Report on the AIAA DEIC Digital Thread Position Paper

Digital Thread Subcommittee

Aviation Forum, Chicago, 30 June 2022

Outline

MC

- Greetings and Introductions
  - AIAA Digital Engineering Series Overview
- Digital Thread
  - Executive Summary & Purpose
  - Definition
  - Value
  - Generic Reference Model
  - Discussion 1
  - Tailoring for Aerospace and Recommendations
  - Discussion 2
- End of session

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SHAPING THE FUTURE OF AEROSPACE

(DEIC) Digital Engineering Integration Committee

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DEIC – Subcommittees & Papers

MC

Vice-Chair
Natalie Straup
(Northrop Grumman)

Chair
Dave Kepczynski
(GE)

Secretary
Olivia Fischer
(Georgia Tech)

Digital Ecosystem Subcommittee	Digital System Model Subcommittee	Digital Thread Subcommittee	Digital Twin Subcommittee
Jason Hatakeyama (Boeing)	Mat French (Northrop Grumman)	Melanie Lorang (Boeing)	John Matlik (Rolls-Royce)
Dave Loda (OshKosh)	Rick Arthur (GE)	Matt Cribb (Raytheon)	Jay Ganguli (PW)
Position Paper (started)	Position Paper	Position Paper (review)	Position Paper (released)
Implementation Paper	Implementation Paper	Implementation Paper	Implementation Paper (approvals)

5th committee is the steering committee

DEIC – Executive Summary

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Jan`22	Feb`22	Mar`22	Apr`22	May ‘22	Jun ‘22	Jul ‘22	Aug ‘22	Sept ‘22	Oct ‘22	Nov ‘22	Dec ‘22		Jan ‘23		Feb ‘23	Mar ‘23
SciTech				Qtrly		Aviation	Qtrly	AA&S		Qtrly		SciTech Prep		SciTech		

Charter

The AIAA Digital Engineering Integration Committee is focused on:

- Establishing a collaborative forum across industry, academia, and government
- Enabling the acceleration, integration, and adoption of existing and new digital engineering capabilities and technologies
- Supporting partners in the development and creation of a technical programs related to digital engineering
- Driving US national competitiveness, security, and operational readiness
- Collaborating with outreach partners in Materials Engineering, Advanced Computing, Computer Aided Engineering & Test, Engineering Software, and Standards

Operations

Membership: 78 (115 Friends) rev04/28/22

Industry	51 (65%)
Government	12 (15%)
Academia	15 (19%)
Total	78

Steering & Subcommittees

Digital Twin
Digital Thread
Digital System Model
Digital Ecosystem

Partner Collaborations

AIA	INCOSE
OMG DTC	NAFEMS
AIAA ICME	IDN TIM
CFD 2030	ISV’s
AIAA STEM K-12	

Forum Planning

	2021/22	2022/23
OMG DTC		New Collab
AIAA ICME		New Collab
AIAA STEM K-12		New Collab
AIA	Yes	Yes
IDN	Yes	Yes
INCOSE	Yes	Yes
NAFEMS	Yes	Yes
AIAA SciTech	Panels, Sessions	Planning
ASME DT Summit	Panels, Sessions	Checking
AIAA Aviation	Plenary, 360's	Planning
AA&S	Panel	Planning
AIAA DEIC	Qtrly, Mthly	Qtrly, Mthly

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DEIC - Digital Thread

Melanie Lorang
Boeing
Lead

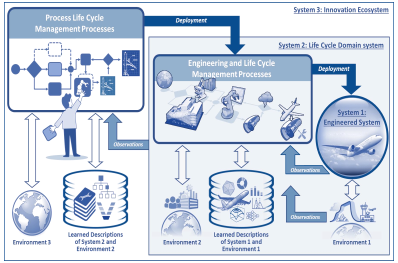
Matt Cribb
Raytheon
Lead

Jan`22 · Feb`22 · Mar`22 · Apr`22 · May '22 · Jun '22 · Jul '22 · Aug '22 · Sept '22 · Oct '22 · Nov '22 · Dec '22 · Jan '23 · Feb '23 · Mar '23

SciTech (Jan`22) · **Qtrly** (May '22) · **Aviation** (Jul '22) · **Qtrly** (Aug '22) · **AA&S** (Sept '22) · **Qtrly** (Nov '22) · **SciTech Prep** · **SciTech**

Overview

The **Digital Thread** links authoritative information of a process, product, or system enabling the capture and communication of knowledge and decision-making throughout its life cycle.



INCOSE ASELCM Level 0 Reference Model—Systems 1, 2, and 3

The Digital Thread describes the comprehensive linkage of models and related product development information, encompasses the entire product life cycle, and includes customers, suppliers, and partners in a system's development. The system of interest can be a product or service and can be as broad as the definition of a system. The Digital Thread seamlessly connects information across the life cycle of a product to enable in-depth understanding, tracking, and reusability of the knowledge acquired from inception through sustainment. The data and information are produced and consumed in a digital (without manual handoff), scalable, and flexible framework. Digital Thread Model-Based Engineering (MBE), is defined by NIST as "an approach to product development, manufacturing and life cycle support that uses a digital model to drive all engineering activities."

Priorities

- **POSITION PAPER 1 – Definition, Value, Reference Model**
  - Sessions – SciTech22, Aviation22
  - Panels – SciTech22
  - Outreach – AIA, ASME, INCOSE, NAFEMS, DTC
- **POSITION PAPER 2 –Case Studies, & Recommendations**
  - Sessions – SciTech23, Aviation23
  - Panels – SciTech 23
  - Outreach – AIA, ASME, INCOSE
- **TRAINING & DEVELOPMENT**
- **ADVOCACY, FEEDBACK, & VERSIONING**
- **STANDARDS**

Next Steps

POSITION PAPER 1 – Definition, Value

- Defining Digital Thread in prose and model form
- Utilizing generic reference models tailored to aerospace from INCOSE
- Providing recommendations and next steps for implementation
- Adjudicated 'Pink' team feedback and recommendations. Completing modifications
- Currently processing 'Red' team review comments

DEIC - Digital Ecosystem

Jason Hatakeyama
Boeing
Lead

David Loda
Oshkosh
Lead

Jan`22 | Feb`22 | Mar`22 | Apr`22 | May '22 | Jun '22 | Jul '22 | Aug '22 | Sept '22 | Oct '22 | Nov '22 | Dec '22 | Jan '23 | Feb '23 | Mar '23

SciTech | Qtrly | Aviation | Qtrly | AA&S | Qtrly | SciTech Prep | Qtrly | SciTech

Overview

The **Digital Ecosystem** is a group of interconnected information technology resources that can function as a unit, regardless of location and throughout the product lifecycle. It is the digital environment in which the Digital Twin, Digital Thread and Digital Systems Model operate and reside.

The Digital Ecosystem represents the data environment and infrastructure that enables interconnectivity between Digital Twins, Digital Threads and Digital Systems Models for a product as it is designed, manufactured and operated/supported in the field. The technology stack enables data exchanges between multiple digital representations of a product that provides for product evolution over time. This systems architecture is technology agnostic in that specific tools and vendor offerings are interchangeable and are expected to change as new digital capabilities are introduced. Hence, the proper design and management of the Digital Ecosystem architecture is critical to ensuring flexibility and connectivity between all Digital variations of a product across its lifecycle.

Priorities

- **POSITION PAPER 1 – Definition, Value**
  - Sessions – SciTech22, Aviation22
  - Panels – SciTech22
  - Outreach – AIA, ASME, INCOSE
- **POSITION PAPER 2 – Reference Model, Case Studies, & Recommendations**
  - Sessions – SciTech23, Aviation23
  - Panels – SciTech 23
  - Outreach – AIA, ASME, INCOSE
- **TRAINING & DEVELOPMENT**
- **ADVOCACY, FEEDBACK, & VERSIONING**
- **STANDARDS**

Next Steps

- Kicking off Digital Ecosystem Position Paper effort at SCITECH 2022 (January 2022)
- Goal is to publish Ecosystem Position Paper EOY 2022
- Digital Ecosystem Position Paper:
- Defines Digital Ecosystem both in prose & model form
- Defines how Digital Engineering elements (e.g. Digital Thread, Digital Twin, etc.) work together
- Utilizes generic reference model tailored to aerospace from INCOSE
- Provides recommendations and next steps for implementation
- Hosting technical panel session at SCITECH 2022 (DGE-04) on Digital Engineering – Aerospace Perspectives

DEIC - Digital System Model

MC

Mat French
Northrop Grumman
Lead

Rick Arthur
GE Research
Lead

Jan`22	Feb`22	Mar`22	Apr`22	May '22	Jun '22	Jul '22	Aug '22	Sept '22	Oct '22	Nov '22	Dec '22		Jan '23		Feb '23	Mar '23
SciTech				Qtrly		Aviation	Qtrly	AA&S		Qtrly		SciTech Prep		SciTech		

Overview

The Digital Systems Model:

Future Work

Priorities

- **POSITION PAPER 1 – Definition, Value**
  - Sessions – SciTech22, Aviation22
  - Panels – SciTech22
  - Outreach – AIA, ASME, INCOSE
- **POSITION PAPER 2 – Reference Model, Case Studies, & Recommendations**
  - Sessions – SciTech23, Aviation23
  - Panels – SciTech 23
  - Outreach – AIA, ASME, INCOSE
- **TRAINING & DEVELOPMENT**
- **ADVOCACY, FEEDBACK, & VERSIONING**
- **STANDARDS**

Next Steps

- Initiating subcommittee meetings
- Next objective will be a Digital System Model Position Paper starting SCITECH 2023:
- Defines DSM both in prose & model form
- Utilizes generic reference model tailored to aerospace from INCOSE
- Provides recommendations and next steps for implementation
- Looking for passionate DEIC participants to join and get involved.

Collaborations

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AIAA Collaborations

- AIA
- OMG DTC
- ASME DT
- AS&S
- AIAA ICME
- AIAA STEM K-12
- AIAA CFD 2030
- IDN
- PLM/MBE ISV’s
- NAFEMS

Opportunities - by Associations

- US Gov ECP
- USCOC
- HPC User Forum

Future Topics

- Pull in Topics from Collaborations
- US Government Exascale Computing
- US Council on Competitiveness
- Advanced Computational Methods
- Model Based Systems Engineering

Executive Summary & Purpose

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- Members from academia, industry, and government collaborated on this paper with these objectives:

1) Provide the aerospace community with a standard definition of the Digital Thread
2) Discuss the value proposition for the creation and use of the Digital Thread as it relates to model-based engineering and enabling data analytics on the product life cycle
3) Describe a generic architecture framework for the Digital Thread
4) Provide recommendations for future focus areas and activities to accelerate value realization using the Digital Thread.

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The authors would also like to acknowledge Dr. Woong Je Sung (Aerospace Systems Design Laboratory, Georgia Institute of Technology) for illustrating several figures of this paper, and Ms. Leann Cribb (UltimateVantage.com) for her technical editing. Additionally, the authors would like to thank Dr. Karen Wilcox (UT Austin), Dr. Pam Kobryn (AFRL/RQ), and Dr. Thomas McCarthy (Raytheon Missiles & Defense) for their helpful feedback and guidance.

What is the Digital Thread?

The Short Definition

A **Digital Thread** is a set of digital artifacts whose consistency is actively managed over the product life cycle.

A Longer Definition Description…

*The **Digital Thread** is a collection of linked authoritative information pertaining to a process, product, or system, whose consistency is actively managed throughout the life cycle. A Digital Thread enhances the accessibility, currency, efficiency, and credibility of information. As a result, the Digital Thread facilitates the capture, communication, and use and reuse of knowledge to inform decisions that realize value.*

Definitions are inadequate to describe, the *Digital Thread* completely, so a *General Reference Model* is provided …

The Value of the Digital Thread

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- Bi-directional Traceability
- Consistency
- Transparency: Increased communication and collaboration across teams, stakeholders, and customers
- Workflow automation
- Analytical capabilities

Report on the AIAA DEIC Digital Thread Position Paper:
Generic Reference Model Section Summary

Bill Schindel, schindel@ictt.com
Digital Thread Subcommittee
Aviation Forum, Chicago, 30 June 2022

V1.1.3

Purpose and scope

- Purpose and scope of this presentation:
  - Summarize leading aspects of the neutral reference model in use within the AIAA Digital Thread Position Paper.
  - Paper has been submitted to wide-ranging Red Team Review.
  - Your questions and additional feedback in today's session.

- Purpose and scope of generic reference model:
  - Provide an implementation-agnostic, generic reference model for describing, analyzing, planning, understanding aerospace digital threads in general.
  - Descriptive, not prescriptive.
  - Configurable to different cases, situations.

Origins of the Reference Model

- Originated as International Council on Systems Engineering (INCOSE) reference model for the analysis of systems of innovation in general, and their agility in particular:
  - INCOSE Agile Systems Engineering Life Cycle Management (ASELCM) Pattern.
  - Used for a series of published INCOSE case studies of Lockheed Martin, Rockwell Collins, Northrup Grumman, and US Navy SPAWAR, during 2016-2018.
- Also in use by the AIAA Digital Twin Implementation Case Studies Team to analyze numerous case studies in the related AIAA Digital Twin publication in preparation.
- More recently, central to:
  - INCOSE INSIGHT Digital Engineering Issue, March 2022
  - INCOSE 2022 International Symposium Digital Engineering Session, June 29, 2022
- (See the References.)

Figure 2. INCOSE ASELCM Level 0 Reference Model—Systems 1, 2, and 3.

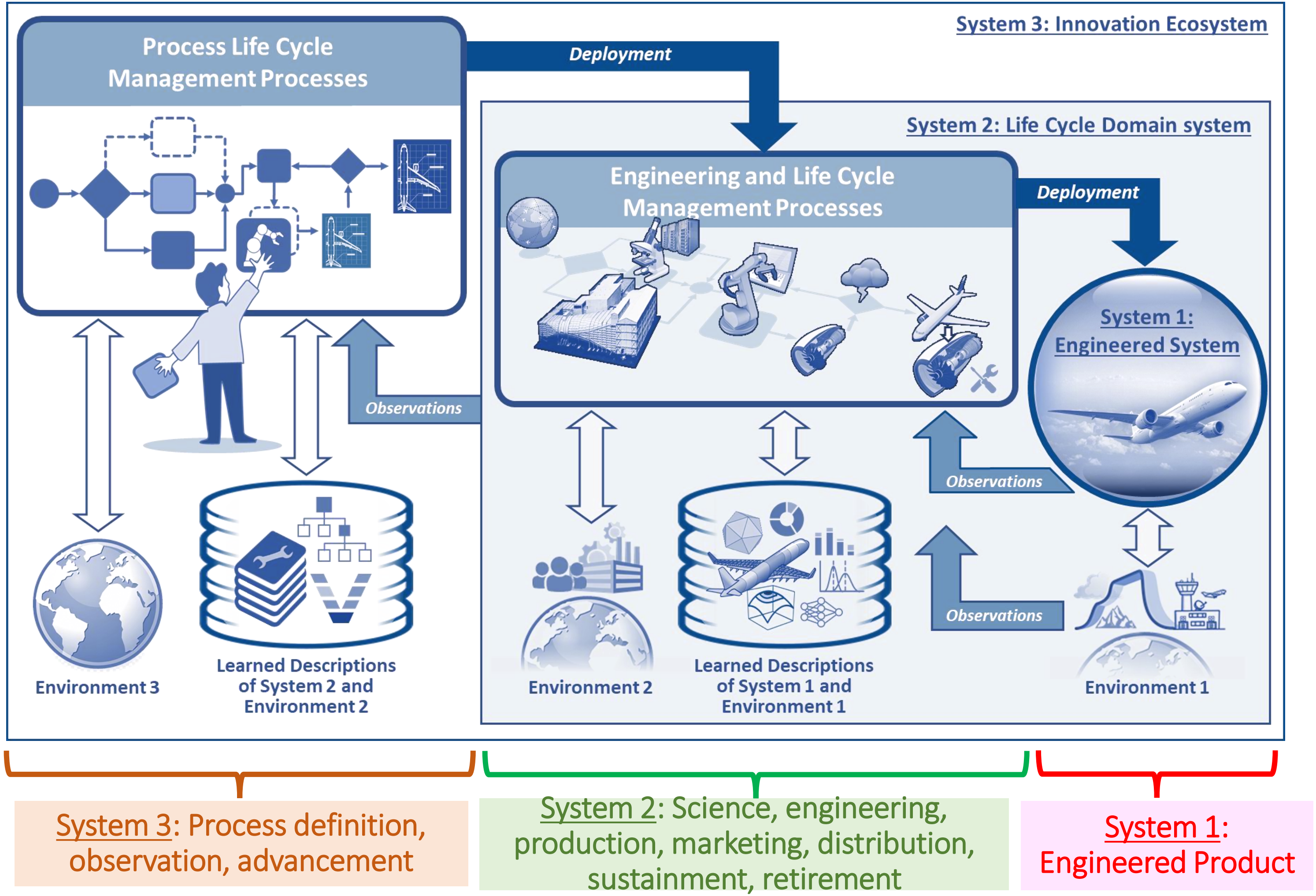


Table 1. Examples of Reference Model Level 0 Entities

Reference Model Boundary	Reference Model Level 0 Entity (See Figure 2)	Aerospace Examples
System 1: Engineered System	Engineered System	Aircraft, Landing Gear Subsystem, Landing Gear Component
System 2: Life Cycle Domain System	Environment 1	Airport, Weather System, Runway, Manufacturing Floor, Maintenance System
	Engineering and Life Cycle Management Processes	Mission Engineering, Design Review, Simulation Process, Manufacturing Process, Service Delivery
	Learned Descriptions of System 1 and Environment 1	Landing Gear Subsystem Requirements, Electrical Schematics, Weather Models, Landing Gear System Model, CFD Simulation, Production Recipes, Physics, Design Patterns, Personal and Tribal Knowledge, Digital Thread Describing System 1 Product
	Environment 2	Industry Funding, Job Market, Pandemic, Workplace
System 3: Process Life Cycle Management Processes	Process Life Cycle Management Processes	Program Definition Process, Engineering Methods Definition, Production Standards Process, Engineering Education, Tooling Specification, Program Analysis, AIAA, INCOSE, IEEE
	Learned Descriptions of System 2 and Environment 2	Enterprise Procedures, Production Job Descriptions, Organization Charts, Handbooks, Courseware, Personal & Tribal Knowledge, Digital Thread Describing System 2 Process
	Environment 3	Methods Research, Competition, Professional & Technical Societies, Engineering Educational Institutions

Figure 3. INCOSE ASELCM Level 1 Reference Model--Explicit **Learning** and **Application of Learning**

Learning: Acquiring and validating new knowledge about System 1 and its environment.

Execution: Applying what we already know about System 1 and its environment

Learning: Acquiring and validating new knowledge about System 2 and its environment.

Execution: Applying what we already know about System 2 and its environment

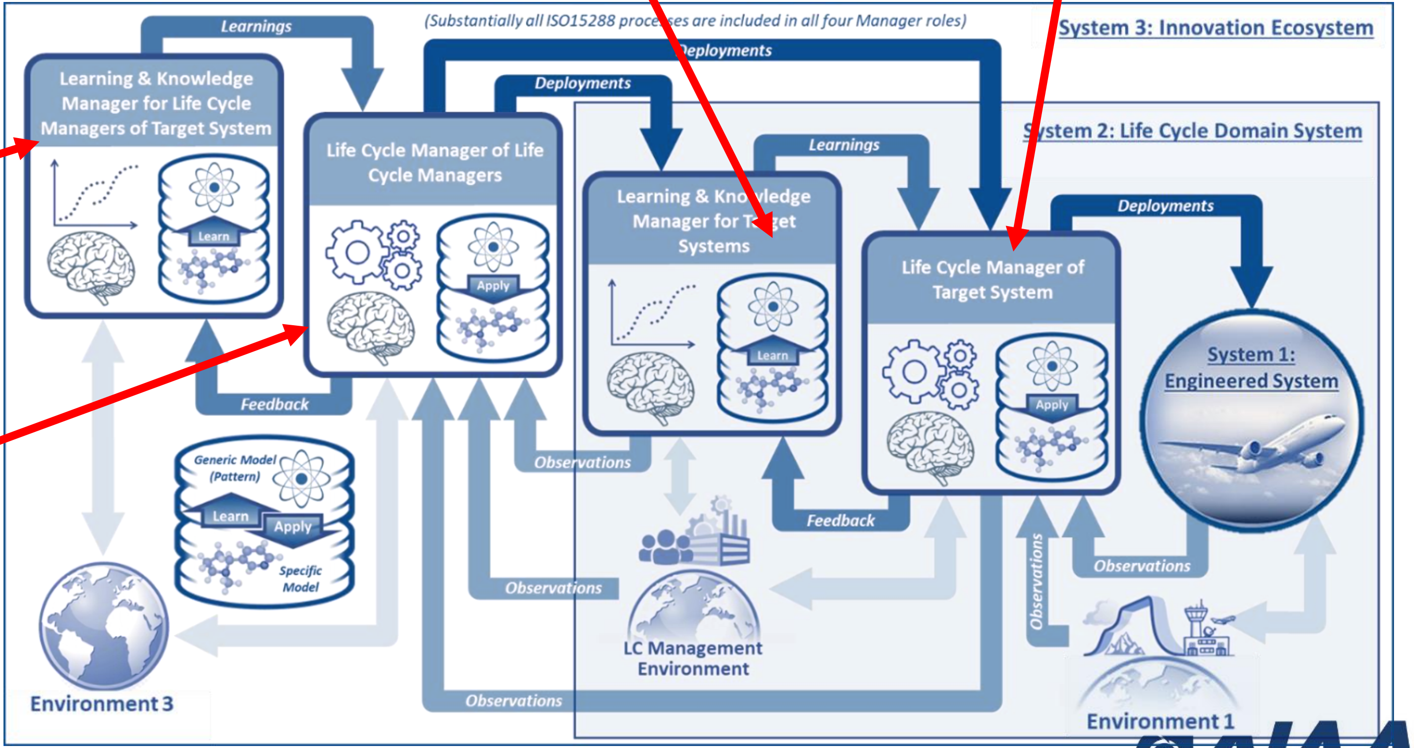


Figure 4. INCOSE ASELCM Level 2 Reference Model— Generic Process & Information Classes

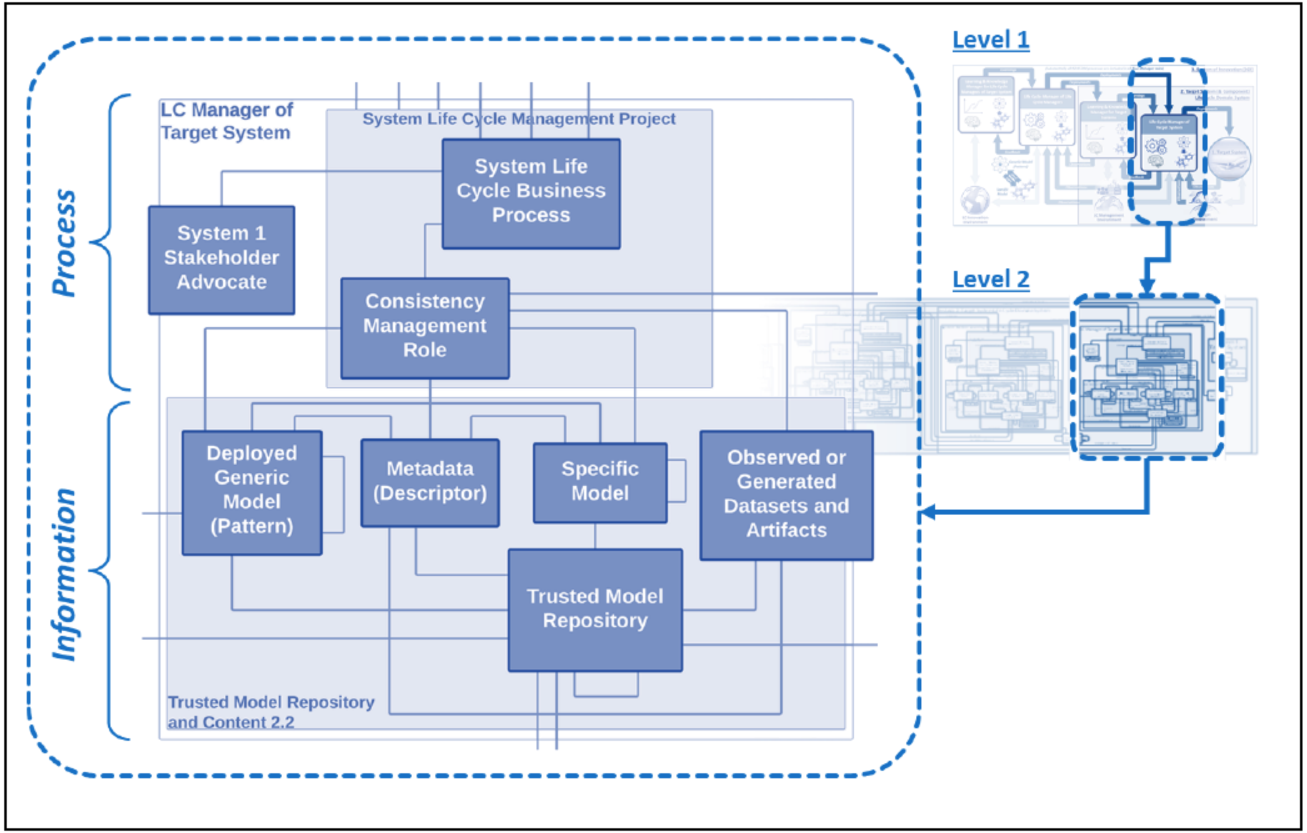
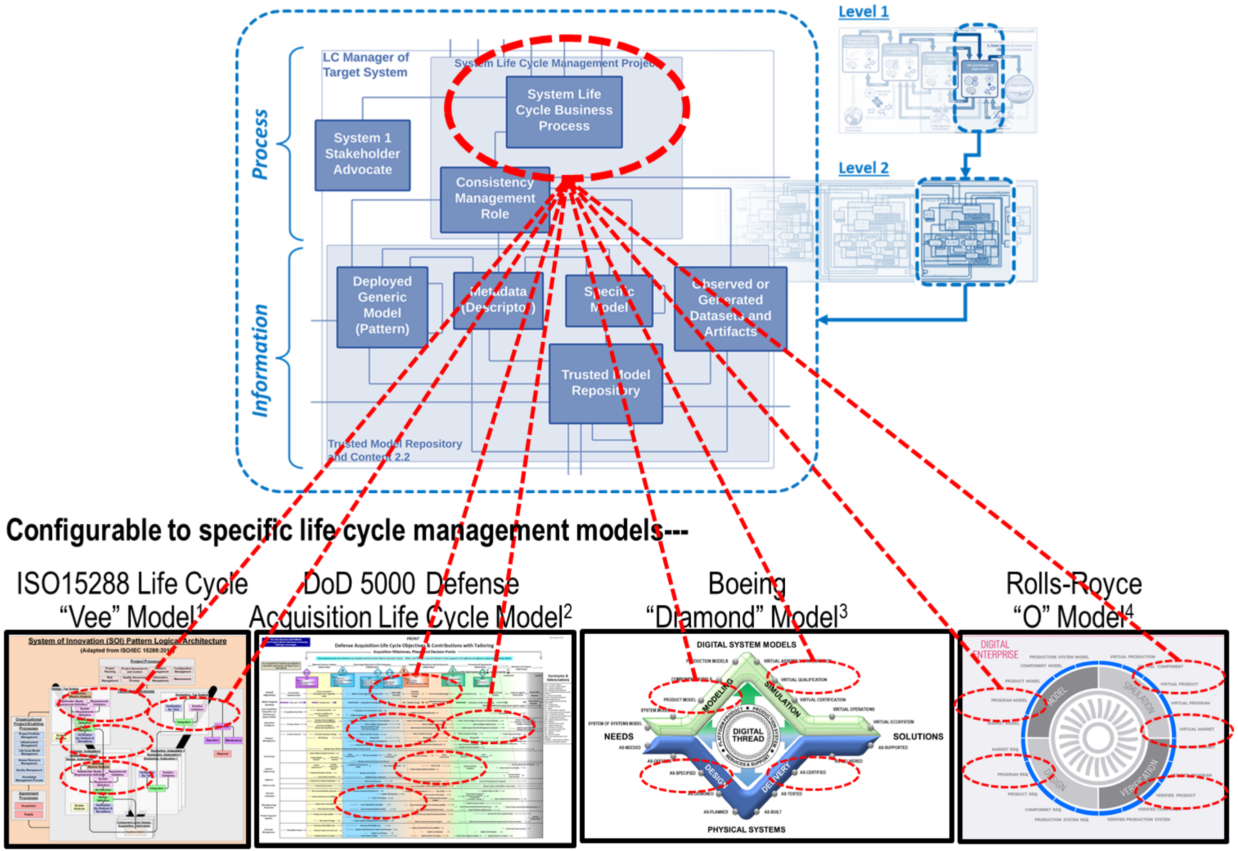
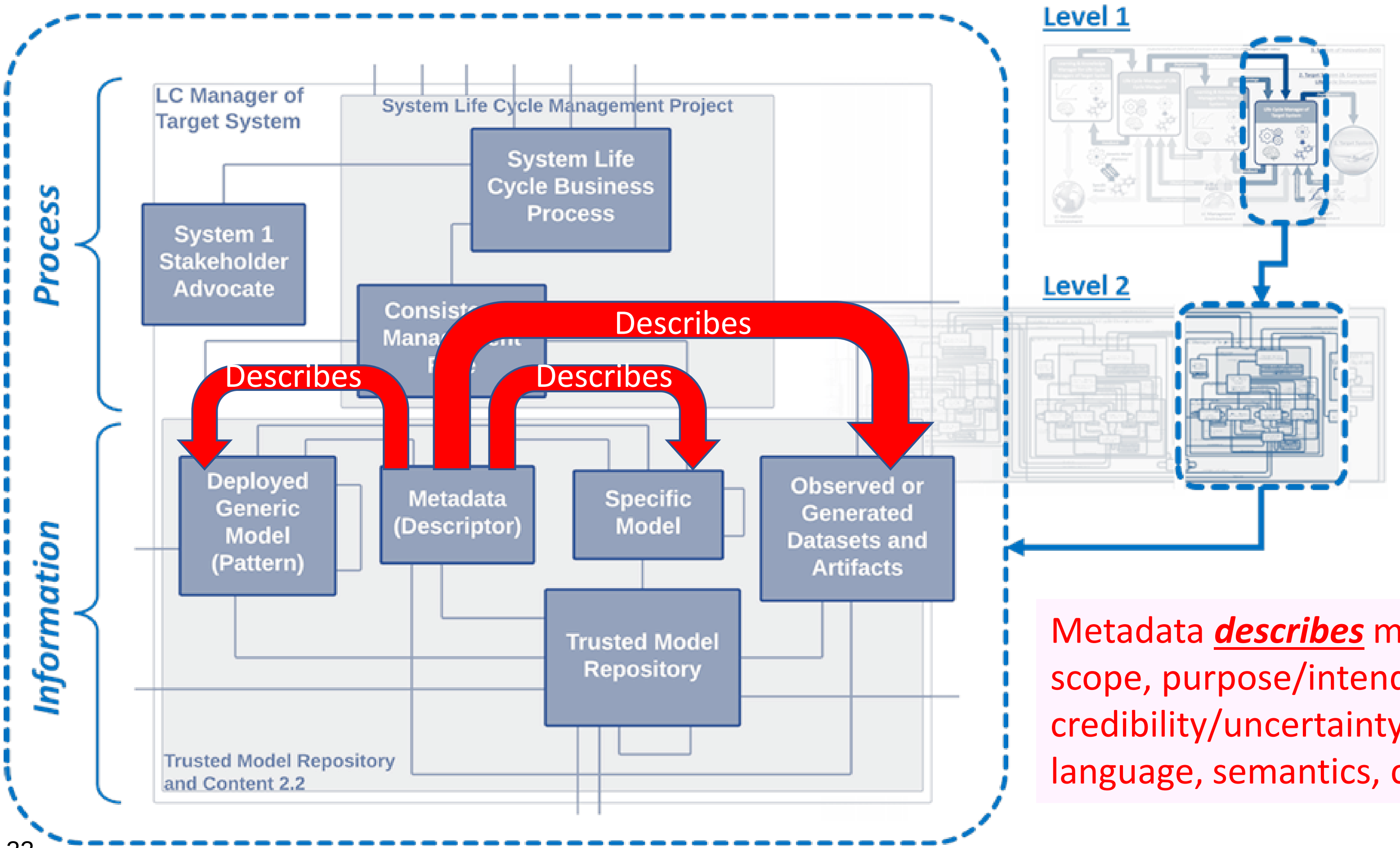


Figure 5: Configuring Reference Model Business Processes Supported by Digital Thread to the Business Processes at Hand



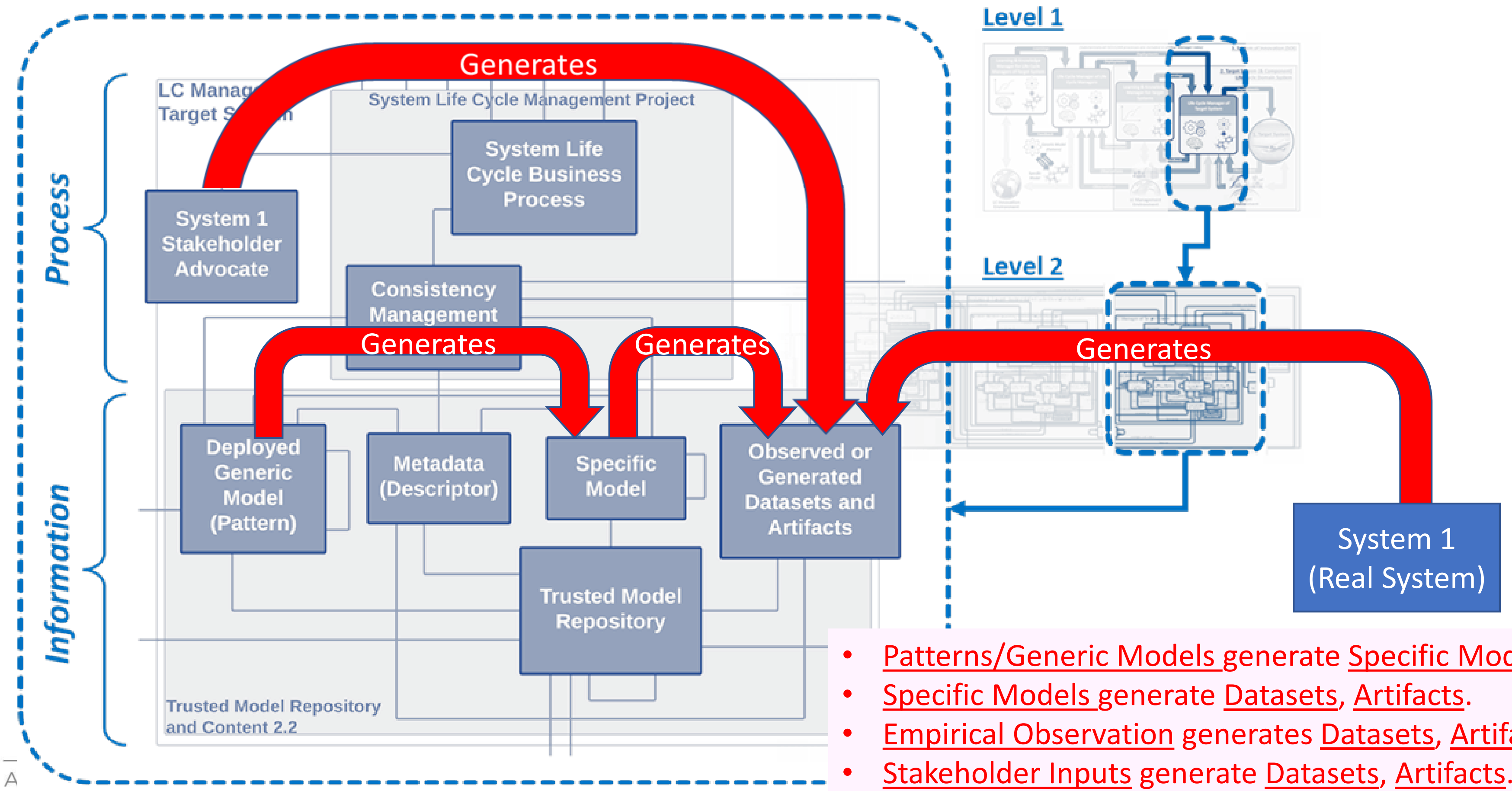
Excerpted or adapted from: (1) ISO15288 and INCOSE SE Handbook; (2) DoD5000 Wall Chart; (3) AIAA Sci Tech, 01.2020, J. Matakeyama; (4) AIAA DEIC Digital Twin Subcommittee, 04.08.19 Donaldson, Flay, French, Matlik, Myer, Pond, Randjelovic

Figure 6. Metadata Is the Guide to Diverse Information Across the Ecosystem



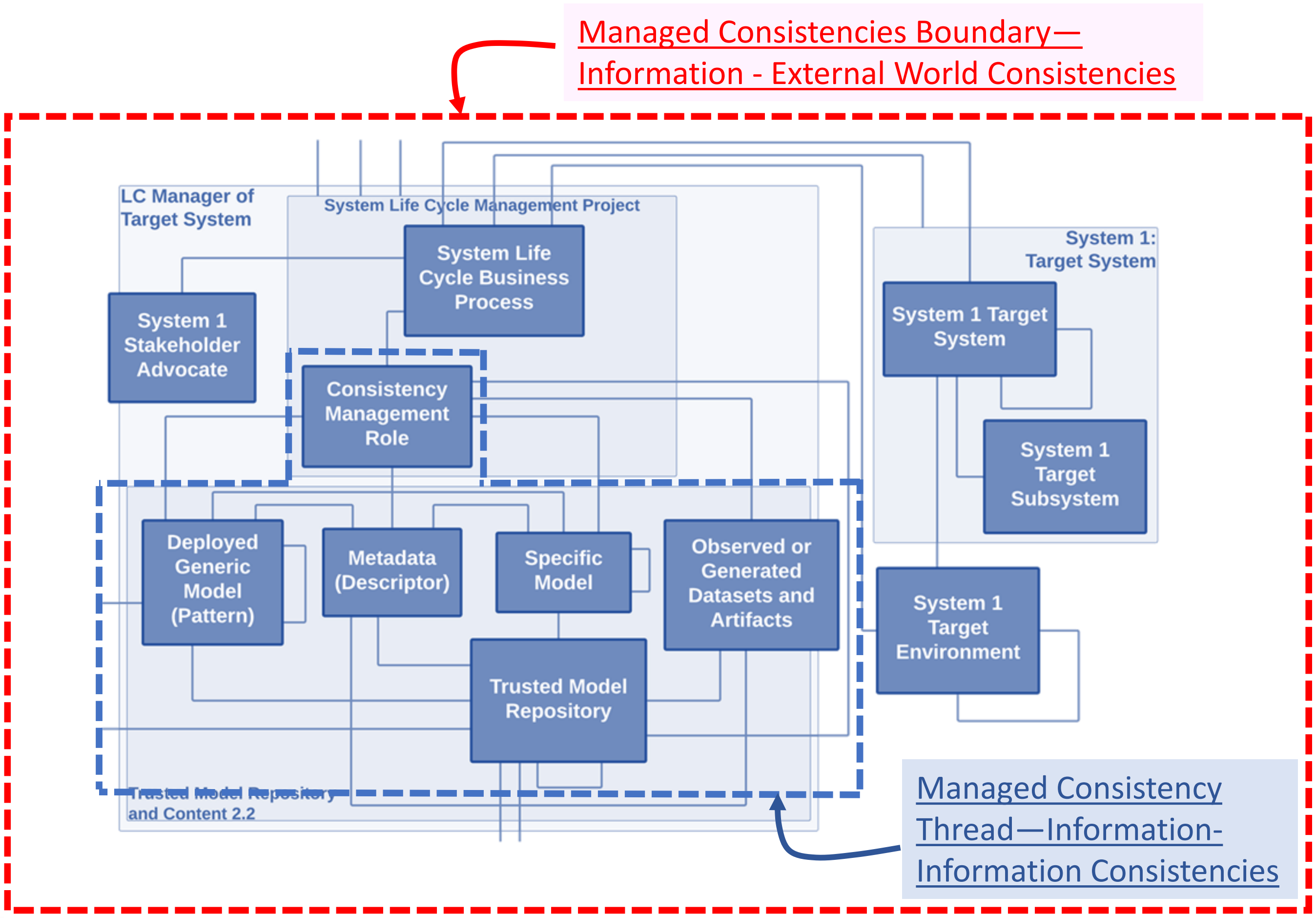
Metadata ***describes*** model and data scope, purpose/intended use, credibility/uncertainty, provenance, language, semantics, consistencies, etc.

Figure 7. Information Propagates from External and Internal Sources



- Patterns/Generic Models generate Specific Models.
- Specific Models generate Datasets, Artifacts.
- Empirical Observation generates Datasets, Artifacts.
- Stakeholder Inputs generate Datasets, Artifacts.

Figure 8. Managed External-Internal and Internal-Internal Consistency.



Managed Consistency Thread System Boundaries

- Managed consistencies: A basic idea fundamental to historical engineering & life cycle management:
  - Not just a new "digital thread" idea—but fundamental to the digital thread.
  - Numerous examples, including Aerospace (SAE AS9145) and Automotive (APQP, PPAP).

- Examples of traditional managed consistencies:
  - Is the product design consistent with the product requirements? (Notice the answer can change over life cycle time.)
  - Are those requirements consistent with the mission and stakeholder needs and priorities?
  - Are the emergent behaviors (both required and to be avoided) in the engineered system consistent with the learned experience about the underlying phenomena from which they emerge?
  - Are instances of the manufactured product consistent with the design specifications? Are the customers' uses of the product consistent with the original product mission and requirements?
  - Is the performance of the deployed product in the field consistent with the specified requirements?
  - Is the environment of use of the product consistent with its representation in the product mission and requirements?
  - Many others . . .

Figure 9. Three Sources of Authority--Often in Inconsistent Conflict.

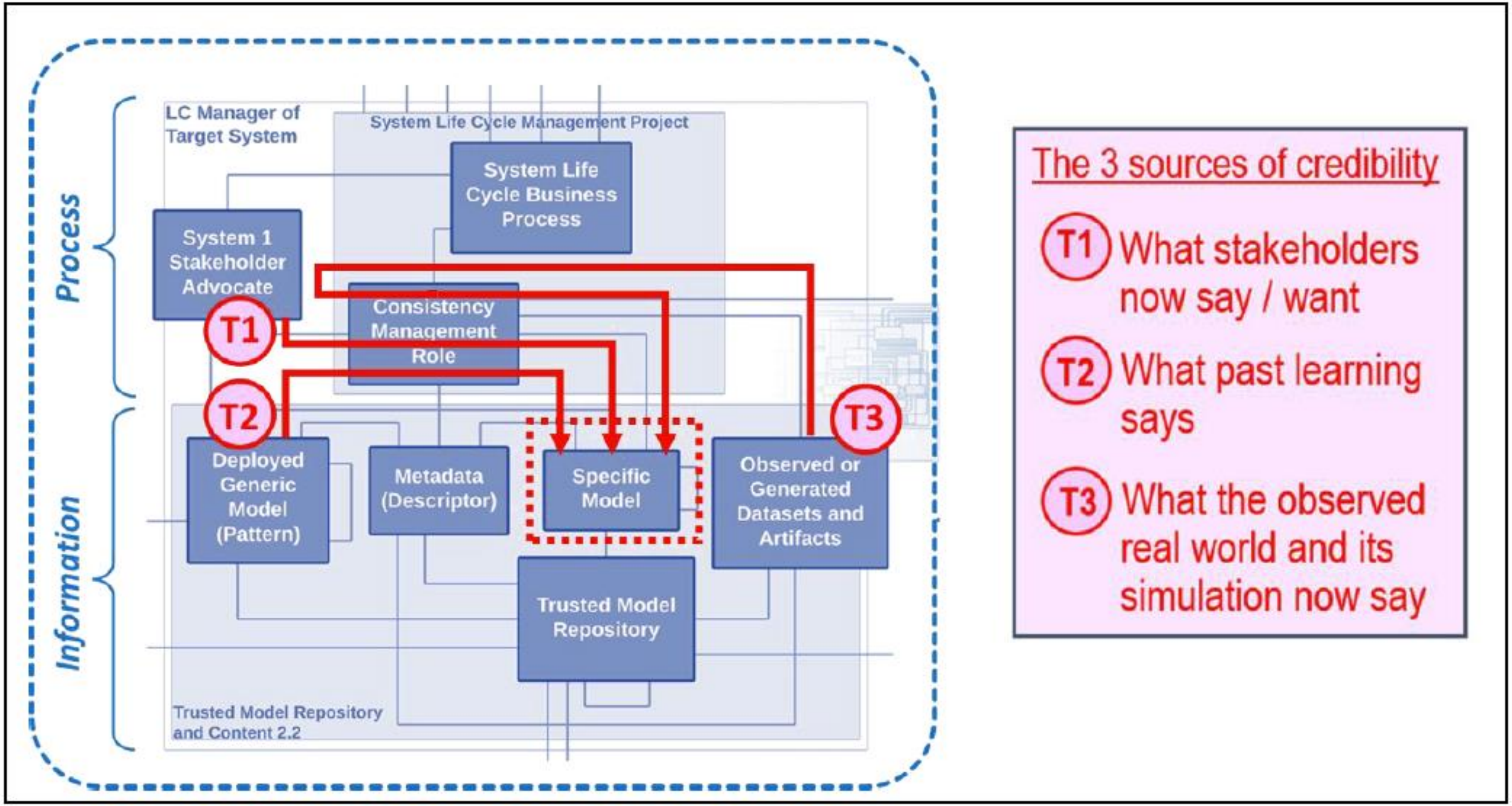
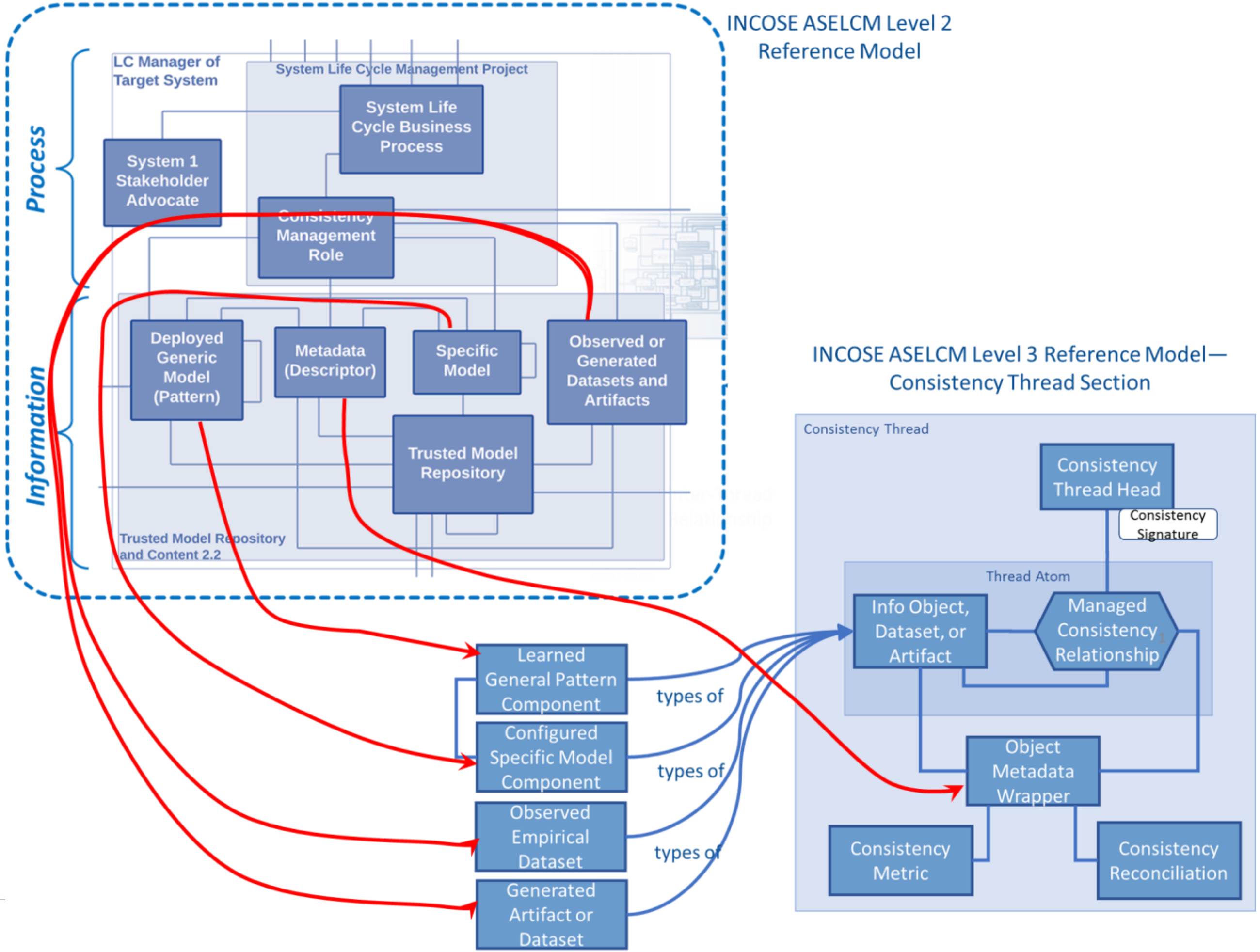


Figure 10. Consistency Threads Span Models, Patterns, Datasets, Artifacts



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Discussion

Tailoring to the Aerospace Domain

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- Aerospace systems share similarities with other domains, but aerospace systems are characterized by a delicate balance between all engineering disciplines, suppliers and customers
- Complexity of aerospace systems drives the need for the Digital Thread
  - Intrinsically model based (especially physics based)
  - the number of parts for an airplane is two orders of magnitude greater than the number of parts in a modern automobile
  - Varying requirements based on commercial and military regulations and missions
  - This requires the integration/incorporation of many individually complex models of these systems within the Digital Thread
- Techniques and methods such as Set Based Design (SBD) combined with Multidisciplinary Design Analysis and Optimization (MDAO) become more critical
- Managing these 10^2 to 10^9 design variants using the Digital Thread will challenge our emerging digital ecosystems' architectures, implementations, and scale.

Recommendations

- Business Case
  - Incremental Agile deliveries
  - Anonymized data collected across industries
- Technical Considerations
  - Standard / Best Practices
  - Fidelity and Efficiency with Models
- Cultural Stack Transformation
- Education and Training

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