34th Annual INCOSE international symposium

hybrid event

Dublin, Ireland
July 2 - 6, 2024

Preparing for the Digital Thread and Machine Learning

All Decisions Are Reconciliations of Inconsistencies

V1.2.4

Contents

- Decisions Across the Life Cycle of Systems
- Consistency Management Patterns
- The Consistency Management Stack
- Preparing for the Digital Thread and Machine Learning
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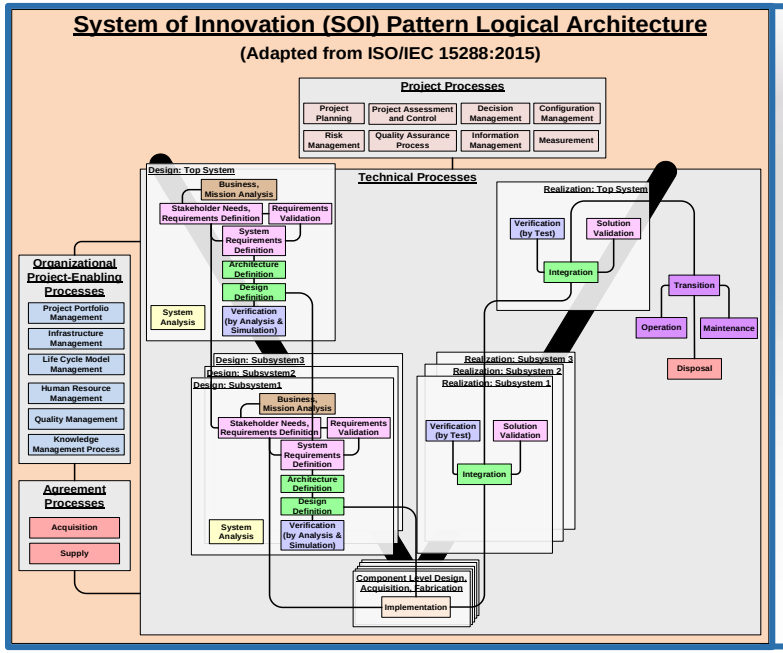
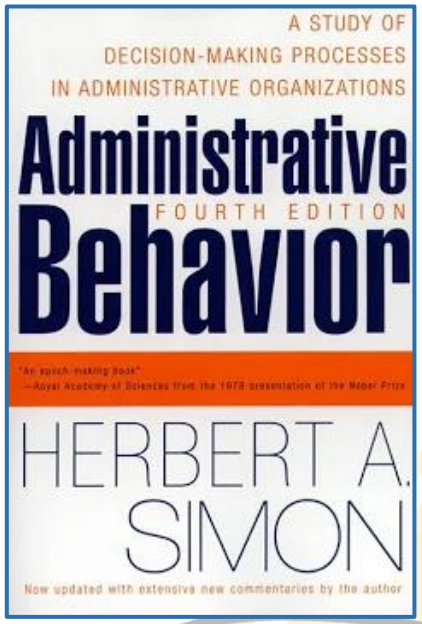
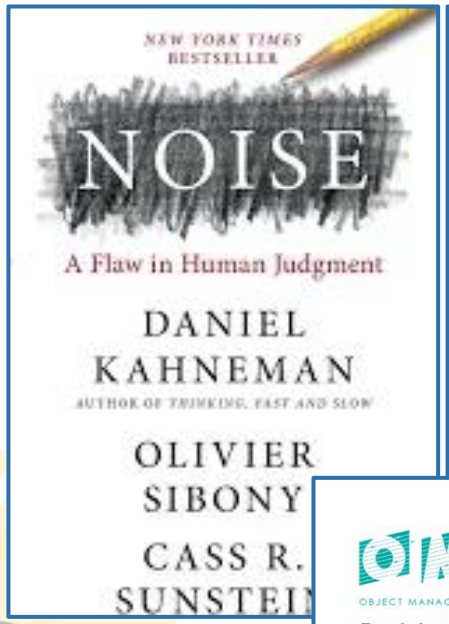
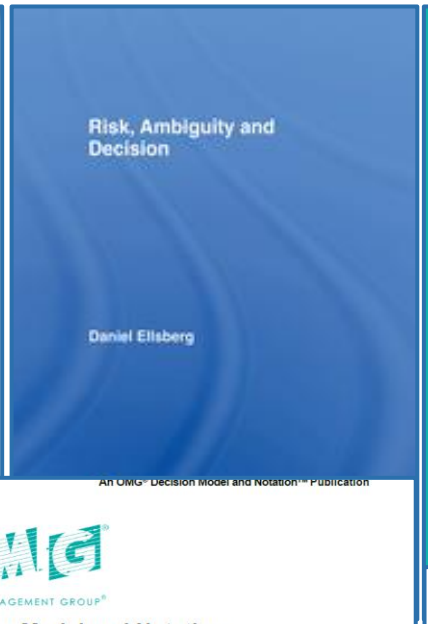
Decisions across the life cycle of systems

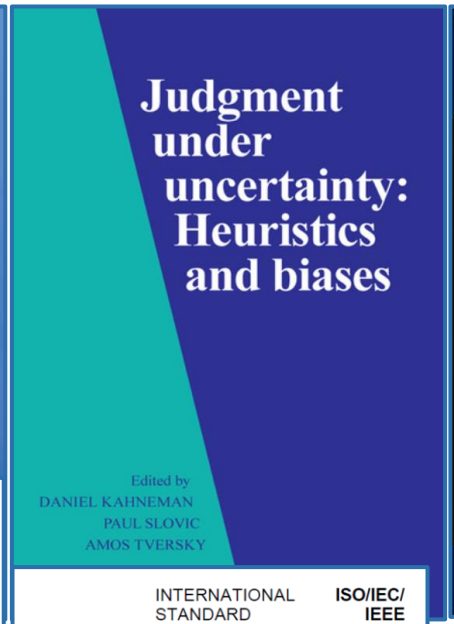


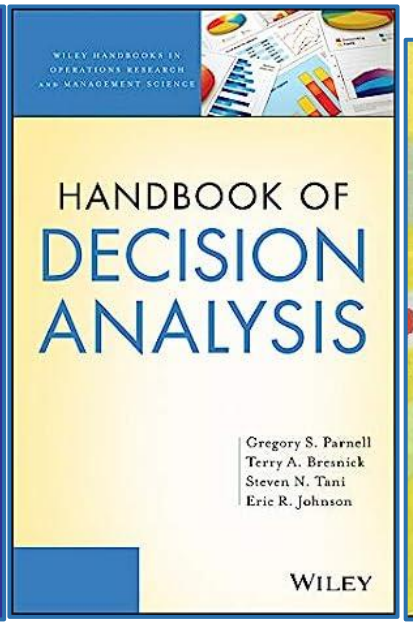
Decision Analysis: Subject of Extensive Historical Work, Multiple Nobel Prizes, Numerous Theories, Pragmatics, References

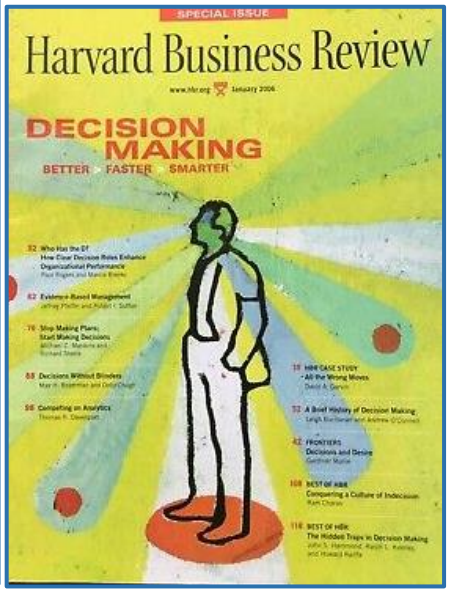


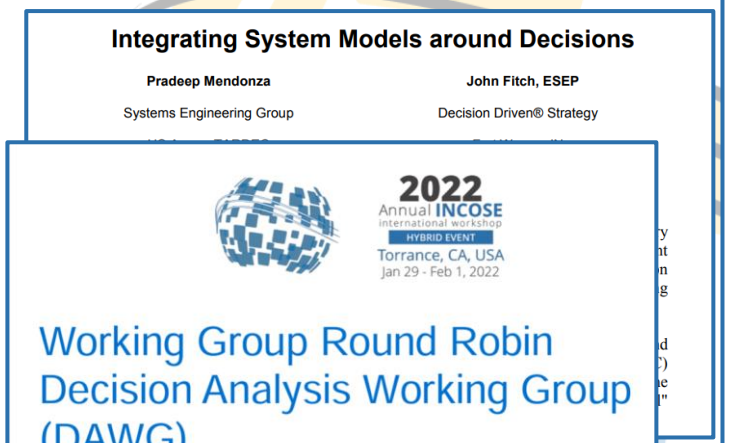


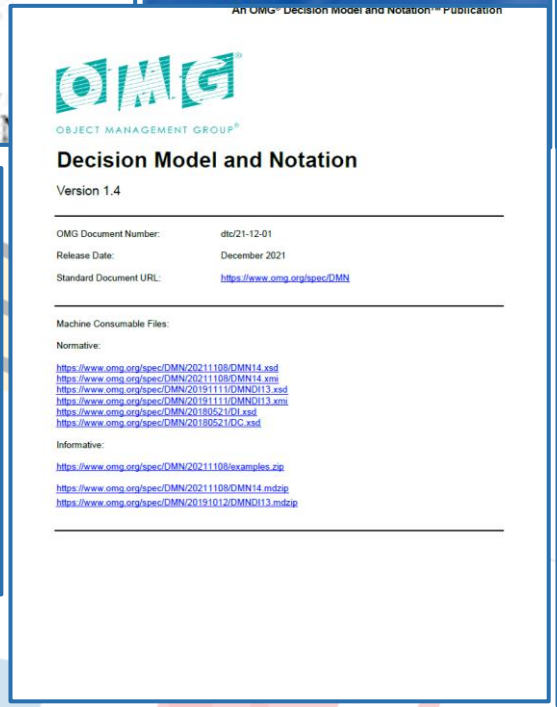


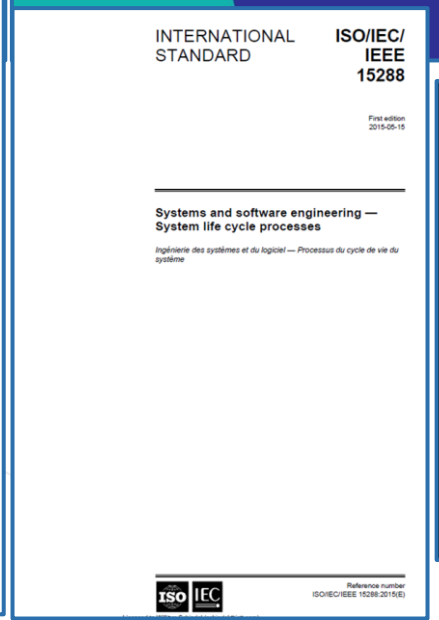


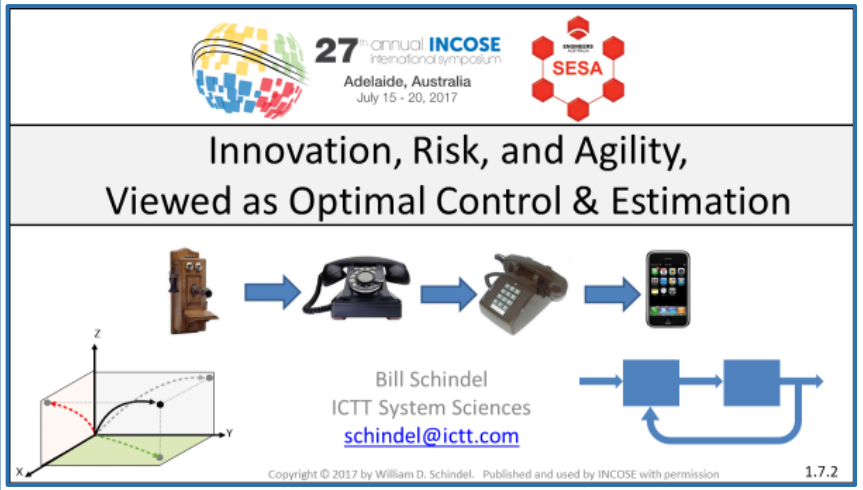






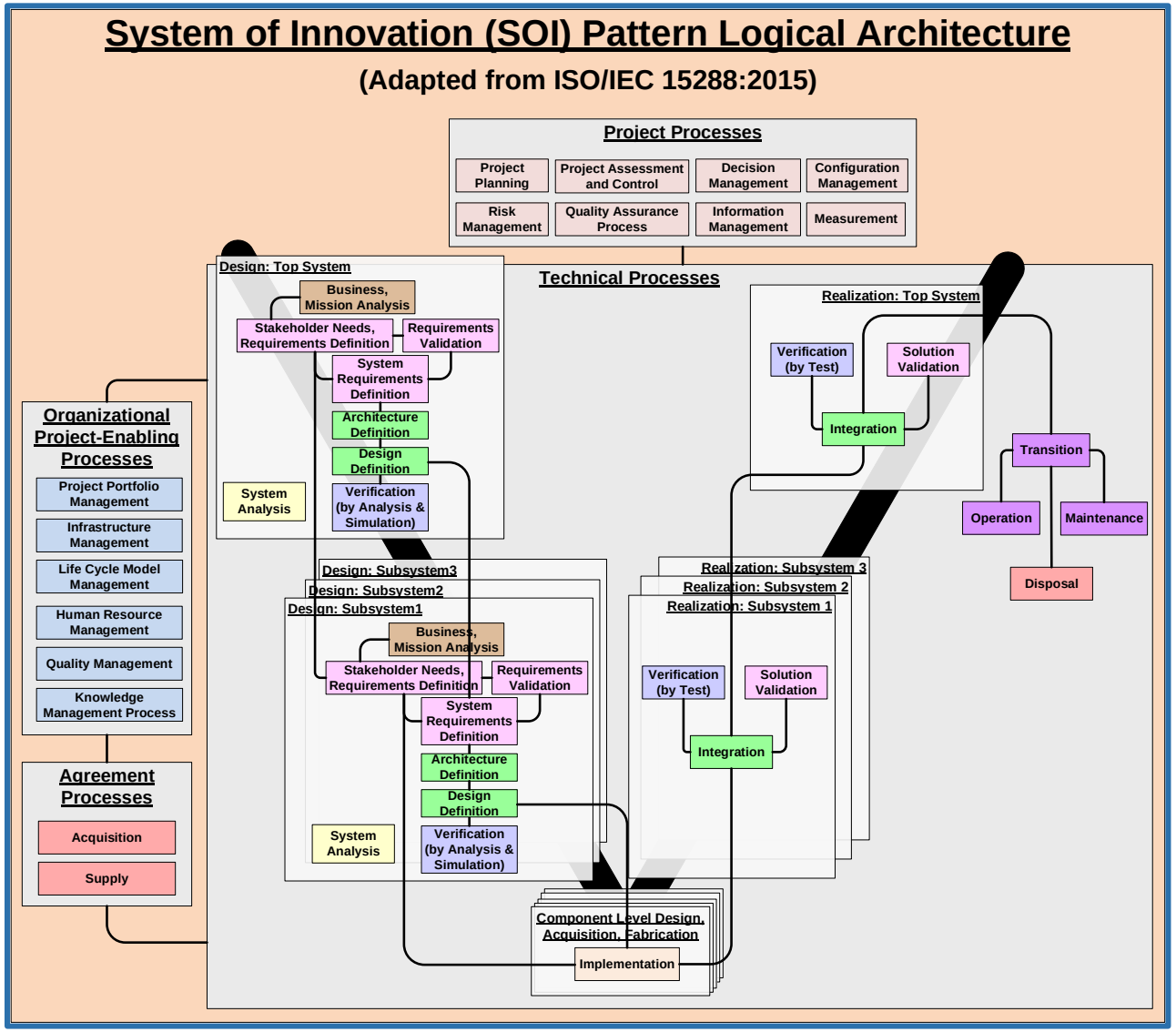


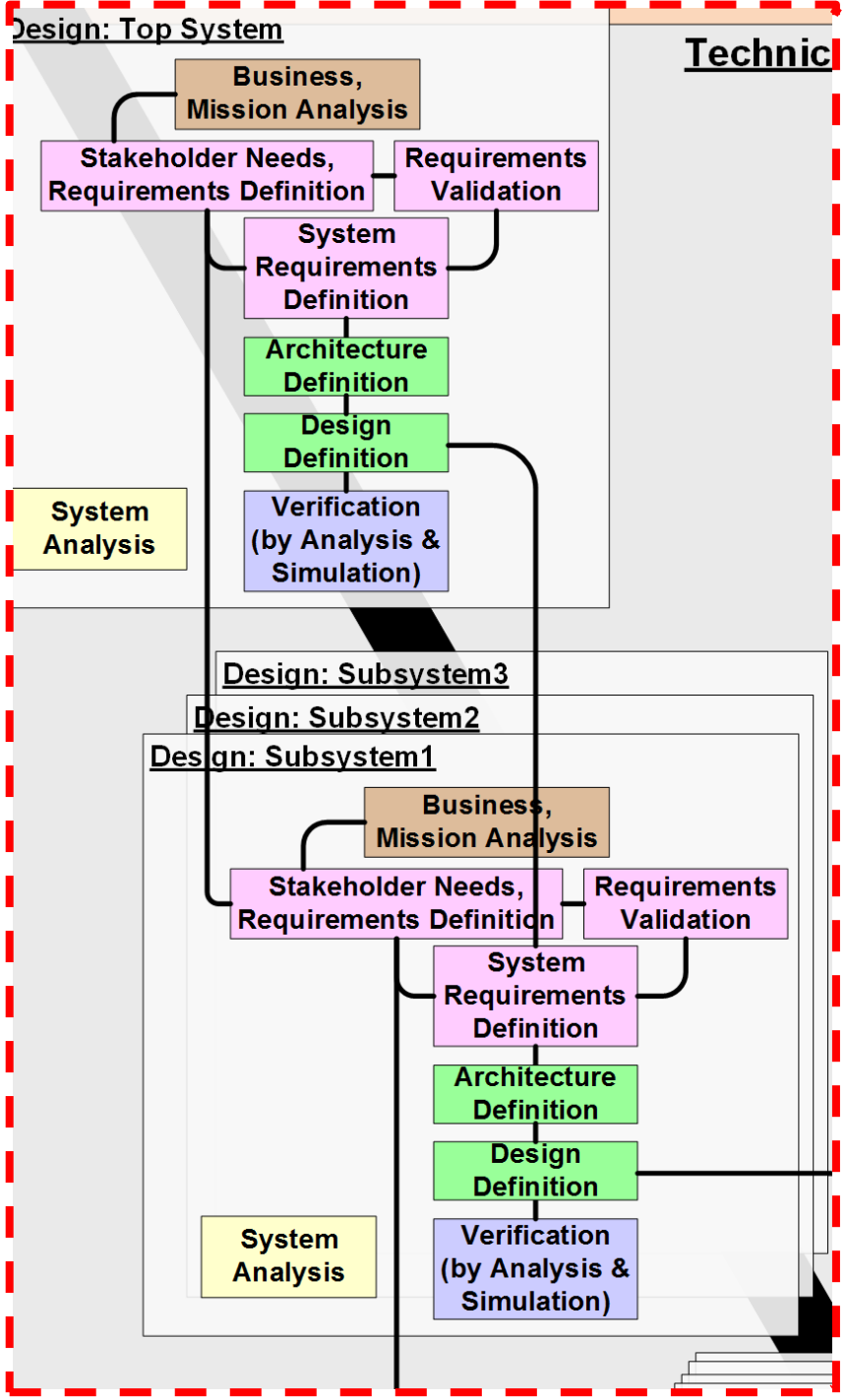


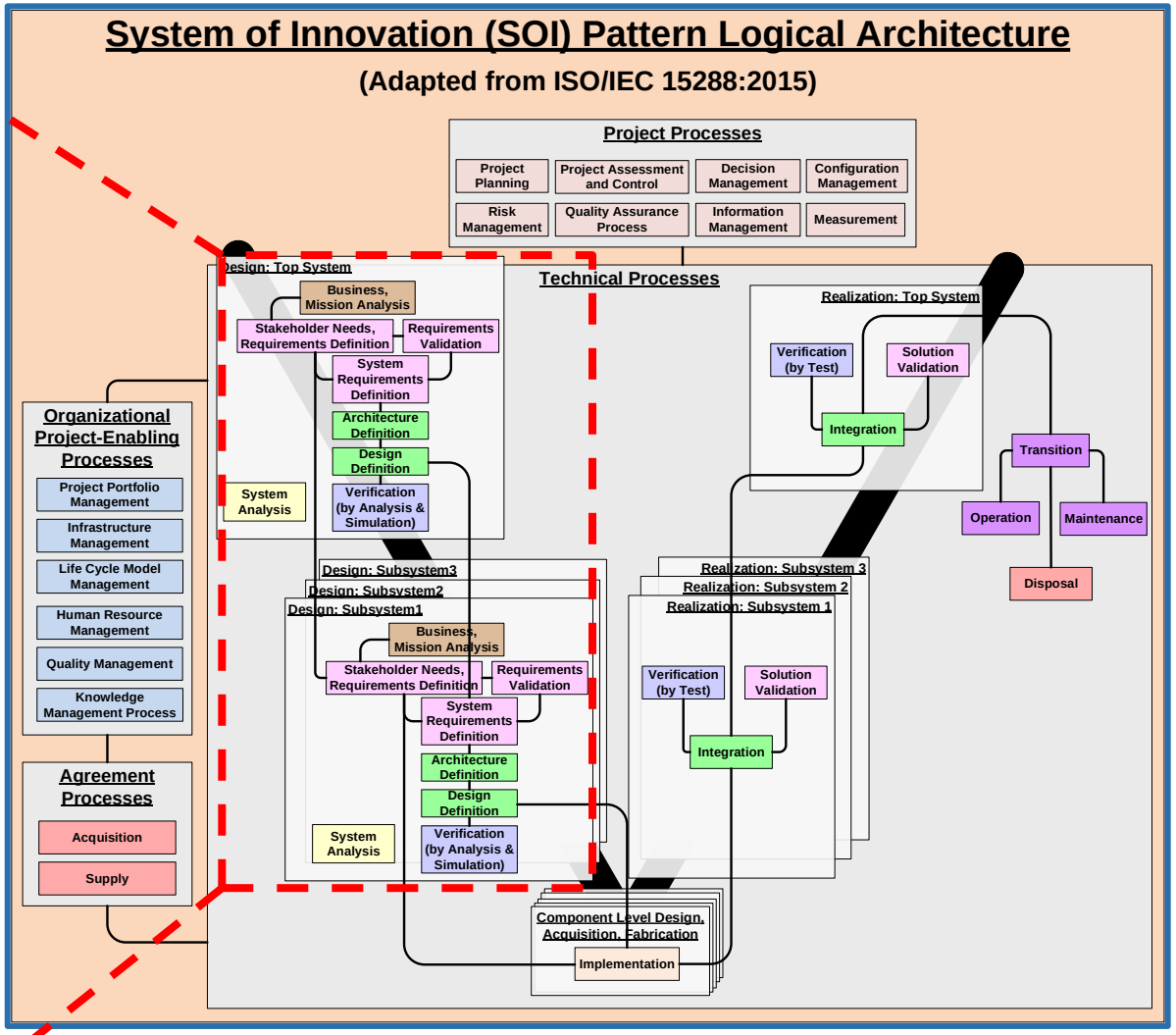


Decision Analysis: Special cases of interest

- The Patterns Working Group's interest in Decisions has been limited to a focus on the decisions which are made across managing the life cycle of systems; see also--
  - See INCOSE SE Handbook
  - ISO/IEC 15288
  - Work by the Decision Analysis WG
- Even those decisions are still relatively diverse—but they are not "decisions in general".
- So, what recurring pattern content can be discerned?





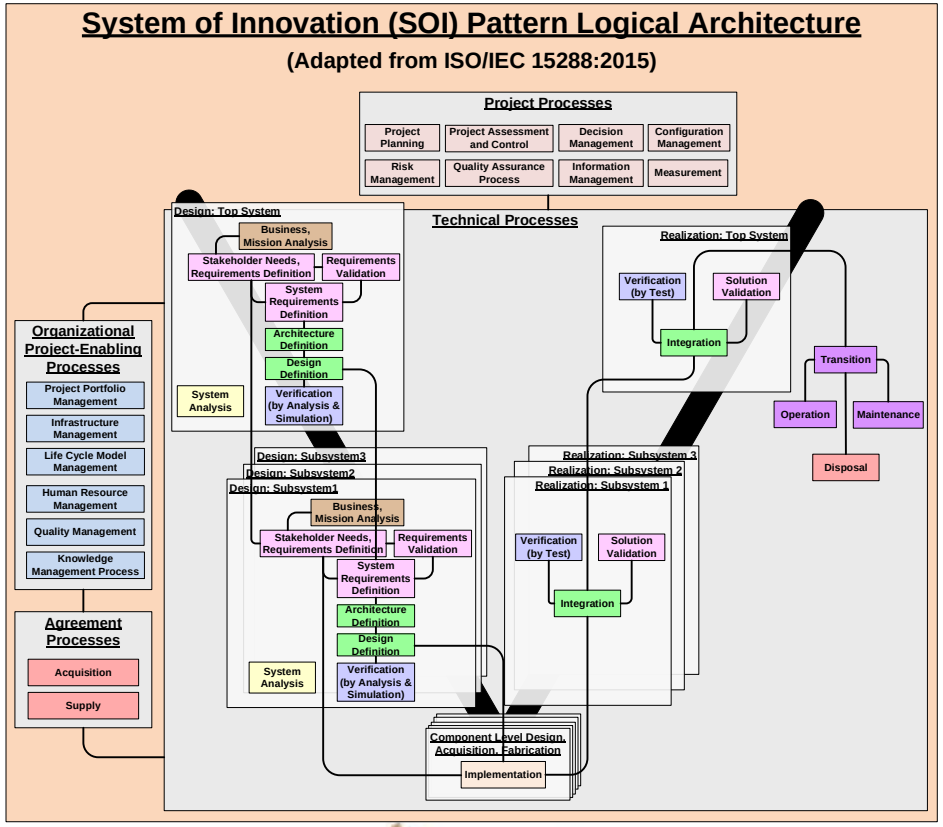


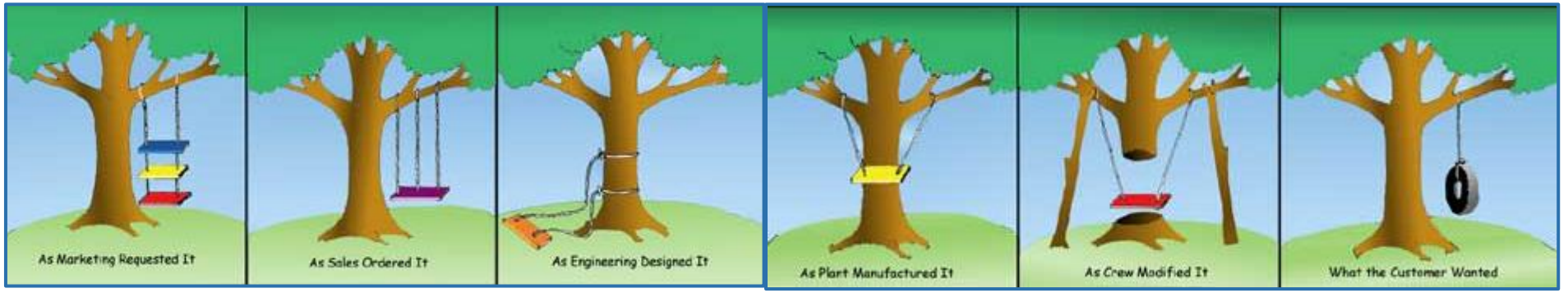
Examples: “Stage Gate” and “Agile Development” decisions seem diverse by nature—but how are they also abstractly similar?

Consistency Management Patterns

"SE Vee model" and "Digital Thread" visually remind us that engineering and other parts of the system life cycle are heavily concerned with:

- –Creating consistent information, or . . .
- –Finding and resolving gaps, shortcomings, or inconsistencies in that information.

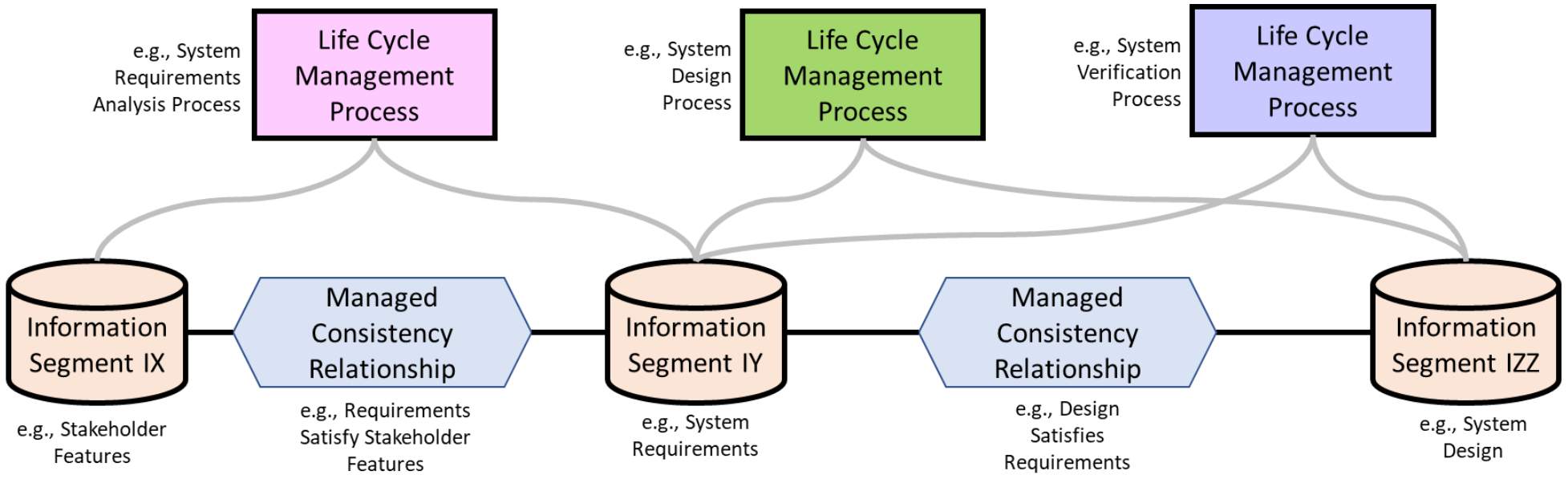


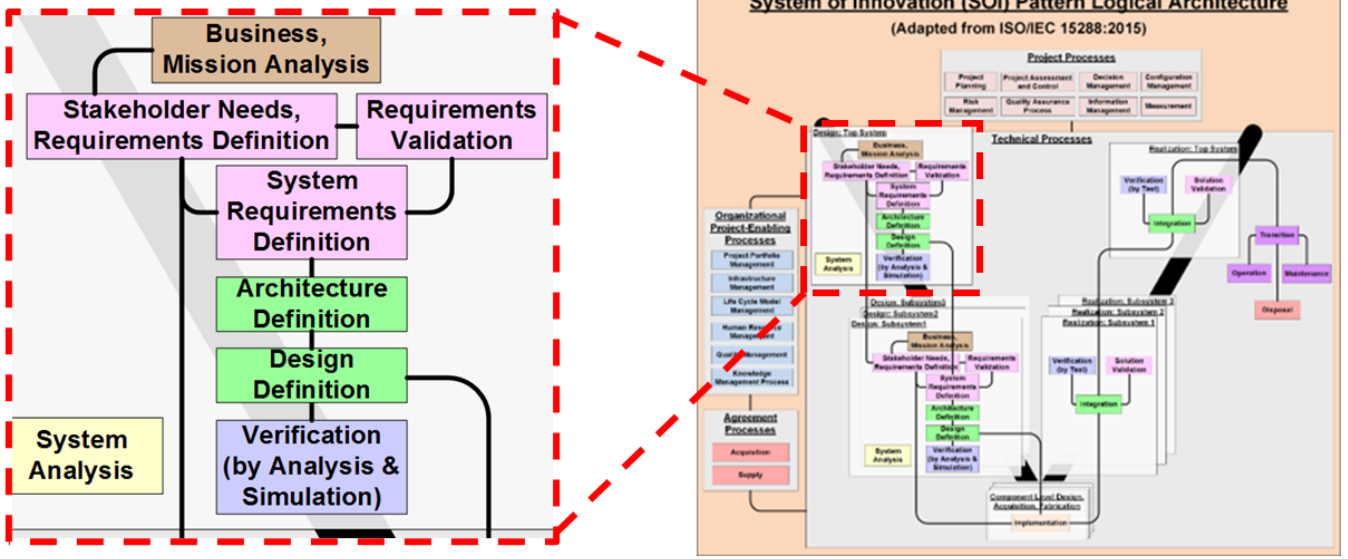


Examples of Managed Consistencies

- Consistency of system requirements with stakeholder needs (requirements validation)
- Consistency of system designs with system requirements (design verification)
- Consistency of virtual simulations with empirical measurements (model VVUQ)
- Consistency of system component production with system design
- Consistency of real system performance with system requirements
- Consistency of system operation with system requirements and design
- Consistency of system sustainment with system requirements and design
- Consistencies of many aspects with applicable technical standards, regulation, and law
- Consistencies of System 2 ecosystem partners, as to capabilities, incentives, conflicts
- Consistencies of many aspects with learned experiences, formal patterns of requirements and design, physical science, product line rules, architectural frameworks, shared ontologies, domain specific languages, and model semantics
- Future: Managed consistencies of the Digital Thread and Digital Twin
- Many other types of consistencies, recorded along "***consistency threads***" . . .

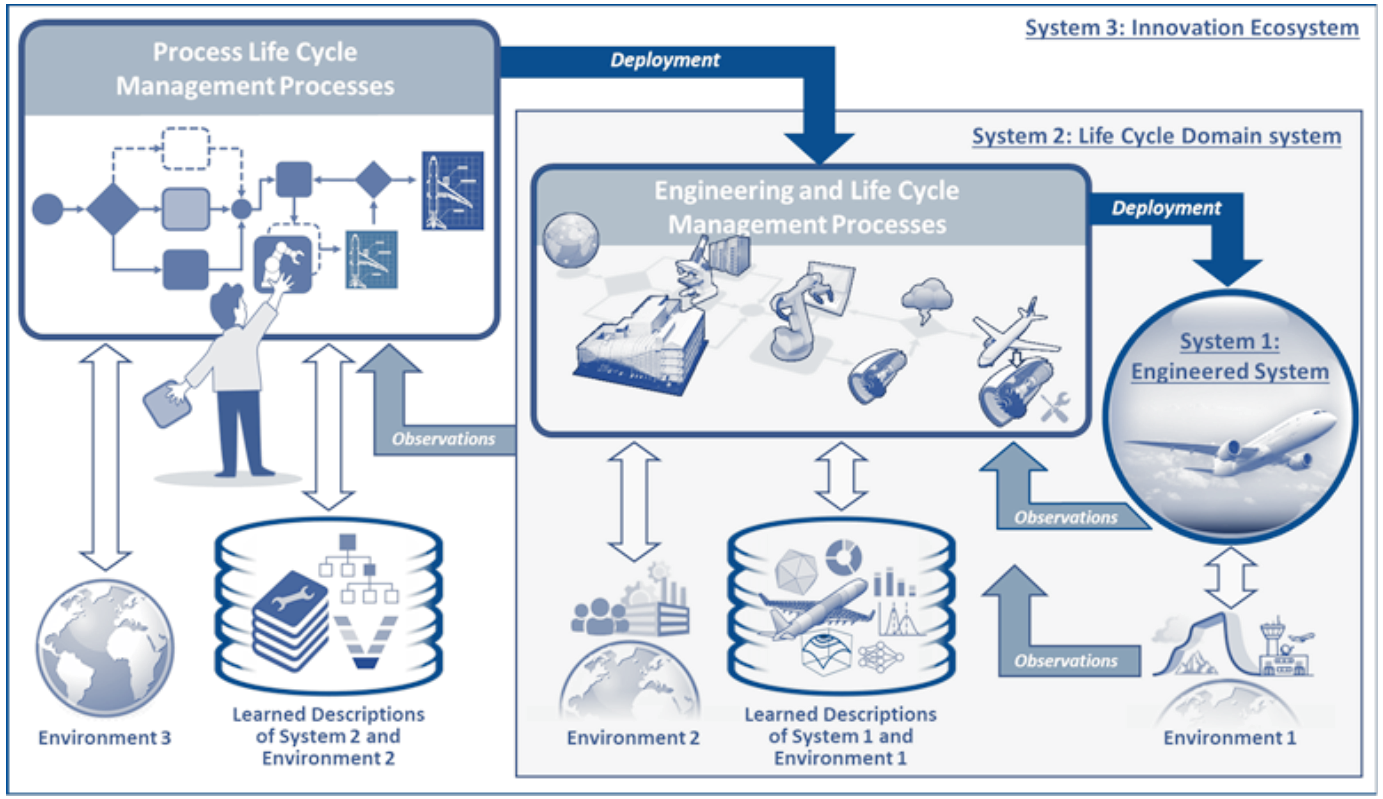
Example of Section of Consistency Thread





Ecosystem Patterns of Consistency Management

- Consistency Management can be studied as part of the larger Innovation Ecosystem Pattern (the Agile SE Life Cycle Management (ASELCM) Pattern.
- That descriptive, not prescriptive, configurable pattern describes any system of innovation, and helps us understand the nature of Consistency Management:



American Institute of Aeronautics and Astronautics (AIAA) has released both its Digital Thread & Digital Twin Reference Models

June, 2023

Both of these are based on the INCOSE MBSE Patterns Working Group Innovation Ecosystem (ASELCM) Pattern.

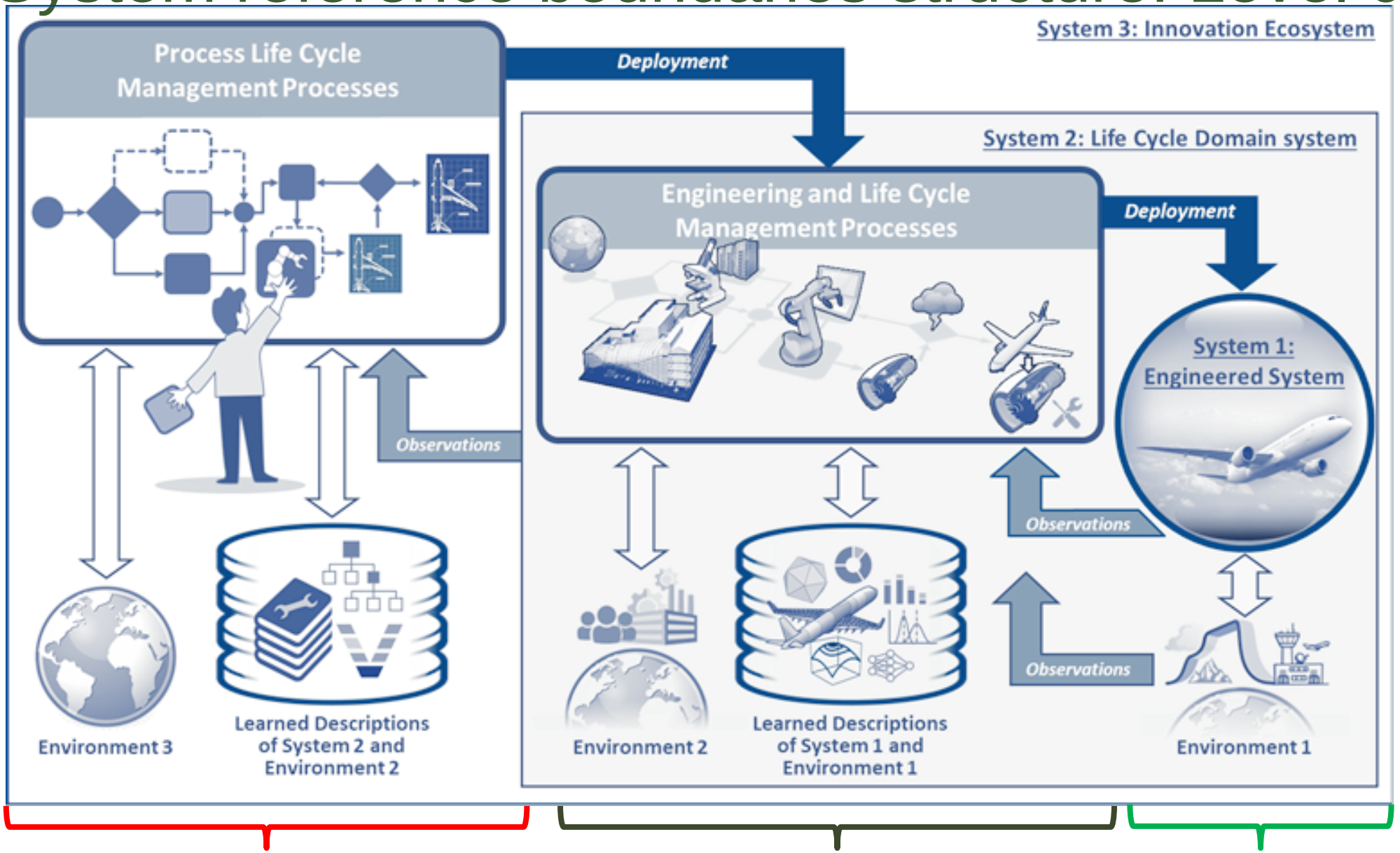
Click to Download Related INCOSE Publication

January, 2023

Click to Download AIAA Digital Thread Reference Model

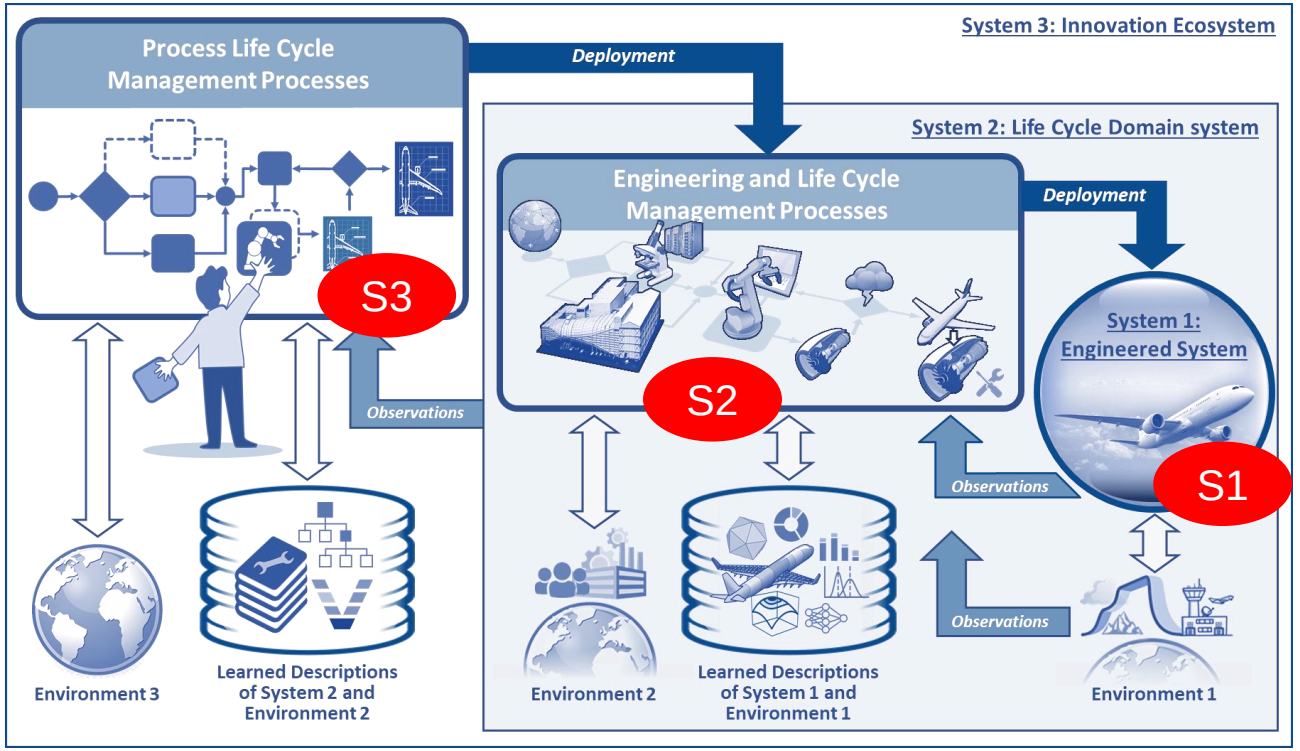
Click to Download AIAA Digital Twin Reference Model

System reference boundaries structure: Level 0



System 3: Life Cycle Manager of System 2 | **System 2: Life Cycle Manager of System 1** | **System 1: Engineered System**

INCOSE ASELCM Pattern, Level 0



System 1--Engineered System (S1):

- System to be planned, designed, analyzed, produced, operated, sustained, improved.
- Manufactured product, operated service, or other system of interacting components.

System 2—Life Cycle Domain System (S2):

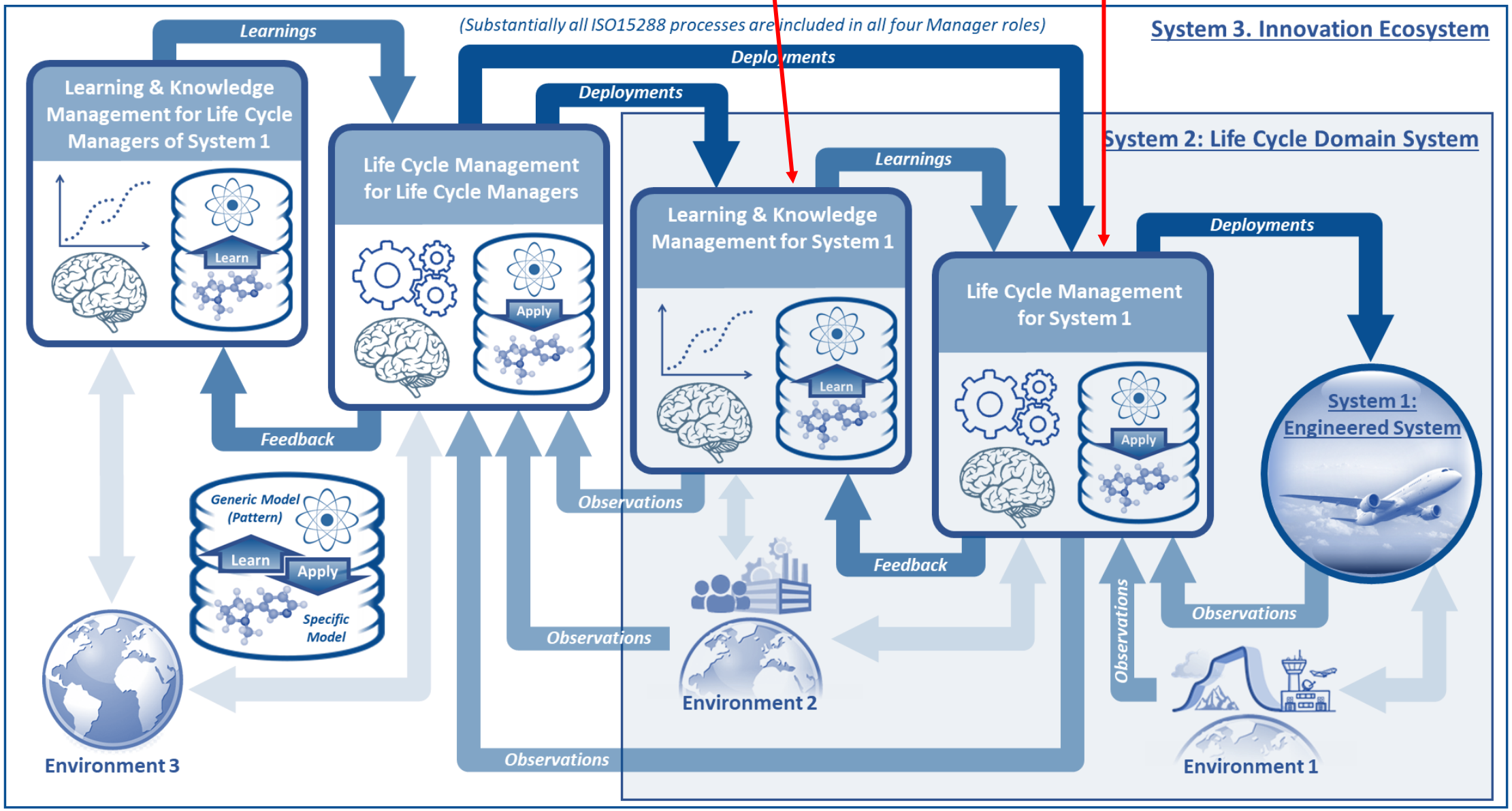
- The total lifetime interaction environment of System 1.
- Includes engineering, production, distribution and deployment, support, operations.
- Responsible to observe & learn about System 1 and its environment, and to apply that learning.
- Contains all the life cycle management processes of ISO 15288.

System 3—Innovation Ecosystem (S3):

- The total lifetime interaction environment of System 2.
- Responsible to plan, analyze, construct, deploy, observe, and support System 2.
- Responsible to represent (document) System 2 engineering, production, distribution, support.
- Responsible to observe & learn about System 2 and its environment, and to apply that learning.

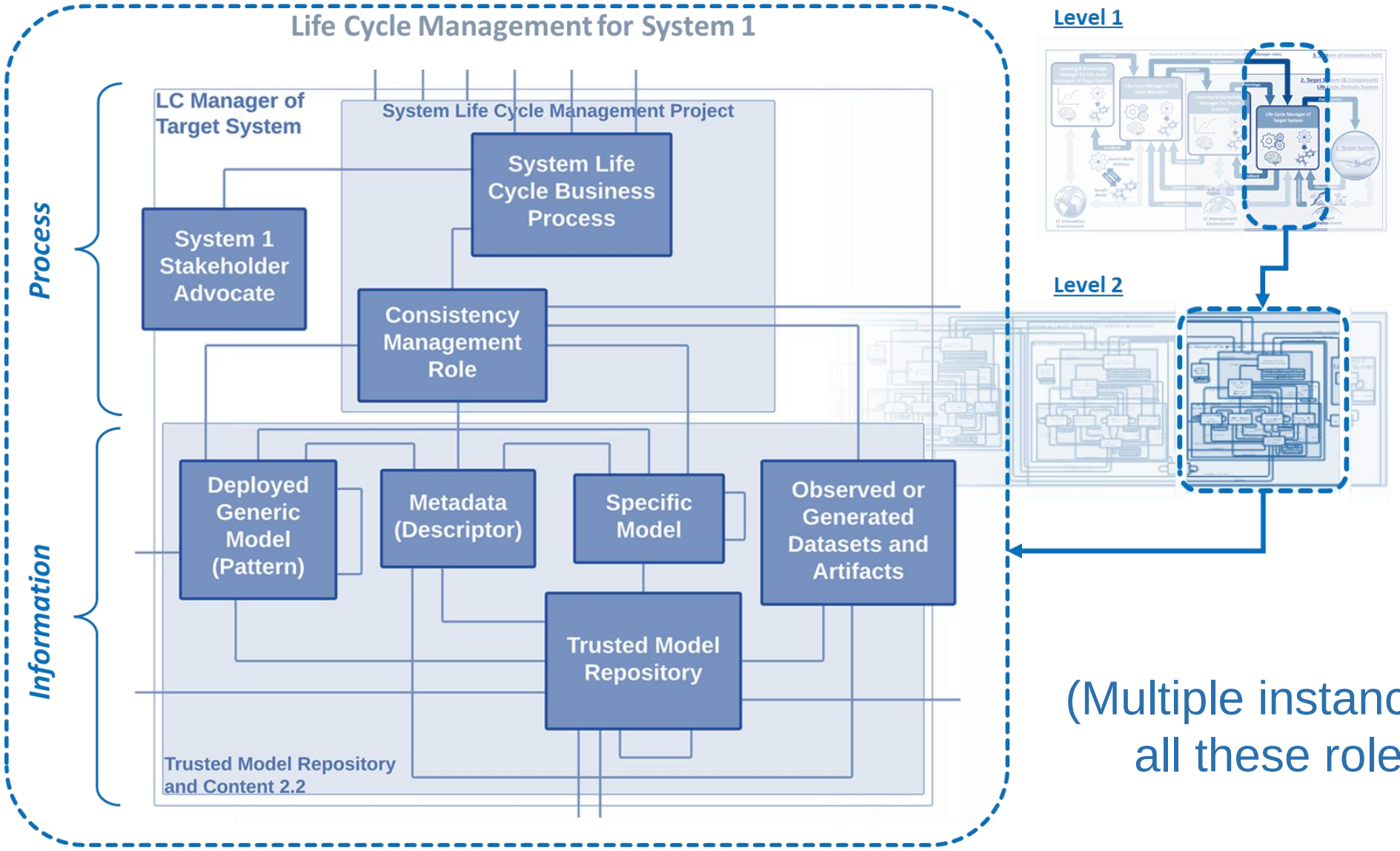
INCOSE ASELCM Pattern, Level 1

(Separation of learning new information from acting on what is already known.)

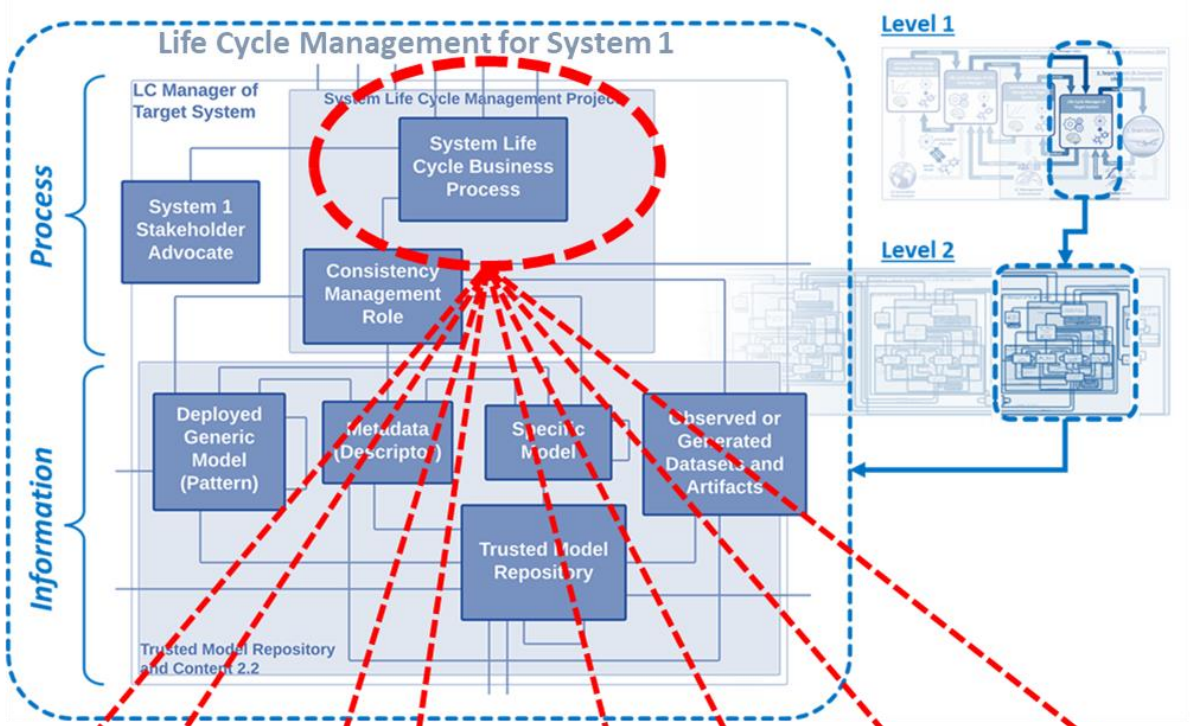


INCOSE ASELCM Pattern, Level 2

(Segment for Application of "Already Learned" Information)



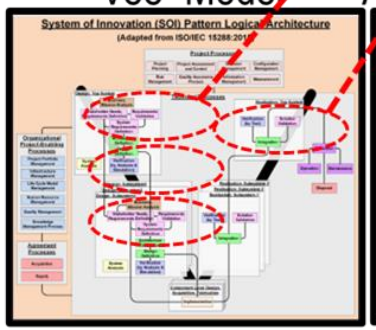
(Multiple instances of all these roles)



- There are typically multiple process-specific instances of the System Life Cycle Business Process, describing local enterprise processes.
- Our interest here is the "Digital Engineering Underbelly" of those processes, described by the other classes shown.

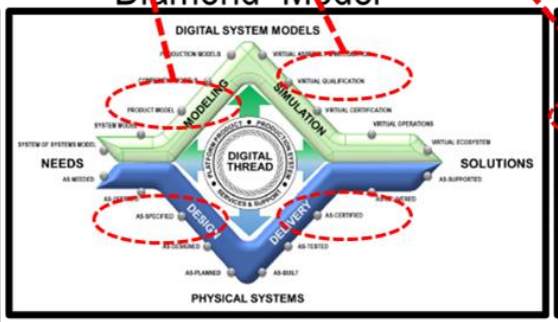
Configurable to specific life cycle management models---

ISO15288 Life Cycle "Vee" Model[1]

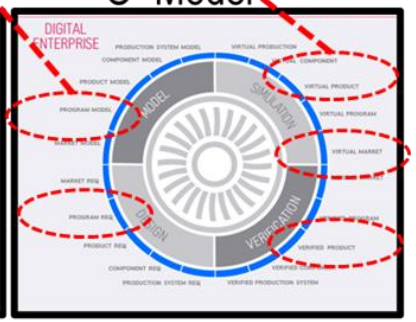


DoD 5000 Defense Acquisition Life Cycle Model[2]

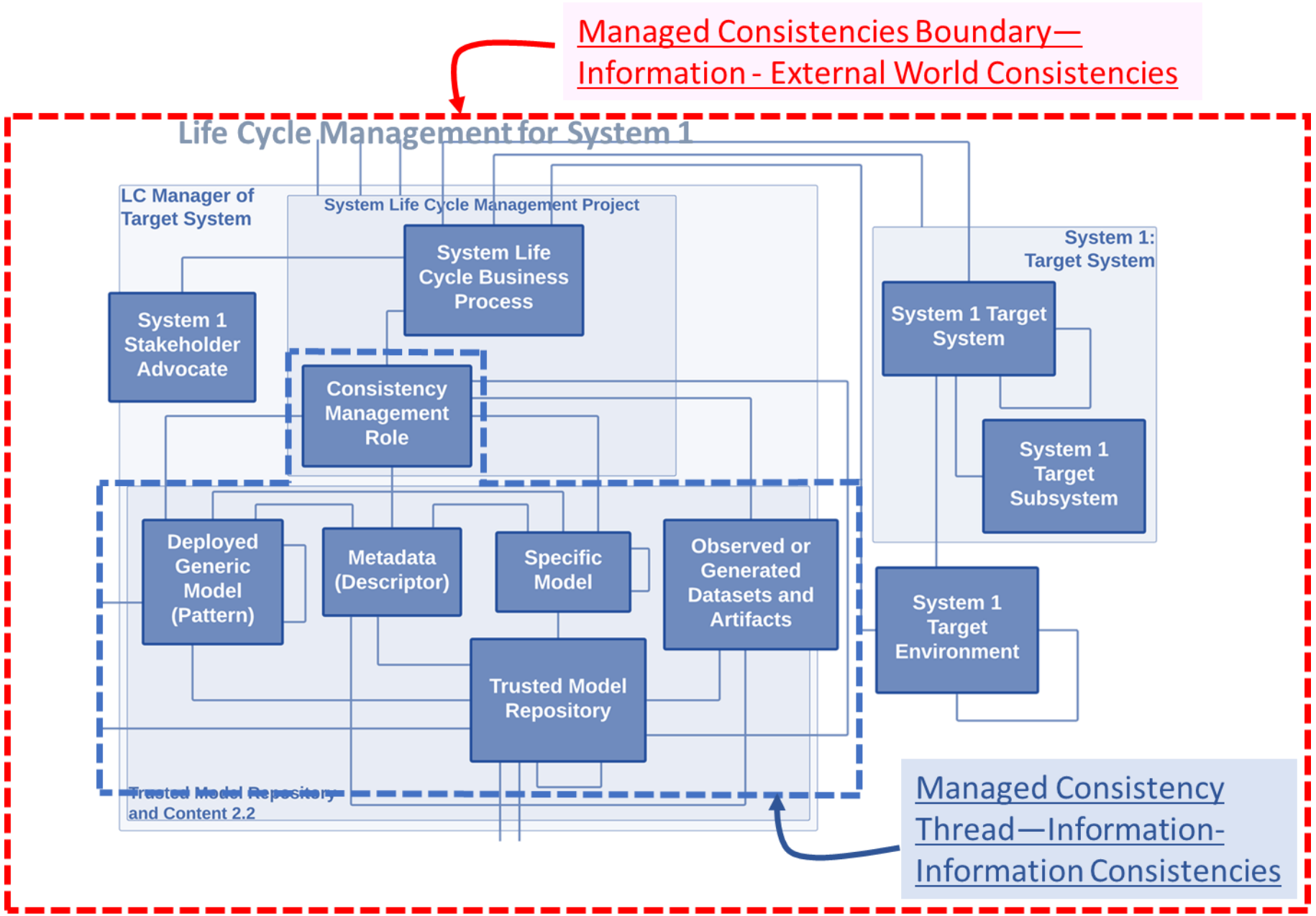
Boeing "Diamond" Model[3]



Rolls-Royce "O" Model[4]

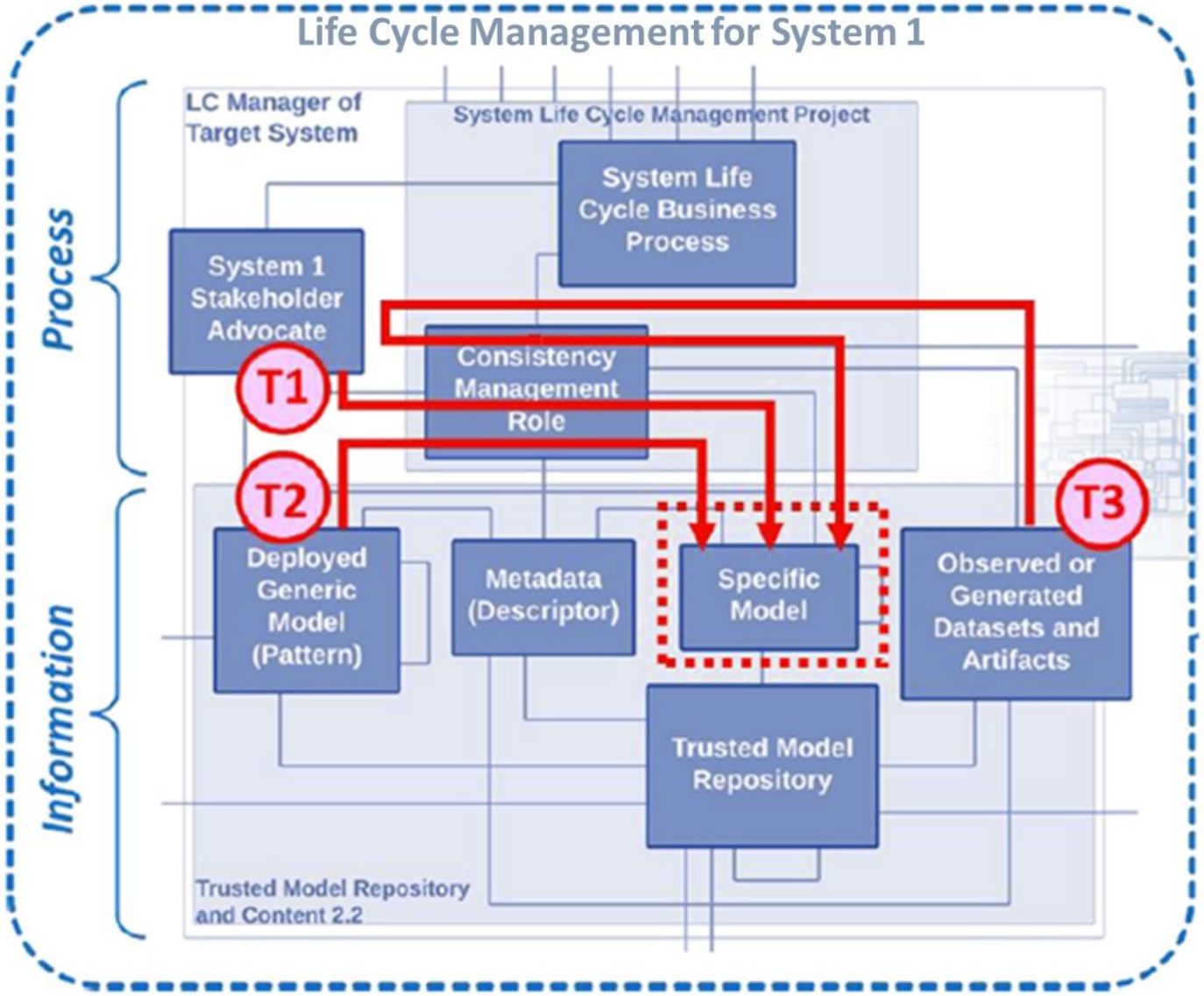


Excerpted or adapted from: (1) ISO15288 and INCOSE SE Handbook; (2) DoD5000 Wall Chart; (3) AIAA Sci Tech, 01.2020, J. Hatakeyama; (4) AIAA DEIC Digital Twin Subcommittee, 04.08.19 Donaldson, Flay, French, Matlik, Myer, Pond, Randjelovic



Managed Consistency Thread System Boundaries

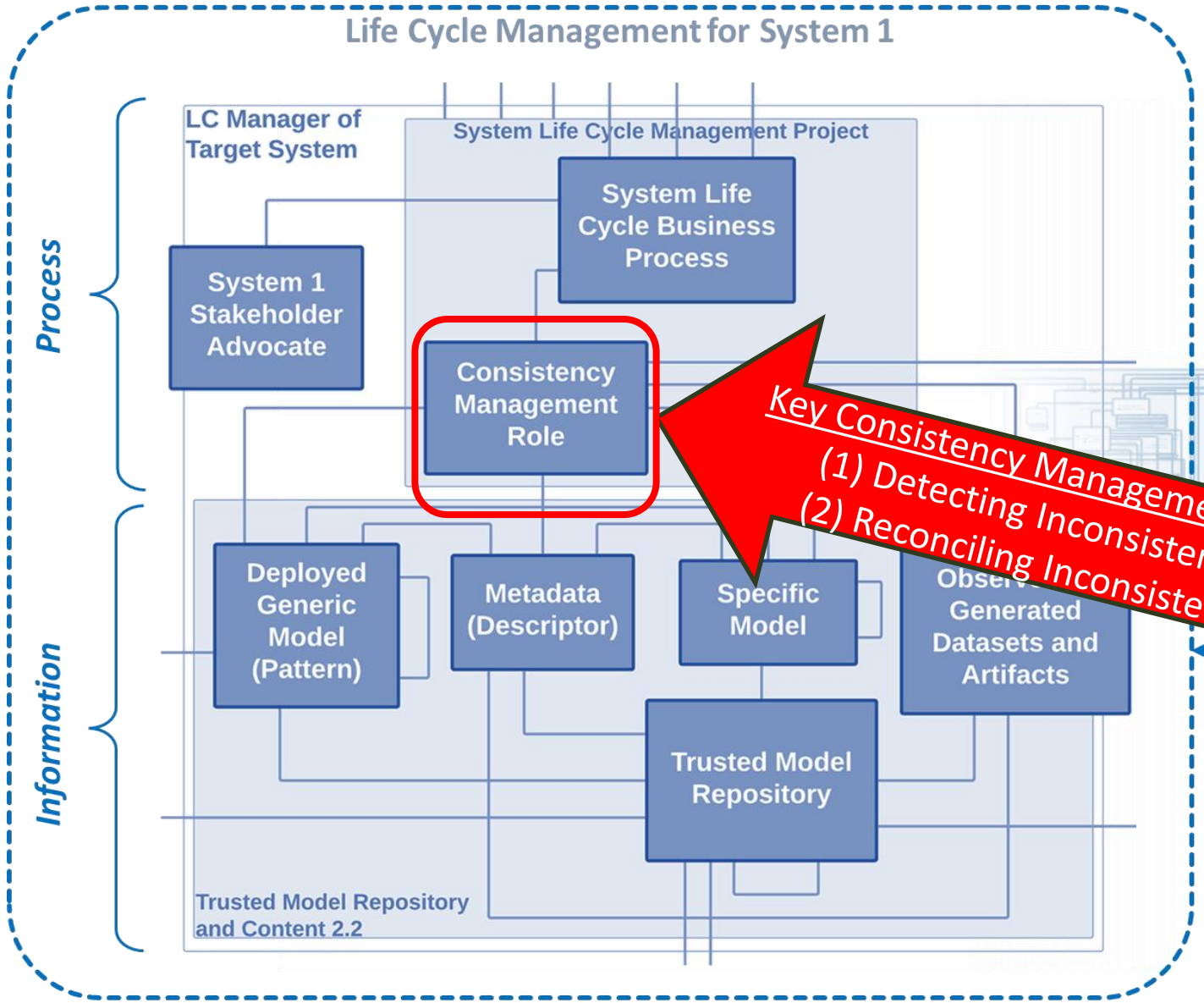
These 3 sources will disagree frequently—reconciling those differences is a major part of life cycle management.

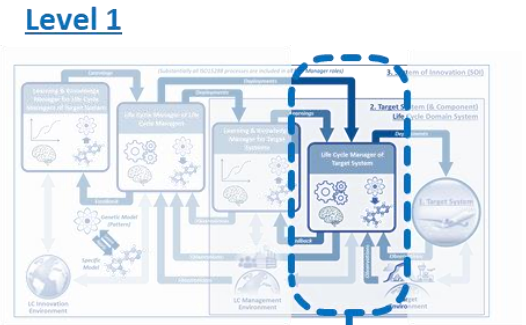


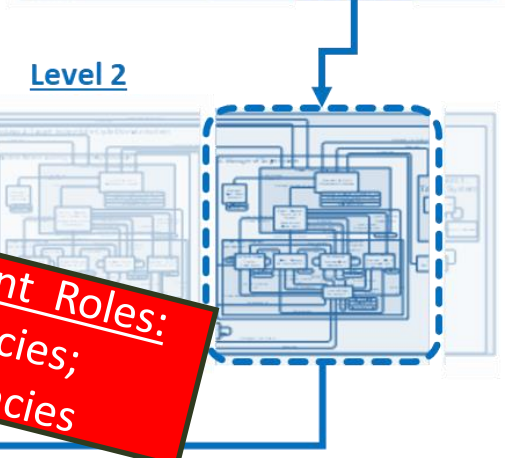
Three Main Authority Sources:

- **T1** What stakeholders now say they want.
- **T2** What past learning says.
- **T3** What the observed real world now says.

The Consistency Management Stack







Key Consistency Management Roles:
(1) Detecting Inconsistencies;
(2) Reconciling Inconsistencies

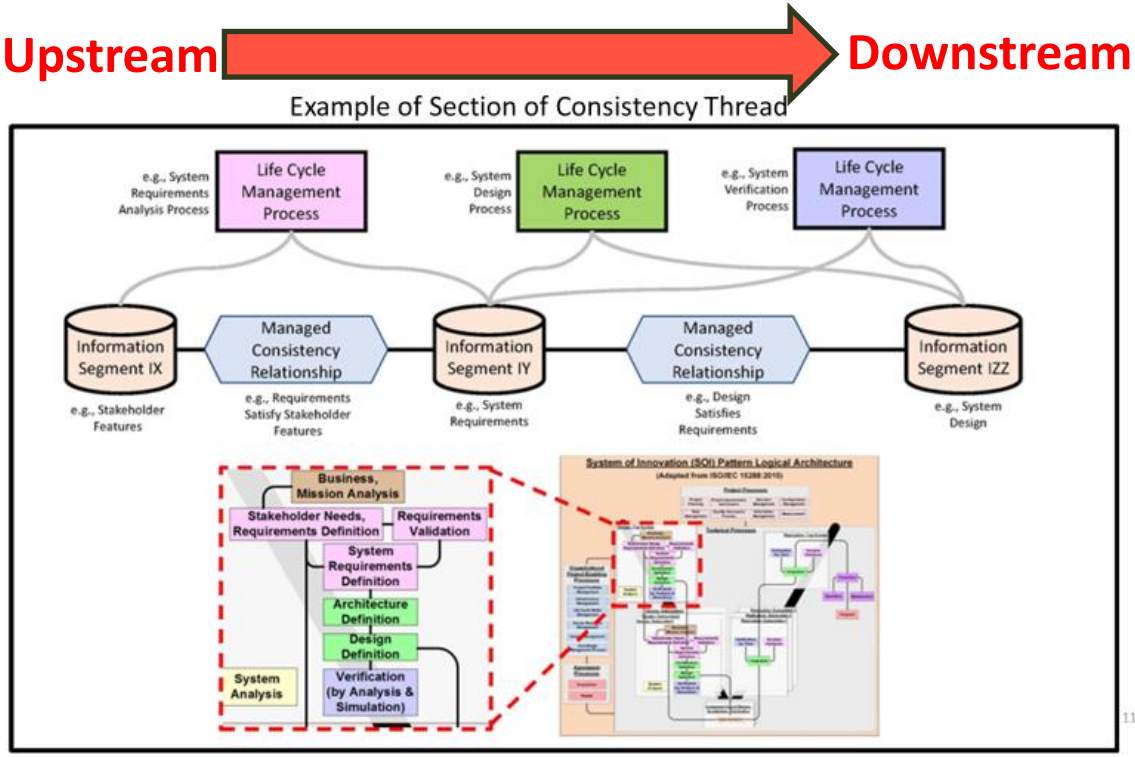
Evolving Roles for Human & Automated Agents:

(1) **Detecting Inconsistencies**: Near-term opportunity for automated assistants.

(2) **Reconciling Inconsistencies**: Traditionally a human strength; now an opportunity for automated assistants. *With Bus Proc concurrence!*

Upstream and downstream

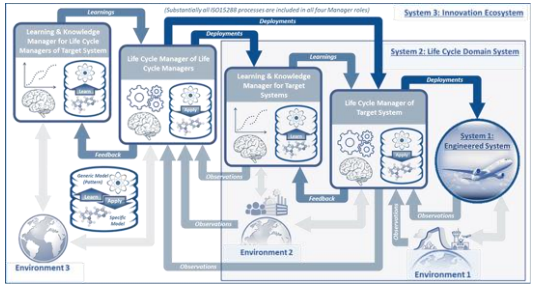
- Think only of information, not process:
  - As if the processes were all concurrent.
- Don't think linear performance of processes with input and outputs—instead, think of "upstream" information that is "more fixed", and downstream information that is "more variable" and whose values are "more determined" by the upstream information:



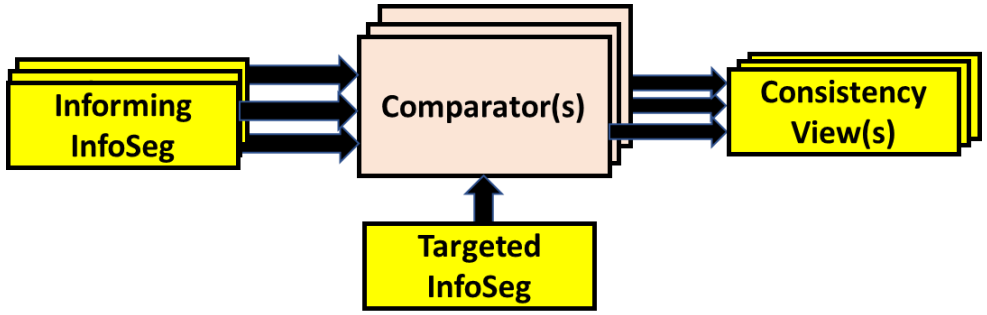
  - For example, Design Information is downstream from Requirements Information.

- **HOWEVER**: The above term "more" indicates that the flow is not 100% from upstream to downstream—sometimes we have feedback from downstream that causes changes in upstream information:
  - For example, sometimes Requirements have to be adjusted/compromised in order to accommodate feedback from downstream Design Information, such as feasibility or cost.

Architectural Pattern for Human and Machine Learning



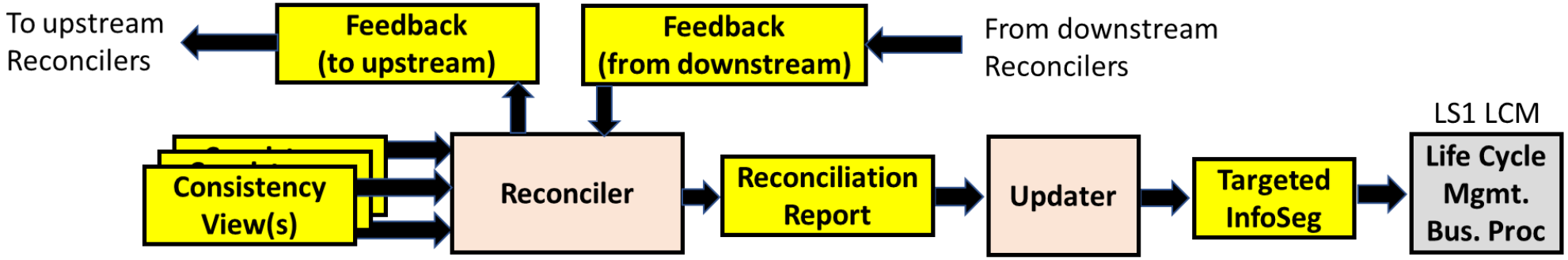
- Roles described can be allocated to humans and (if up to it) to automated agents, including hybrids.
- Includes hybrid human-machine collaboration roles for:
  - **Inconsistency Detection**: Higher duty cycle even if simpler:



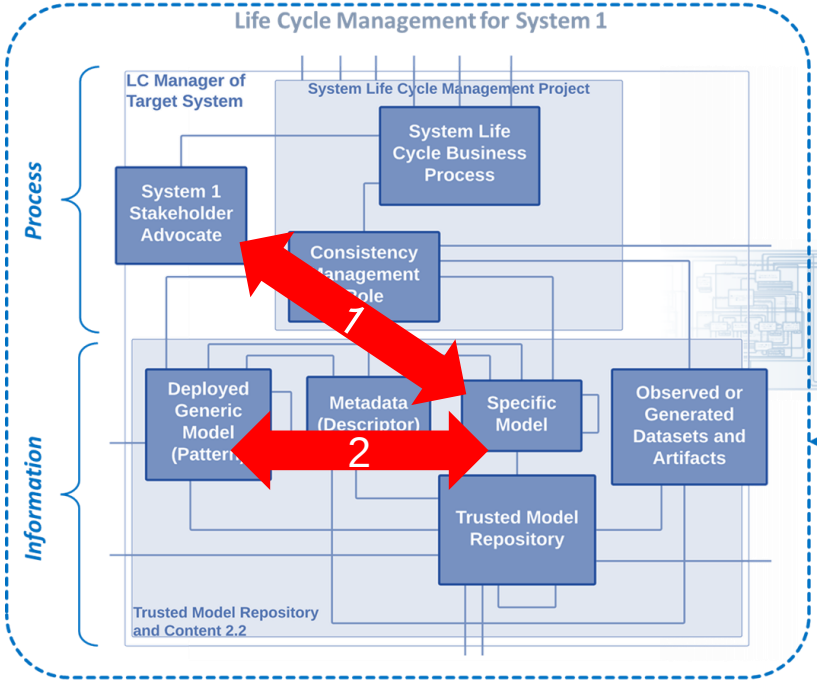
← Demonstrated in INCOSE ST4SE Project, 2022:

Link to ST4SE Project Report

  - **Inconsistency Reconciliation**: Historically the domain of humans, a lower duty cycle opportunity for machine assistance based on learned patterns:



Examples of leading edge applications to date



- A <u>Consistency Management perspective</u> helps us "push the envelope" in identifying opportunities to improve innovation decisions / performance.
- Two classes of <u>existing</u> leading edge applications--

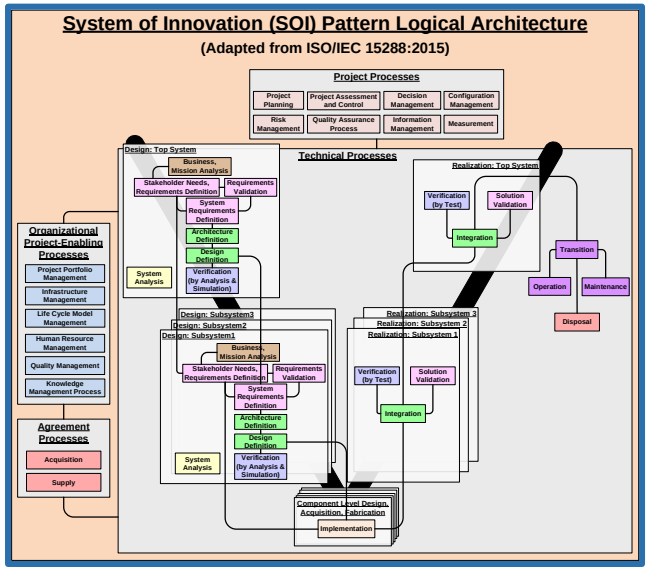
1 <u>Faster discovery of stakeholder needs and opinions</u>:
A revolution in "experiments" is driving innovation better than design ideas alone--

- Schrage, M., *The Innovator's Hypothesis: How Cheap Experiments Are Worth More Than Good Ideas*, MIT Press, 2014.
- Manzi, J., *Uncontrolled: The Surprising Payoff of Trial-and-Error for Business, Politics, and Society,* Basic Books, 2012.

2 <u>Machine learning of patterns applicable to manufacturing decisions</u>--

- Tuv, E, et al, "Faster, More Accurate Defect Classification Using Machine Vision", Intel White Paper 2018. https://www.intel.com/content/dam/www/public/us/en/documents/best-practices/faster-more-accurate-defect-classification-using-machine-vision-paper.pdf
- "Six Powerful Use Cases for Machine Learning in Manufacturing", ELEKS, https://eleks.com/blog/machine-learning-in-manufacturing/

Future Implications



- "Consistency Management" (AKA verification, validation, etc.) *may* seem like an important but limited part of the overall SE fabric of ISO 15288.
- *However*, as learning algorithms are becoming more prominent, the relationship between learning and generation is becoming clearer.
- The potential for *spanning* the information parts of the Vee with ML related technologies beckons.
- An initial implication is how this informs the theoretical foundations of *human-performed* systems engineering:
  - Schindel, W., "Innovation Ecosystem Dynamics, Value, and Learning I: What Can Hamilton Tell Us?", accepted to appear in *Proc. of INCOSE 2024 International Symposium*, Dublin, Ireland, 2024.

Questions, discussion

Thank you!

34th Annual INCOSE international symposium

hybrid event

Dublin, Ireland
July 2 - 6, 2024

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- Schindel, "Planning, Implementing, and Evolving the Ecosystem: Realizing the Promise of Digital Engineering", in Proc. of INCOSE 2022 International Symposium, Detroit, MI, 2022. Retrieve from -- https://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:patterns:incose_is2022_realizing_the_promise_of_digital_engineering_v1.1.3.pdf
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Automating Support for Decisions and Consistency Management:

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- Herzig, S., Paredis, C. 2014. "A Conceptual Basis for Inconsistency Management in Model-Based Systems Engineering", Paper presented at CIRP Design Conference, 2014, retrieve via https://www.sciencedirect.com/science/article/pii/S2212827114007586/pdf?md5=c9bdd8aba94e820ec43b56330225daa6&pid=1-s2.0-S2212827114007586-main.pdf
- Mendonza, P. and Fitch, J.A. 2013. "Integrating System Models around Decisions", in Proc. of 2013 INCOSE International Symposium, Philadelphia,2013.
- "Decision Model and Notation", Version 1.5 Beta, OMG., retrieve from https://www.omg.org/spec/DMN

AIAA Reference Models for Digital Threads and Digital Twins

- American Institute of Aeronautics and Astronautics (AIAA) has released both its Digital Thread & Digital Twin Reference Models, based on INCOSE ASELCM Innovation Ecosystem Pattern. Link to AIAA Reference Patterns for Digital Thread and Digital Twin
- AIAA Digital Thread Reference Pattern Link to AIAA Digital Thread Reference Model
- AIAA Digital Twin Reference Pattern Link to AIAA Digital Twin Reference Model

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- See covers page for others

Energy Based Machine Learning:

- Hopfield, J. "Neural Networks and Physical Systems with Emergent Collective Computational Abilities", *Proc. of the National Academy of Sciences of the United States of America*. 1982. 79: 2554-8. Retrieve from https://www.pnas.org/doi/10.1073/pnas.79.8.2554
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References, continued

INCOSE Working Groups:

- INCOSE MBSE Patterns Working Group:
  - https://www.omgwiki.org/MBSE/doku.php?id=mbse:patterns:patterns
  - https://www.incose.org/incose-member-resources/working-groups/transformational/mbse-patterns
- INCOSE Decision Analysis Working Group: https://www.incose.org/incose-member-resources/working-groups/analytic/decision-analysis
- "A Cross-Society Collaboration Project, Mapping Consistency Confirmation Frameworks of Different Communities", accepted for presentation at ASME VVUQ 2024 Symposium, May, 2024, College Station, TX.

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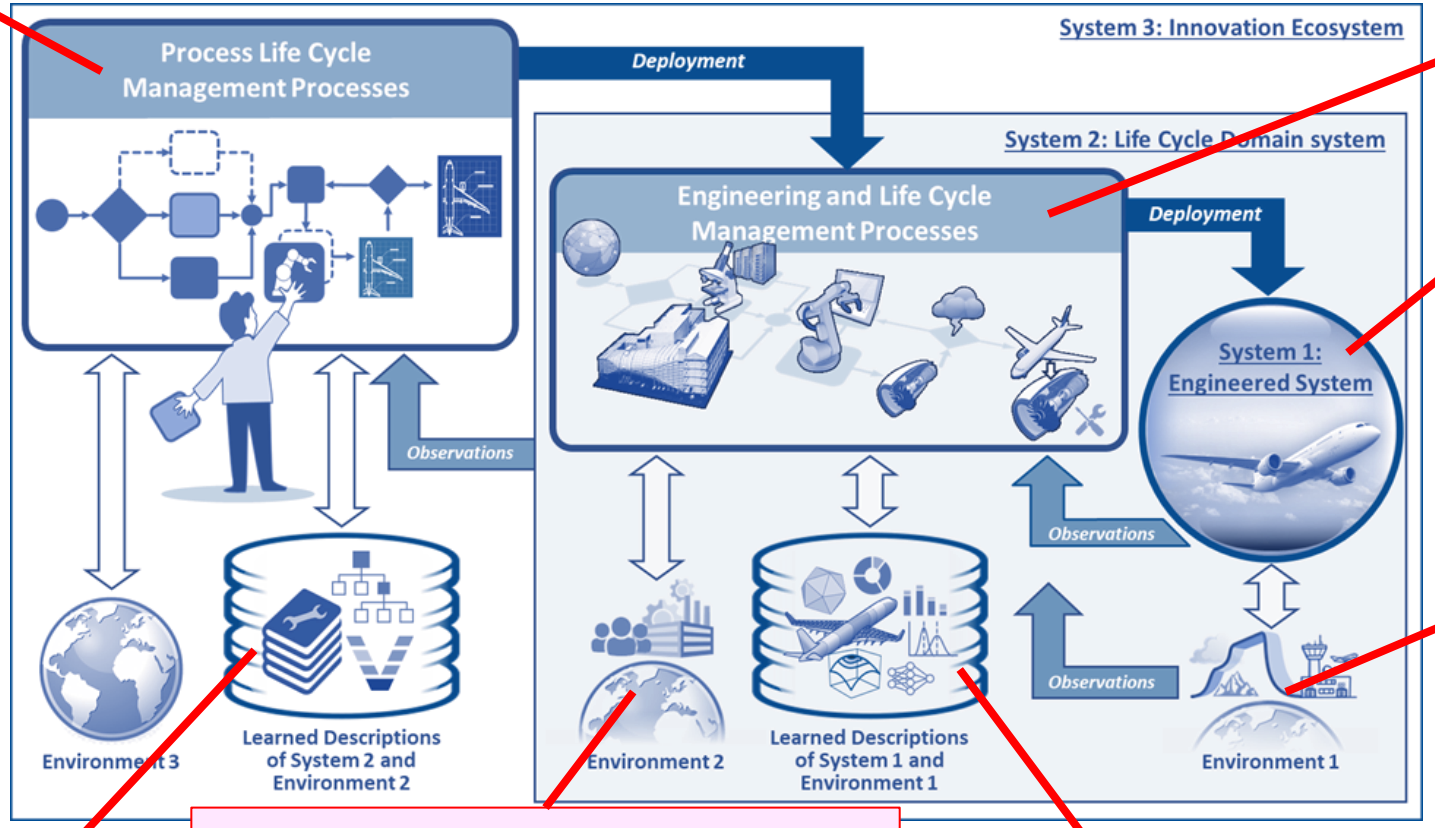
- "Six Powerful Use Cases for Machine Learning in Manufacturing", ELEKS, https://eleks.com/blog/machine-learning-in-manufacturing/

Examples: Engineering Education, Engineering Methods Owner, Engineering Tooling Architect, HR Department, Engineering Procedures Author, INCOSE, IEEE, ASME

Examples: Systems Engineering Department, Senior Electrical Engineer, Design Review, Simulation Platform, Engineering Toolchains, Learning Machines, Digital Threads, Digital Twins, Manufacturing Process, Service Delivery Process, PLM system, Production MES.



- **Examples**: Aircraft, landing gear, bearings, avionics.

EXAMPLES

- **Examples**: Atmosphere, weather, runways

INCOSE ASELCM Level 0 Reference Model

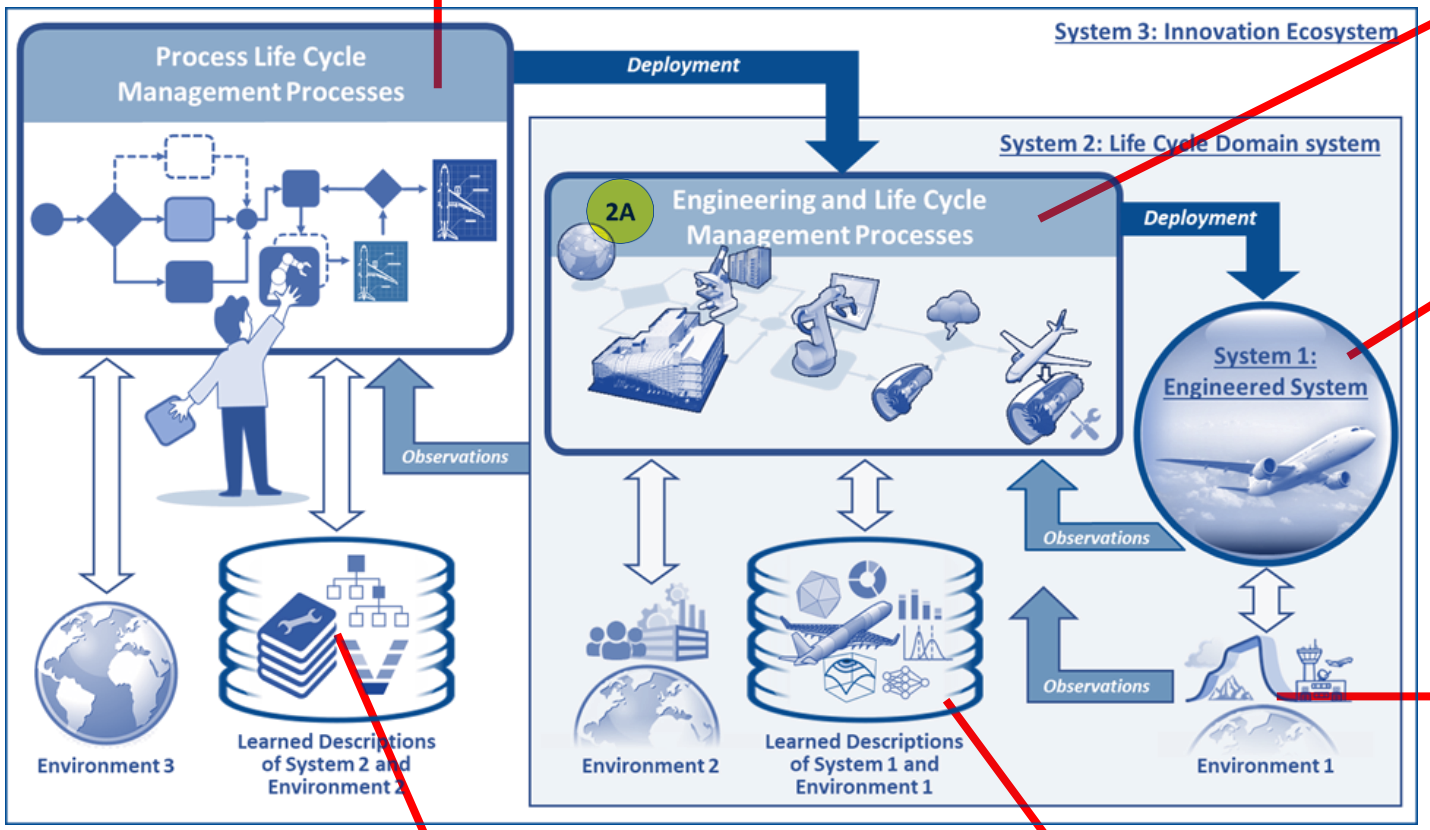
- **Examples**: COVID19 Pandemic, Industry Funding, Job Market

- **Examples**: Landing Gear Requirements, Designs, Schematics, MBSE Models, CFD Simulations, Part Prints, Production Recipes, Assembly Diagrams, Raw Materials Lists, Physics, Personal & Tribal Landing Gear Knowledge

- **Examples**: Enterprise Procedures, Job Descriptions, Organization Charts, Policies, INCOSE Handbook, SEBoK, Methodology Primers, Personal & Tribal Process Knowledge

- Systems & processes responsible to learn about, describe, understand System 2A and Environment 2, or to plan, engineer, develop, educate, deploy, integrate, install, maintain, or retire System 2A. People, tools, facilities.

- Systems & processes responsible to learn about, describe, understand System 1 and Environment 1, or to engineer, develop, fabricate, integrate, distribute, deploy, install, maintain, or retire System 1. Includes people, tools, facilities.



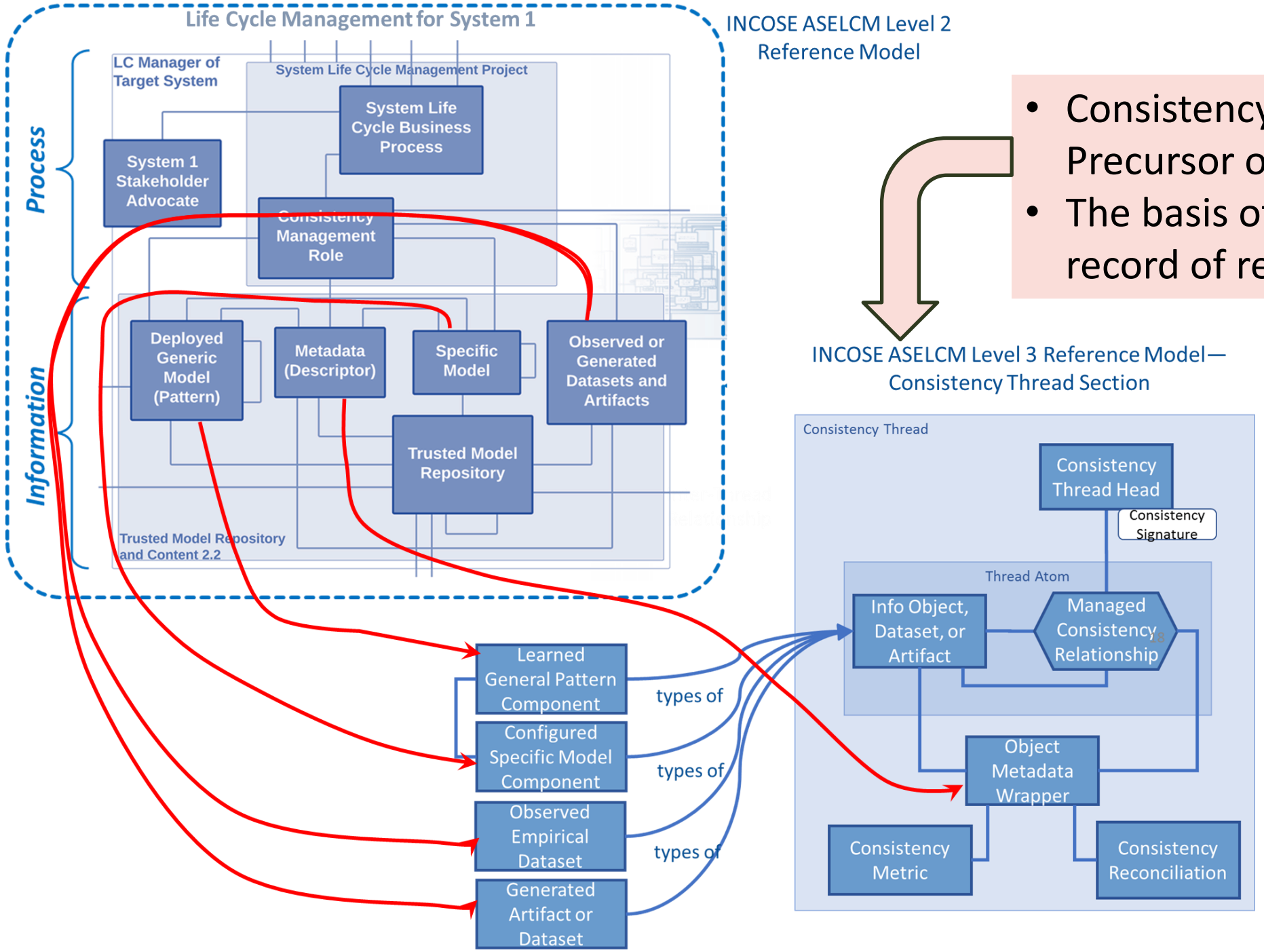
- Any engineered system, including manufactured products, service-providing systems; or any object of scientific study.
- Includes systems-of-systems, subsystems, or components.

DEFINITIONS

- The environment in which System 1 is operated, sustained, distributed, manufactured, or retired.
- Anything that directly interacts with System 1 during its life cycle.

- Accumulated knowledge of System 2A and Environment 2, including explicit procedures, work instructions, organization charts, models, implicit and tribal knowledge, captured empirical data or simulations, plans, prints, diagrams, prose, or other descriptions.

- Accumulated knowledge of System 1 and Environment 1, including explicit models, prose descriptions, implicit and tribal knowledge, captured empirical data or simulations, plans, prints, diagrams, prose, or other descriptions.



- Consistency Thread: Historical Precursor of the Digital Thread.
- The basis of group learning from record of reconciliations.

Speaker background

- Bill Schindel is president of ICTT System Sciences. His engineering career began in mil/aero systems with IBM Federal Systems, included faculty service at Rose-Hulman Institute of Technology, and founding of three systems enterprises.
- He chairs the INCOSE MBSE Patterns Working Group, and served on the lead team of the INCOSE Agile Systems Engineering Life Cycle Discovery Project. He is an active member of the ASME VV50 working group on model credibility in advance manufacturing, and the AIAA digital thread and digital twin reference model and case study teams.
- Schindel is an INCOSE Fellow and CSEP, and is a director and past president of the INCOSE Crossroads of America Chapter.
- schindel@ictt.com