integrated 3-D Model of Innovation Competencies ”, Proc. of ASEE 2011 Conference (2011).
23. W. Schindel, “Systems of Innovation II: The Emergence of Purpose”, *Proceedings of INCOSE 2013 International Symposium* (2013).
24. INCOSE System Sciences Working Group, Systems of Innovation Project web site: https://sites.google.com/site/syssciwg/projects/o-systems-of-innovation
25. C. Mims, “A New Dawn for Gadgets”, *The Wall Street Journal*, p B1, March 2015.

***Other Systems Life Cycle Management References*:**

26. ISO/IEC 15288: Systems Engineering—System Life Cycle Processes. International Standards Organization (2008). (Updated version will release in 2015)
27. ISO/IEC TR 24748-:1 Systems and Software Engineering—Life Cycle Management, Part 1: Gide for Life Cycle Management”, 2010.
28. *INCOSE Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*, Version 3.2, International Council on Systems Engineering (2010). (Updated version will release in 2015.)
29. W. Schindel, “Failure Analysis: Insights from Model-Based Systems Engineering”, *Proceedings of INCOSE 2010 Symposium*, July 2010.
30. Friedenthal, S., et al, “A World in Motion: Systems Engineering Vision 2025”, INCOSE, 2014
31. INCOSE Agile Systems Engineering Life Cycle Model Project web site: http://www.parshift.com/ASELCM/Home.html
32. Web site of Open Services for Life Cycle Collaboration (OSLC) http://open-services.net/

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Product Service System Patterns	**Product Distribution System Patterns**	**Plant Operations & Maintenance System Patterns**	**Oil Filter Pattern**
Life Cycle Management System Patterns	**Production Material Handling Patterns**	**Engine Controls Patterns**	**Military Radio Systems Pattern**
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