



Digital Engineering for Enterprise Ground Systems

Stephen Marley, PhD

Erin Ryan, PhD

Fredda N. Lerner, PMP

Scott Schnee, PhD

Michael Alba

Mary Covert

February 2025

Agenda



	Topic
08:00 – 08:30	Introduction to Digital Engineering
08:30 – 09:30	Digital Engineering Lifecycle Processes
09:30 – 09:45	Break
09:45 – 10:15	Requirements, Reference Architectures, and CONOPS
10:15 – 10:45	DE Sandbox
10:45 – 11:15	Cost Estimation integration into Digital Engineering
11:15 – 11:30	Wrap Up



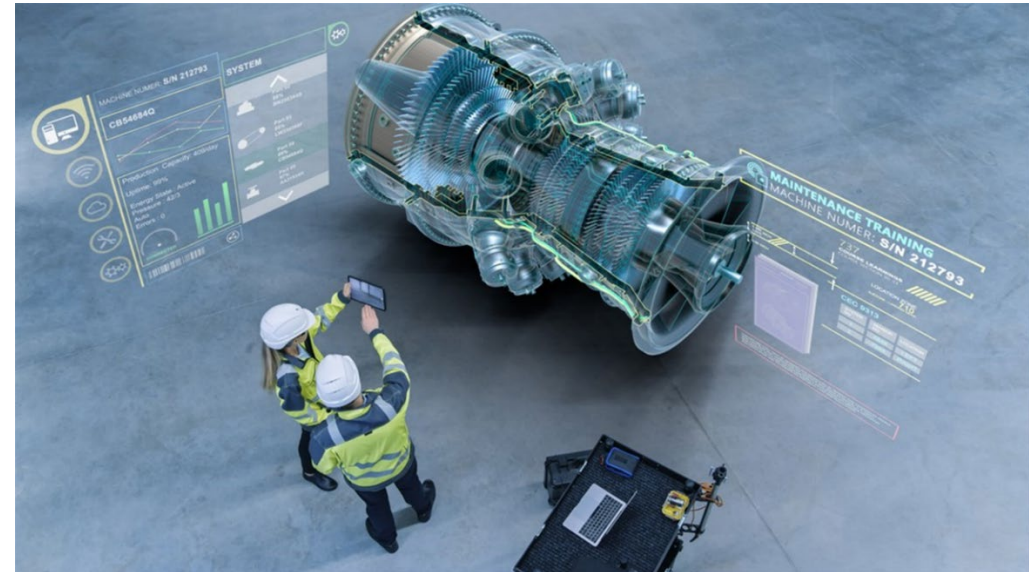
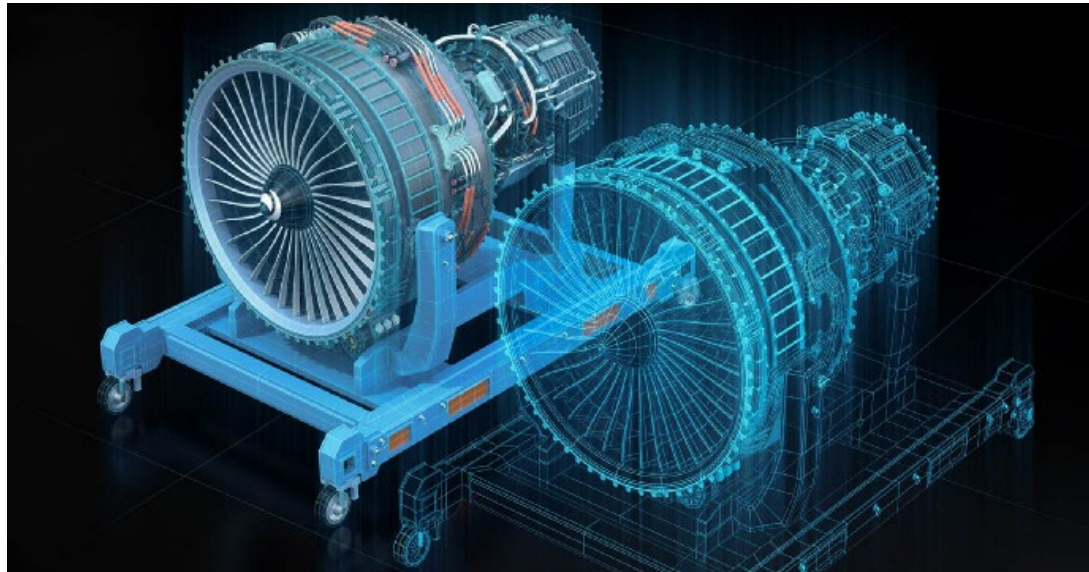
Digital Engineering Overview

Erin Ryan, PhD
Digital Innovation Division

February 2025

Agenda

- What Is Digital Engineering (DE)?
- Digital Engineering in Practice

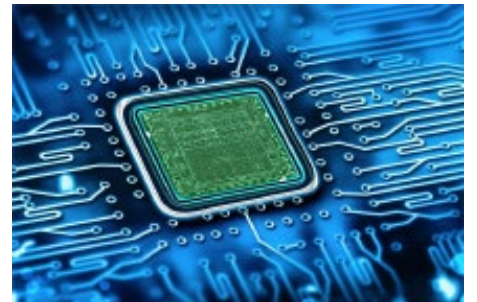




What Is DE?

Why Is it Important?

- **Increasing system and enterprise complexity**
 - Traditional methods cannot keep pace w/ growing complexity
 - Driven further by the threat and by space as a warfighting domain
- **Increasing need for speed and agility**
 - Enables real-time access to authoritative sources of data
 - Accelerates decision-making across the system lifecycle
- **Increasing need for efficiency**
 - Automates process workflows, leverages AI, maximizing productivity
 - Enables the creation of “digital twins”
 - Allows insights into future alternatives to better optimize across lifecycle
- **Increasing need for effectiveness**
 - *Facilitates knowledge management and transfer*
 - *Enables data-driven decision-making at an enterprise level*





What Is DE?

Official Definitions

An *integrated digital* approach that uses *authoritative sources* of system *data and models* as a continuum *across disciplines* to support *lifecycle activities* from concept through disposal.

—DoD Digital Engineering Strategy, 2018

An *integrated digital* approach that uses *authoritative sources* of *systems' data and models* as a continuum *across disciplines* to support *lifecycle activities* from concept through disposal.

—Defense Acquisition University; DE M&S Glossary, 2022

An *integrated, computation-based approach* that uses *authoritative sources* of system *data and models* across disciplines to support *lifecycle activities* from concept through disposal.

—US Navy & Marine Corps Digital Systems Engineering Transformation Strategy, 2020

[A] means of using and integrating *digital models and the underlying data* to support the *development, test and evaluation, and sustainment of a system*.

—DoDI 5000.97, “Digital Engineering,” 2023

Digital engineering *updates traditional systems engineering practices* to take advantage of *computational technology, modeling, analytics, and data sciences*.

—OUSD/R&E, 2022

Powered by *authoritative sources of truth*, incorporating *big data* approaches, utilizing techniques like *model-based systems engineering*, and anchored to a shared modeling and simulation (*M&S framework*)...

—USSF Vision for a Digital Service, 2021



What Is DE?

Key Takeaways

- **Definitions of DE lack full consensus**

- Reasonably consistent definitions across DoD; less so outside of DoD (even defense industry)
- Definitions from DAU / DoD DE Strategy doc and DoDI 5000.97 most referenced

- **Emphasis on both models and underlying data; notion of ASOT is central concept**

- **DE is “integrated” across disciplines with scope of integration greater than SE**

- Includes other engineering domains and science disciplines
- Prominent mentions of “computation technologies” => modern infrastructure / cloud technologies

- **DE is fully applicable to systems/programs, but also intended to address broader SoS/enterprise challenges**

An integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support lifecycle activities from concept through disposal.

—Defense Acquisition University, 2022

[A] means of using and integrating digital models and the underlying data to support the development, test and evaluation, and sustainment of a system.

—DoDI 5000.97, “Digital Engineering,” 2023



What Is DE?

MBSE vs. DE

- **DE ≠ MBSE**

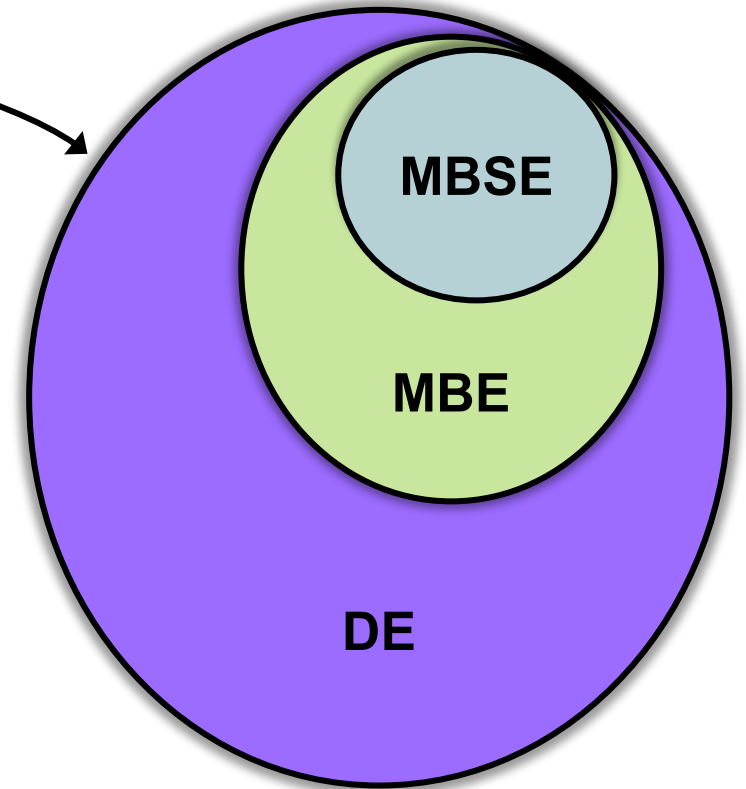
- MBSE and DE are related but distinct
- Both MBSE and MBE are a proper subset of DE

- **Differing Scope**

- MBSE is focused on models; DE is focused on models and data
- MBSE uses models to perform various SE activities
- DE incorporates MBSE models but seeks to connect them with models (and data!) from other technical disciplines across every aspect of capability development and deployment
- DE may also incorporate data/models from non-technical domains (contracts, business processes, mission operations)

- **Level of Maturity / Impact**

- MBSE has been used for a couple of decades whereas DE is much less mature
- MBSE is an evolution; DE may be more of a *revolution*





What Is DE?

DE Ecosystem

*The **interconnected infrastructure, environment,** and methodology (**process, methods, and tools**) used to store, access, analyze, and visualize evolving systems' data and models to address the needs of the **stakeholders**.*

—Defense Acquisition University

*... includes the **infrastructure** and architecture necessary to support automated approaches for **system development, design, testing, evaluation, production, operation, training, and sustainment** throughout the defense acquisition process. The infrastructure consists of ... **Hardware, Software, Networks (including cloud services), Tools, and Workforce***

—DoDI 5000.97, “Digital Engineering,” 2023

• Key Takeaways (Some Extrapolation)

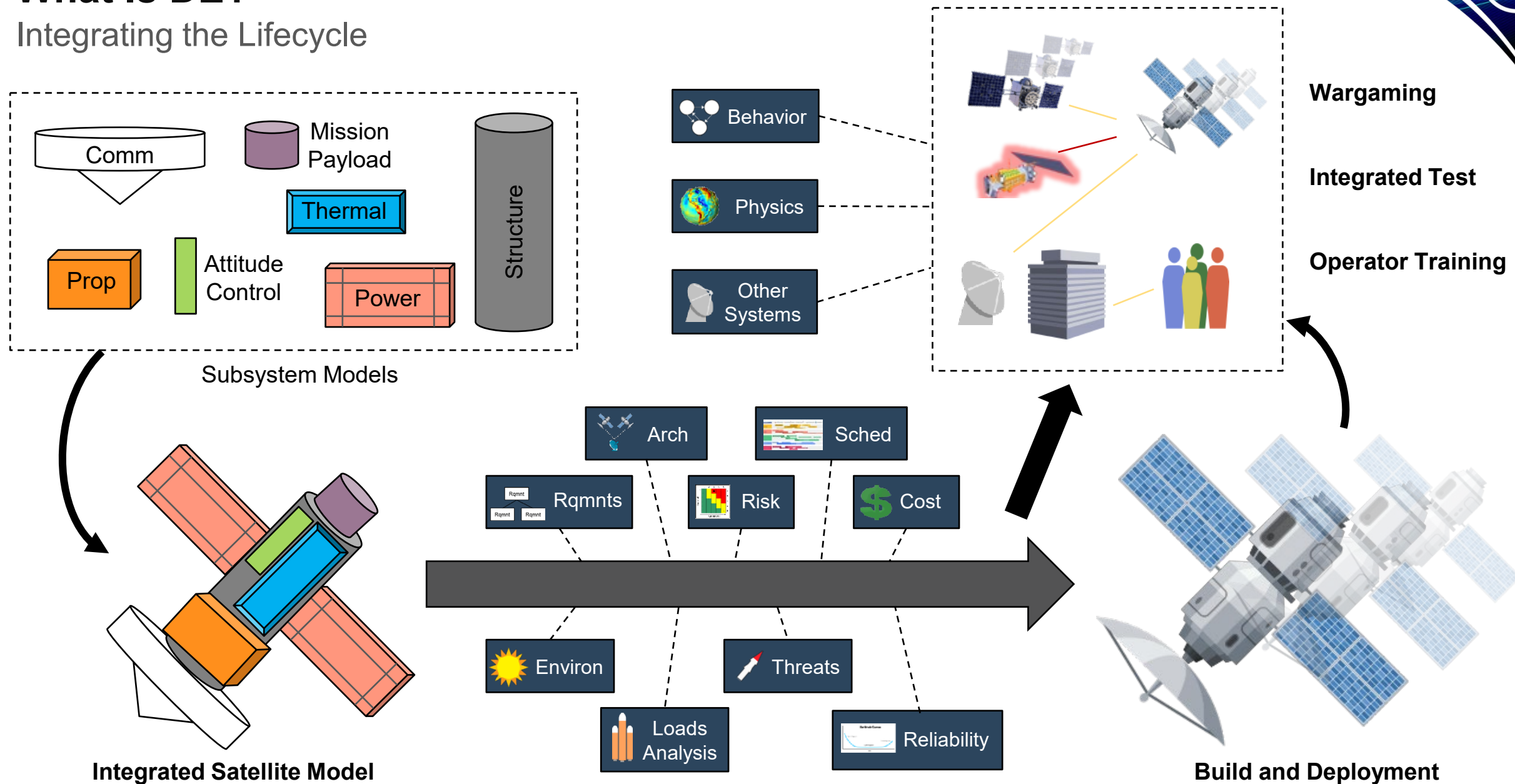
- *DE ecosystem is interconnected; consists of infrastructure & environments*
- *Includes hardware, networks, software/tools (and people!)*
 - Typically cloud-based
- *Serves as the technological foundation for enabling DE*
- *A DE ecosystem helps users do what they need to do*





What Is DE?

Integrating the Lifecycle



DE in Practice

Aerospace Pillars



Mission Information Technology (M-IT)

Michael AuYeung
Principal Director

- Enterprise data sharing via cloud services
- SAP networking
- Enterprise software licensing
- Cross-domain solutions

Capability Transformation (CT)

Richard Deakins
Principal Director

- Enterprise integration / kill chain analysis
- Digital twins
- Reusable modules
- Cloud migration of apps

Data and Software Operations (DSO)

Chris Lawson
Principal Director

- Centralized data mgmnt (ASOTs)
- Data-centricity via Data mgmnt platform
- Modernized DevOps (SW factory)

Artificial Intelligence Integration (AI-I)

Shawn Sloan
Corporate Tech Fellow

- Generative AI tools
- Automated workflow management
- Decision support
- AI-augmented software development

CROSS PILLAR CAPABILITIES: Governance, Integration, Standards, Architecture, Customer Support, Requirements, Outreach, Training and Education



DE in Practice

Helping with the Digital Transformation Challenge

- **Digital Transformation Blueprint**

- *DT is something that has been happening across the private sector w/ increasing urgency for a while*
- *U.S. govt lacks same track record of success*
 - *Though many govt entities recognize value of DT, almost universally struggling with implementation*
- *This drives the core purpose of the DT Blueprint*

Assist U.S. govt entities in navigating the intimidating gulf between the promise of DT and the reality by providing a “blueprint” for digital transformation along with actionable guidance to govt decision-makers and practitioners wherever they may be on their journey.

- **Status of Digital Transformation Blueprint**

- *Planning to release this quarter as Distro C*
- *First portion nearly complete*
 - *Seeking reviewers and collaborators*
- *Need more content and assistance to populate the archetype section*

AEROSPACE REPORT NO.
TOR-2024-000001
[CLICK ON LINK TO OBTAIN NUMBER](#)

Digital Transformation Blueprint:
A Guide to Implementing Digital Engineering in U.S.
Government Organizations

Month dd, yyyy (12-pt. Times New Roman)

Digital Innovation Division
Name of author's cost center
Name of cost center parent

Prepared for:
Space Systems Command
United States Space Force
483 N. Aviation Blvd.
El Segundo, CA 90245-2808

Contract No. FA8802-19-C-0001

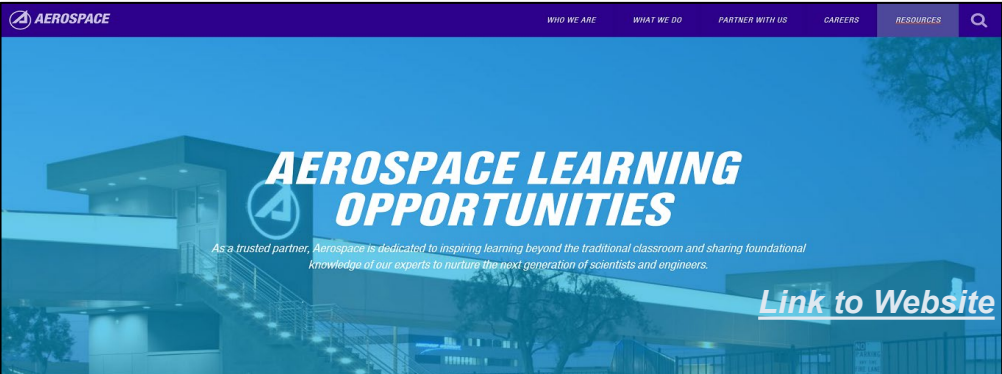
Authorized by: Choose an item.

Distribution Statement (INSERT LETTER B-F, Statement A only for use with Technical Publications' assistance): Author must select from SSC-approved list: (pick from list and fill in reason), (date of determination) and (controlling DoD office) as necessary.



DE in Practice

Learning Opportunities



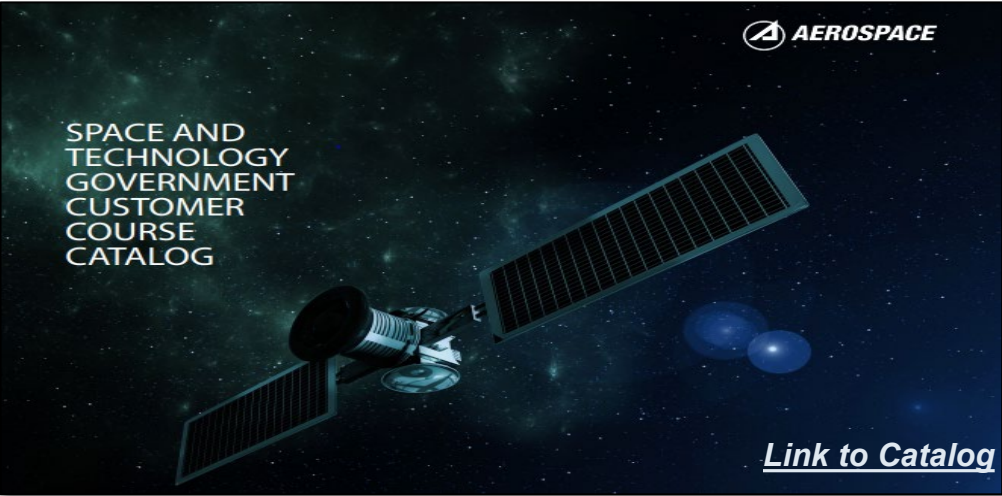
AEROSPACE LEARNING OPPORTUNITIES

As a trusted partner, Aerospace is dedicated to inspiring learning beyond the traditional classroom and sharing foundational knowledge of our experts to nurture the next generation of scientists and engineers.

[Link to Website](#)

The trainings available here exhibit our legacy of learning and highlight the future of adaptability and agility we all must reach towards as technology inspires curiosity, capability and continuous evolution of our practices.

May our shared values spark a passion for what is next and create opportunities for purposeful career progression and the insight to further collaborate across the space enterprise.



SPACE AND TECHNOLOGY GOVERNMENT CUSTOMER COURSE CATALOG

[Link to Catalog](#)

SYSTEMS ENGINEERING		
Course ID	Title	Description
S4560	Enterprise Planning and Portfolio Analysis Overview	Enterprise Planning and Portfolio Analysis is for those who would like an understanding of how Aerospace supports our customers utilizing Enterprise Systems Engineering frameworks to include support to agency budget build processes, capability road-mapping, and other acquisition strategy activities. This class describes a framework and several of the tools Aerospace utilizes to support our customers across the space enterprise when doing Enterprise Planning and Portfolio Analysis activities, including the interaction between enterprise architectures, program budgets and schedules, and programmatic risks and opportunities.
S5020	MBSE: Learning SysML	MBSE: Learning SysML provides a theoretical introduction to Model Based Systems Engineering (MBSE) and the Systems Modelling Language (SysML). During the course, participants will get practical experience using a SysML tool to complete hands-on exercises. Non-Aerospace personnel must have their own working copy of Cameo Systems Modeler installed on their computer.
S5010	Model Based Systems Engineering (MBSE) Overview	Model Based Systems Engineering (MBSE) Overview is for those interested in learning how to leverage the use of model-based techniques and tools in systems engineering practice. This course is intended to introduce fundamental concepts of MBSE and provide examples to illustrate the use of model-based techniques and tools to address systems engineering challenges in practice.



AEROSPACE

Digital Fluency Overview

[Link to Video](#)

Aerospace govt customers may attend select Aerospace University courses within our technical curriculum on a space-available basis. Customers should consult their Aero counterparts to determine eligibility and begin enrollment process.



Using Digital Engineering and Models in the Acquisition Lifecycle

Fredda N. Lerner, PMP

February 2025



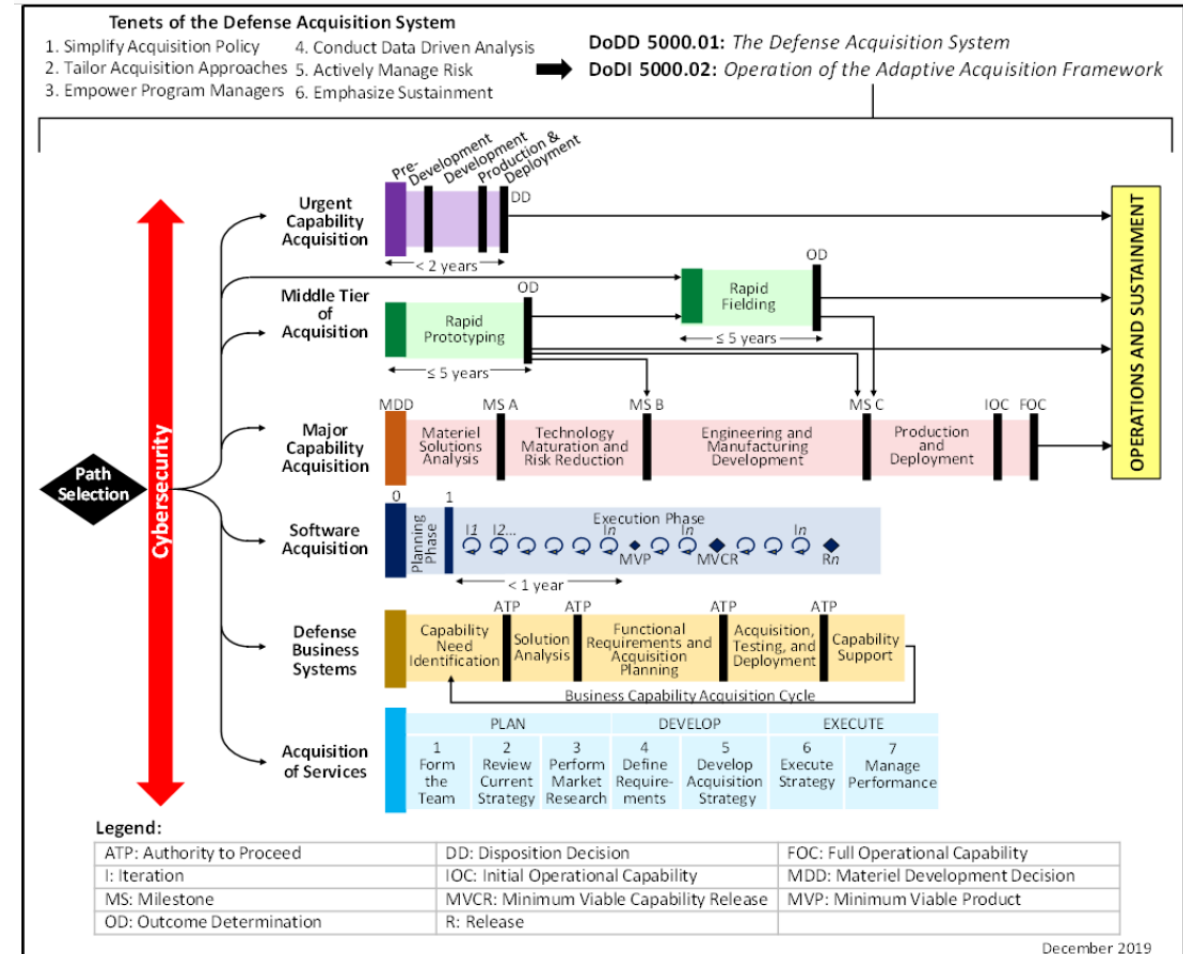
Agenda

Digital Engineering-based Acquisition and Systems Engineering Lifecycle Management

- Acquisition lifecycle process overview
- System Engineering and reviews
- Model-enabled systems engineering
- Using Models to Successfully ***Execute a Review***
- Defining model-based ***MCA Lifecycle Process Execution***
- Using a models to Support Transition to the Digital Engineering (DE) Context

DoD Adaptive Acquisition Framework

- The DoD recognizes many several acquisition processes
- Specific definitions of maturity coupled with specific definitions are unique to each acquisition
- Most large acquisitions follow the Major Capability Acquisition process
- Other federal agencies follow similar process as shown in the AAF

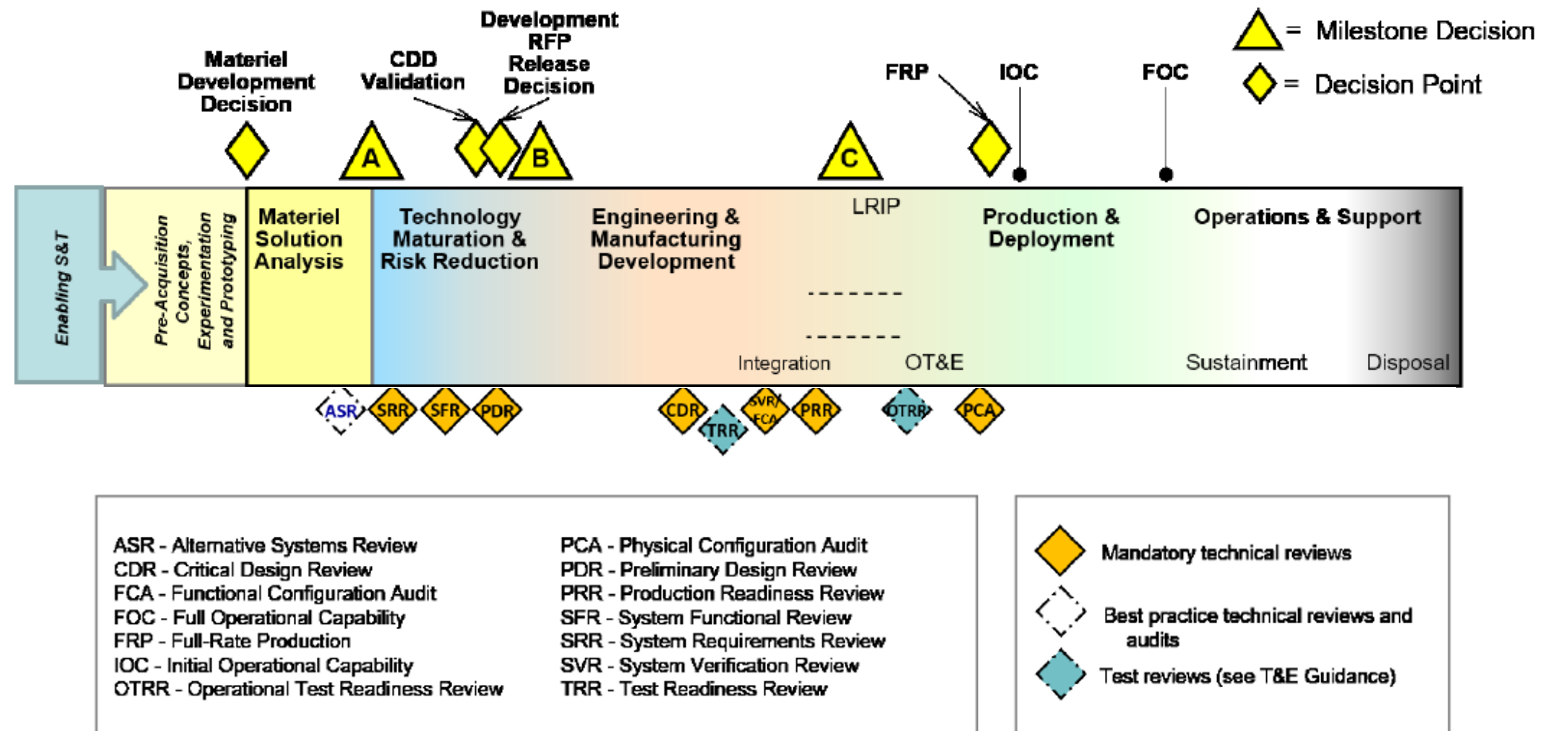


Reference: DoDI 5000.02 §4, Figure 1 [2020]

Major Capability Acquisition (MCA)

Depending on the acquisition, the lifecycle maturity timeline can span many decades

- The MCA defines the end-to-end lifecycle of an acquisition as it matures through time
- The MCA acquisition lifecycle is punctuated by milestones and decision points
 - *Although the acquisition lifecycle timeline is a continuum, its milestones and decision point events are conducted as disconnected events*
- In parallel, the system engineering (SE) end-to-end maturity lifecycle is punctuated by SE reviews
 - *Correspondingly, its SE lifecycle reviews are executed as disconnected events using disparate documents, sometimes models, and data*
 - *The data used in these reviews are often known as descriptive data*
- ***Descriptive data and models developed in SE reviews are also contained in acquisition lifecycle event artifacts***



This timeline is not to scale

The DE context can change this de facto process

System Engineering Reviews

Details



- Reviews demonstrate the contractor's understanding of the acquisition throughout its lifecycle to the government
- There are specific definitions of maturity for each review defined in the DoD SE Guidebook
 - *Evidence for review success is **inferred** through review of contractor-generated artifacts*
 - *Although entrance and exit criteria **examples** are shown in the DoD SE Guidebook, the government defines **actual** criteria for each review in the contract*
 - *Contractors must successfully complete review to receive authority to proceed to the next review phase*
- In accordance with the DoD SE Guidebook, each review is best executed using the same process from each review
 - *The entrance and exit criteria for each review changes **because** the acquisition matures*
- The key outcomes of each review is **authority to proceed** to the next phase/milestone and a ***new descriptive requirements baseline***
- Incorporating SE with models, specifically model-based system engineering, provide better details and greater insight into acquisition maturity and increase the likelihood of review success



Models and Data in a Successful Review

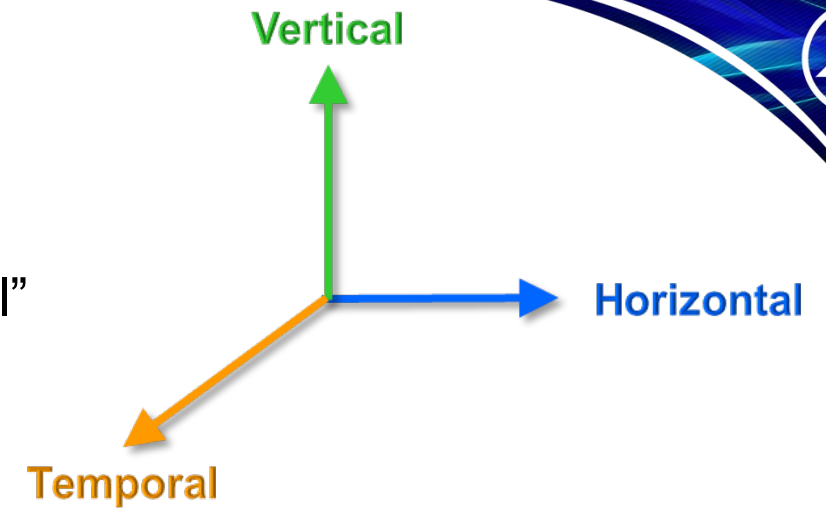
Successful PTR execution requires underpinned models with purpose

- To execute a successful review with models in the DE context, the models and data must be purposely traceable and “connect-able”
- Because a key outcome of each PTR is an approved requirements baseline, the overarching program model must define traceability in 3 dimensions
 - *Vertically traceable to ensure integration up, down, and through a program*
 - *Horizontally traceable to ensure addressing impacts as well as integration across related systems in a SOI or portfolio*
 - *Temporal traceable to ensure version and CM baseline control over time – at the very least, each PTR will generate a new baseline*
- Connect-ability means that models must be built so that they can be understood and reconstructed anyone anywhere
 - *Using neutral standards, SysML, UAF, etc.*
 - *Use design templates applicable parts of models and data can connect with the least difficulty*

Systems Engineering 101

Requirement Elicitation and Traceability

- **Vertical** and **horizontal** traceability are defined in the “traditional” capabilities/requirements hierarchical ASOT in a requirements management (RM) tool and define a new requirements baseline at the conclusion of each successive SETR
 - **Vertical (y-axis)** traceability is defined by bidirectional decomposition and allocation of capabilities and requirements within a single system or system of systems. Vertical traceability represents “generational decomposition/allocation from “grandparent” to “parent” to “child” and so on, that is, $1 \rightarrow \text{many} \rightarrow \text{many more} \rightarrow \text{etc.}$
 - **Horizontal (x-axis)** traceability is defined through “sibling” relationships, that is, relationships between capabilities/requirements that are at the same level of abstraction. Horizontal traceability, for example, trace/relate constituent systems in a system of systems (SoS).
- **Temporal (z-axis)** traceability manages successive requirements and model baselines as they progress/mature through time



In general, descriptive requirements cover about 80% of the total system/program requirements





The Other 20% Requirements

For every review, there are additional requirements outside of mission documentation

- Other specs/requirements that are levied on programs include those that are imposed by the enterprise and outside of the system or program; these can include (not an exhaustive list)
 - *Safety*
 - *Reliability*
 - *Quality*
 - *Maintainability*
 - *Resilience*
- These requirements are also part of the baseline even though they do not trace to the system/program. They can have an impact on solution delivery; omission of these requirements will have a distinct negative impact on lifecycle progression and events.

Models can show the relationship of these overarching requirements to the mission – these are not parent/child “traditional” relationships

Robust Systems Engineering

The Secret Sauce: A Socio-Technical Problem with a Socio-Technical Solution

- Connect-ability

- Top-down rules and guardrails – defined in overarching concept model
- Development of models that follow a similar design structure
- Curation, management, and development of disparate authoritative sources of truth (ASOTs) that contain the data elements that when interconnected by models that define digital threads, build the digital engineering (DE) data ecosystem

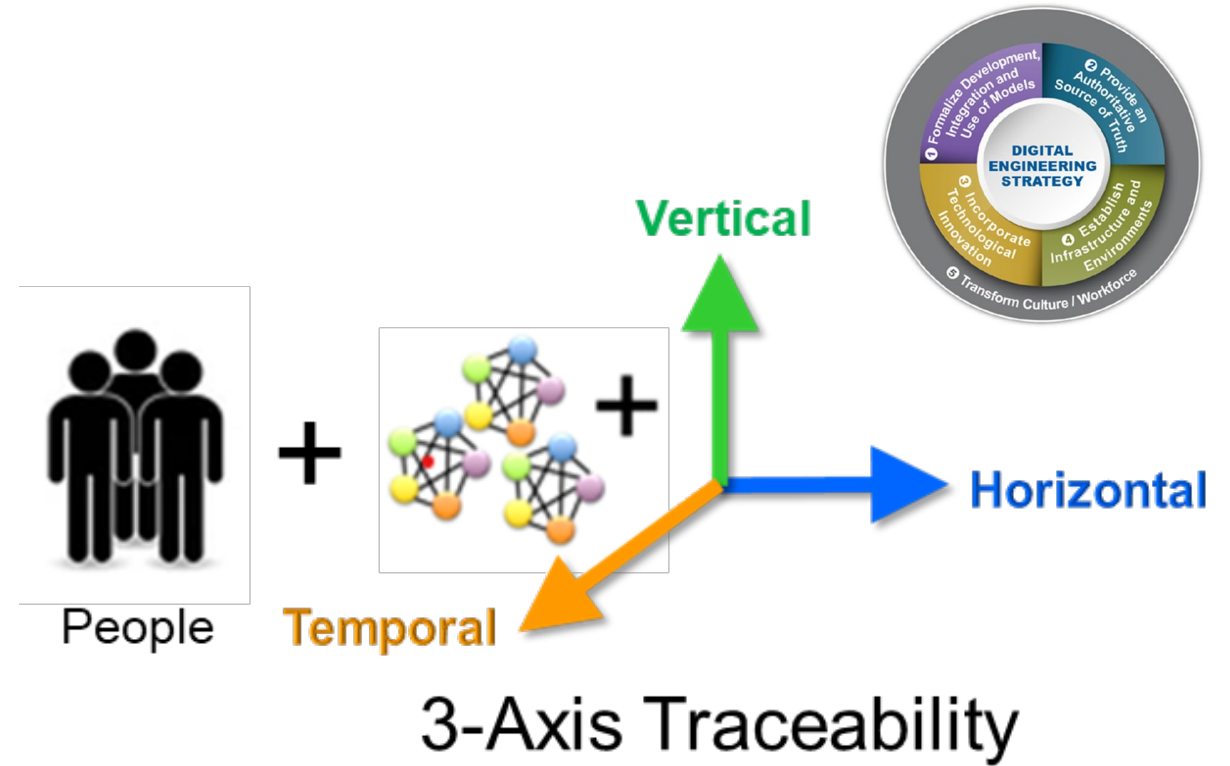
- Traceability

- Vertical
- Horizontal
- Temporal

- End-to-End Lifecycle management

Connect-ability + Traceability + Lifecycle Management = Integrate-ability

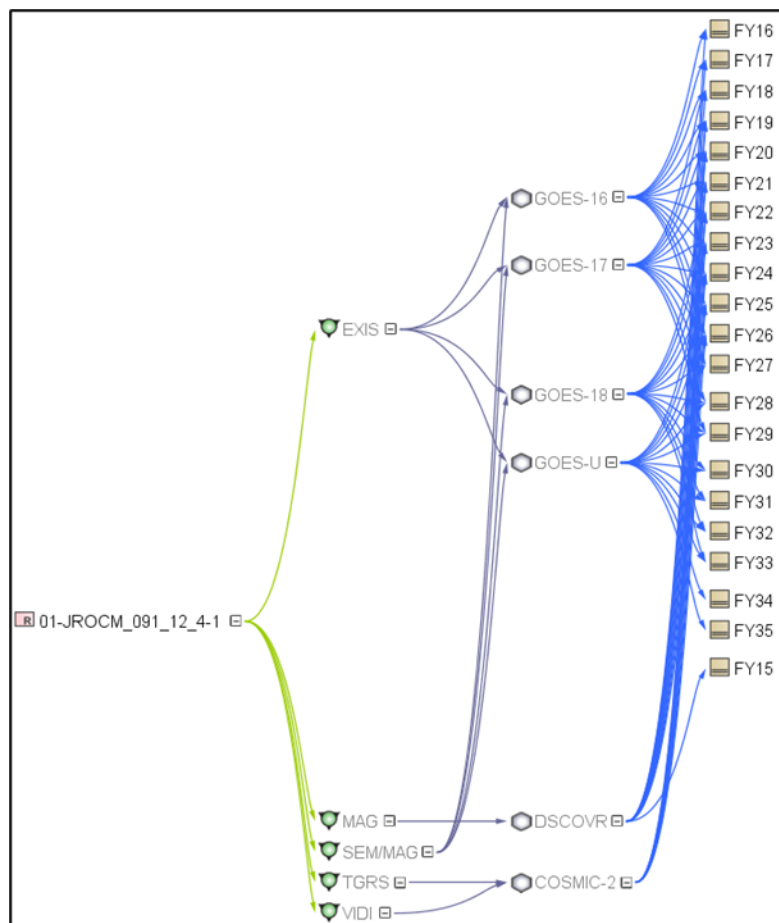
Models-based Architecture Systems Engineering Requirements Management Successful Outcome



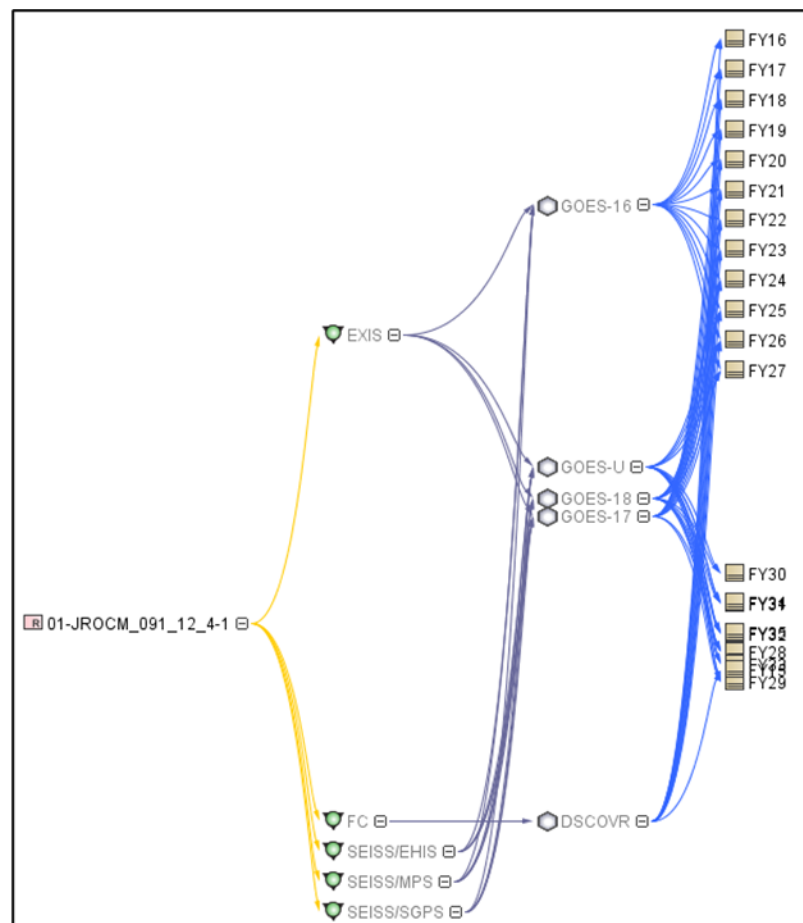
MBSE – Ionospheric Density (Detail View)



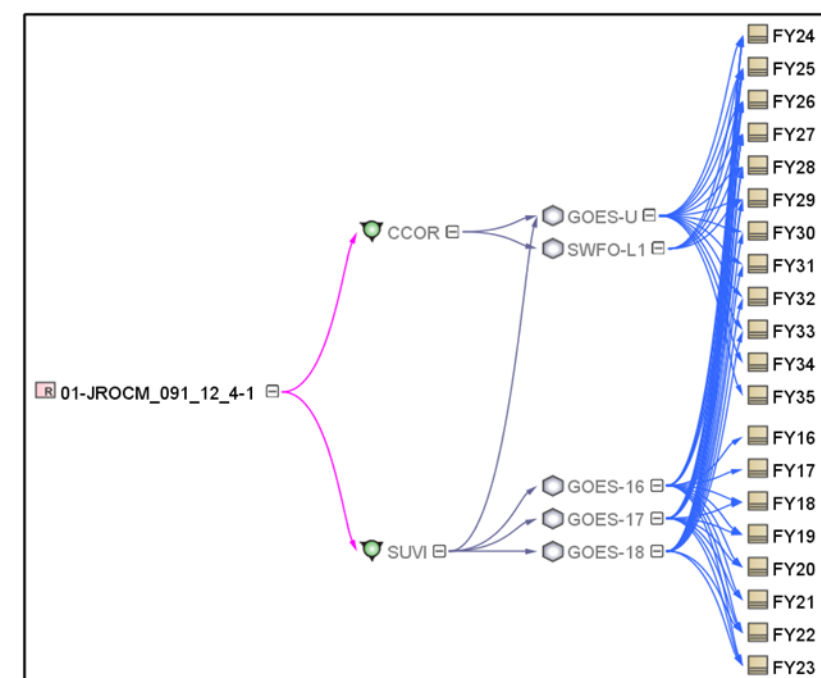
High



Medium



Low

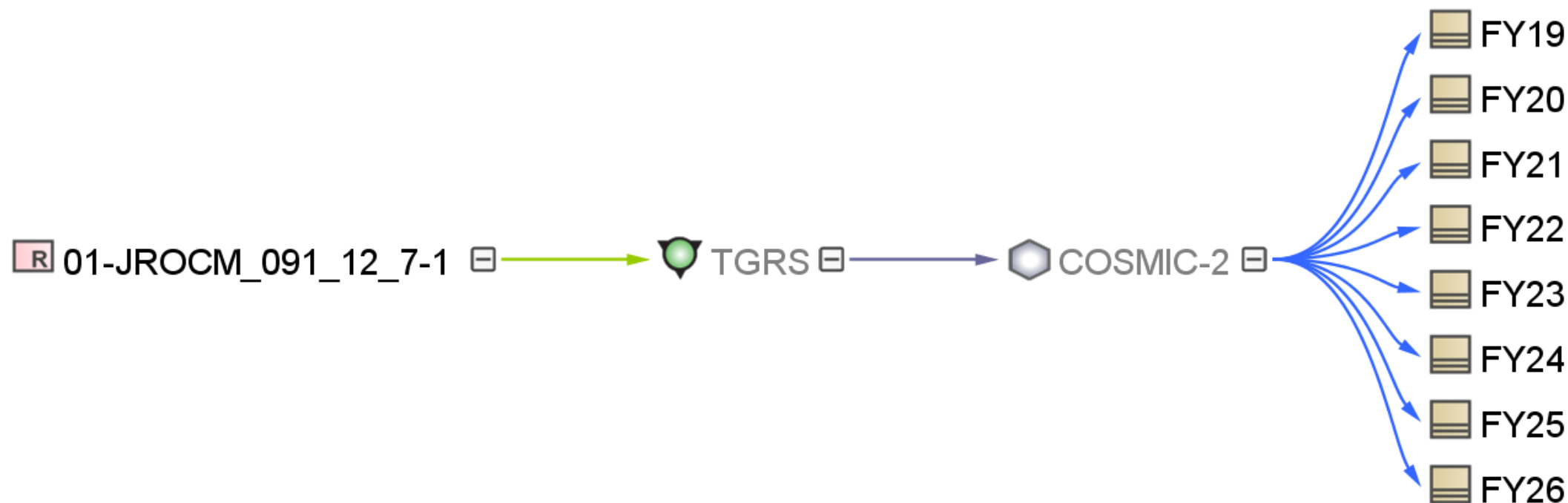


Legend

- Allocated From
- High Satisfied By
- Low Satisfied By
- Medium Satisfied By
- Part Of
- Multiple (two-way)

Model-based SE analyses of several source documents uncovers capability gaps (to include temporal), overlaps, unintended duplications, and defines relationships between key mission elements

MBSE – Gap Analysis Equatorial Ionospheric Scintillation



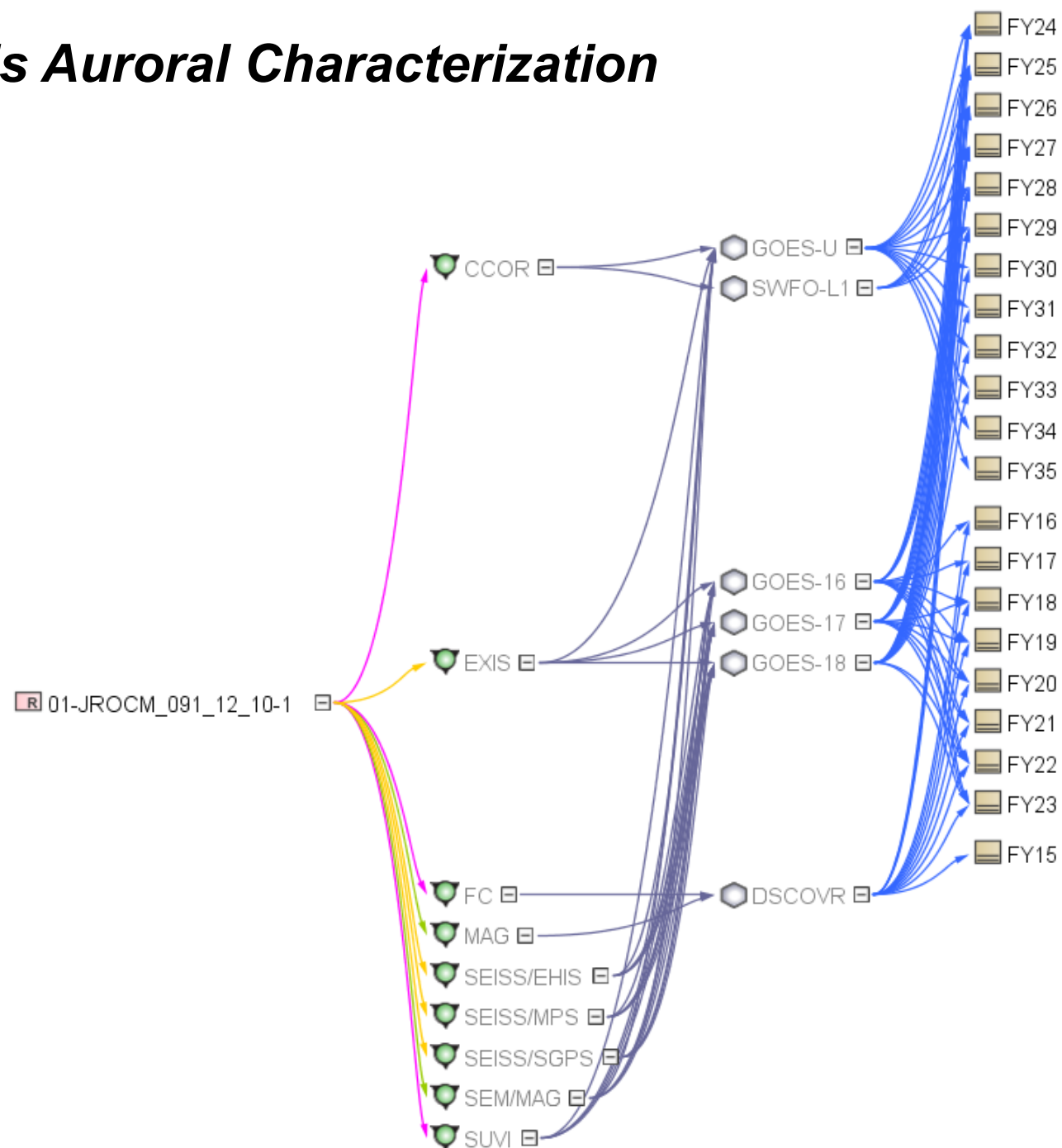
- TGRS measures ion density and scintillation but while it is sort of remotely sensed, it is doing it in the same fashion as a SATCOM signal, for example, would travel.
- It could also be only 'partial' because there is no long-term plan to replace COSMIC-2.

Legend

- Allocated From
- High Satisfied By
- Low Satisfied By
- Medium Satisfied By
- Part Of
- Multiple (two-way)

MBSE – Gap Analysis Auroral Characterization

- Low - CCOR, SUVI, FC
- Med - EXIS, SEISS
- Hi - MAG



Legend

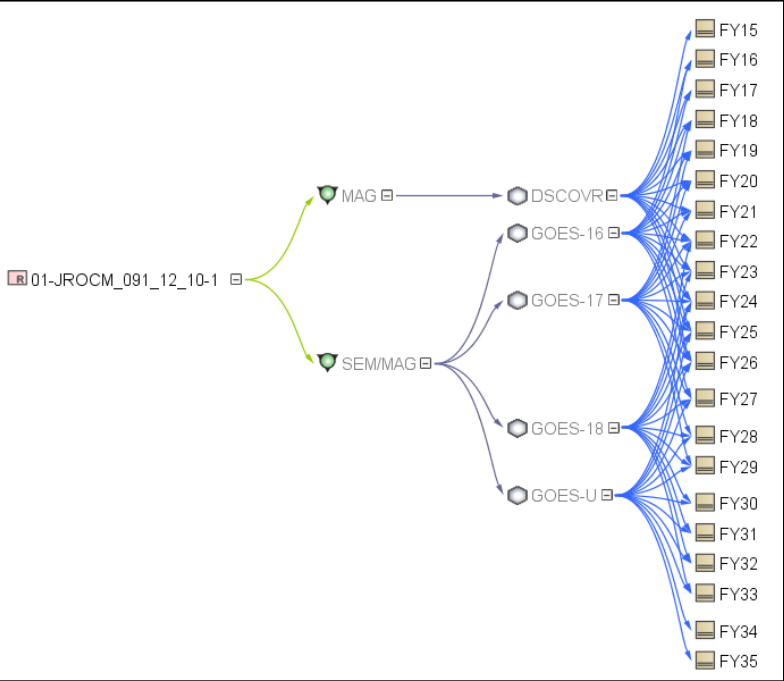
- Allocated From
- High Satisfied By
- Low Satisfied By
- Medium Satisfied By
- Part Of
- Multiple (two-way)



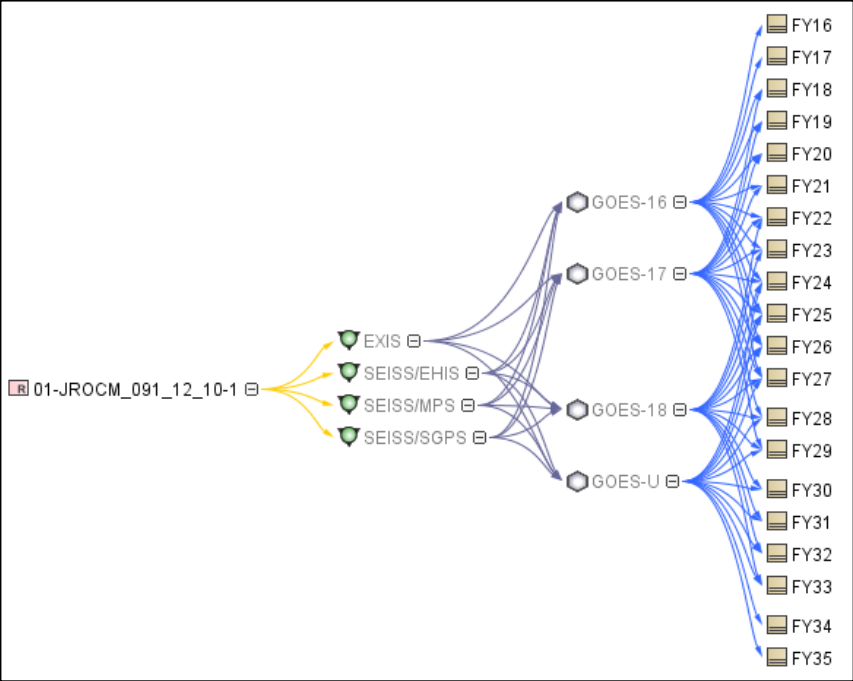
MBSE – Gap Analysis Auroral Characterization (Detail View)



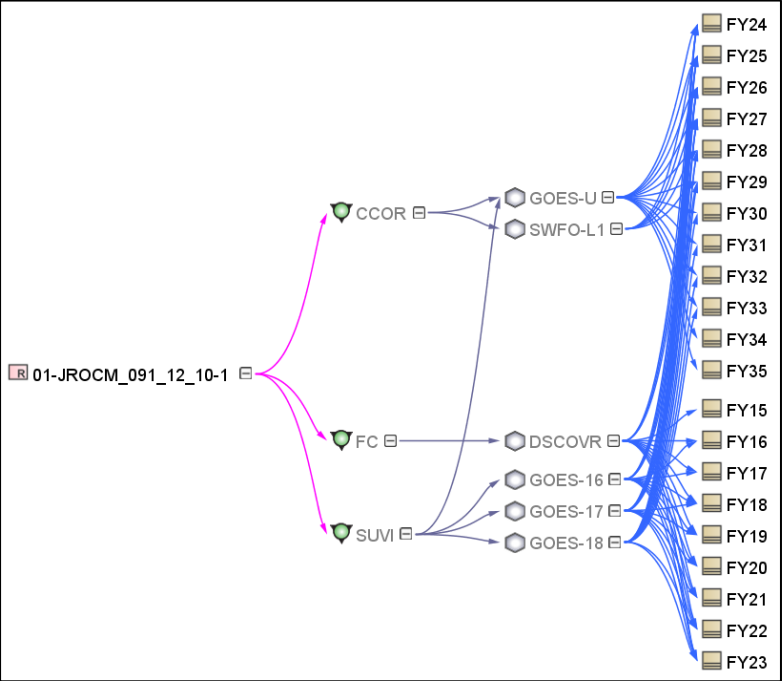
High



Medium



Low



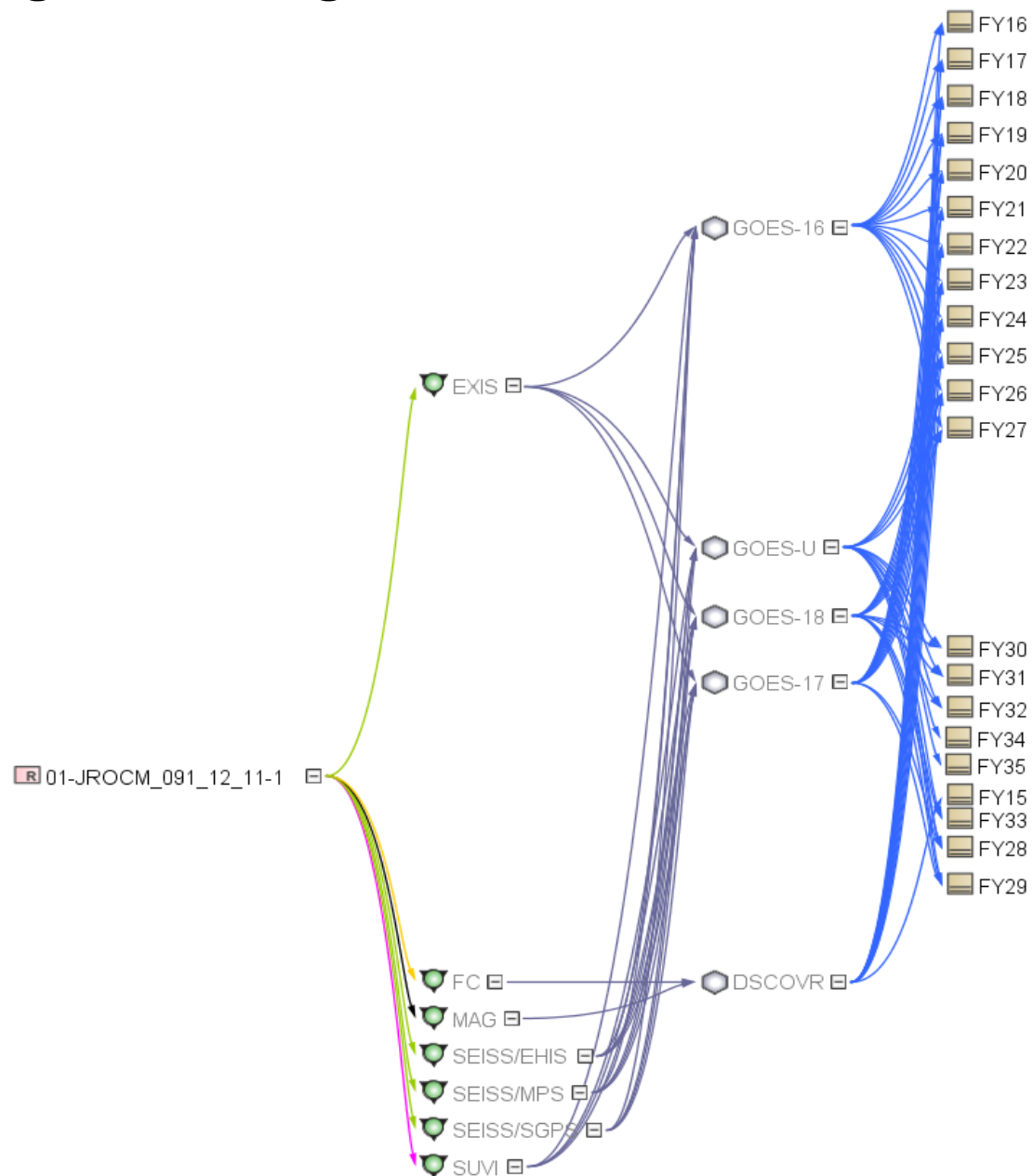
Legend

- Allocated From
- High Satisfied By
- Low Satisfied By
- Medium Satisfied By
- Part Of
- Multiple (two-way)

MBSE– Gap Analysis Energetic Charged Particle Characterization



- Low - SUVI
- Med - FC, MAG
- Hi – MAG, EXIS, SEISS



Legend

- Allocated From
- High Satisfied By
- Low Satisfied By
- Medium Satisfied By
- Part Of
- Multiple (two-way)



Better SE Delivers Better Reviews

- Robust systems engineering, that is, Models with Requirements can generate a more comprehensive and robust review outcome
- Modeling tools and requirements management (RM) tools (RMTs) working in tandem are the backbone of better reviews
- Historically, requirements and exit criteria has enabled execution of challenging reviews – often not enough to ensure that a contractor understands the entire system lifecycle
- Models alone do not provide adequate information to successfully pass any SETR
- However applying SE rigor in requirements management and modeling – using RTMs with modeling tools – can better deliver the evidence in each review that demonstrates that the contractor fully understands all the requirements throughout the maturity lifecycle

This chart deck will discuss how RM with MBSE will increase the likelihood of SETR success.

Model-Enabled Artifacts versus Model-Enabled (DE-Based) MCA Process



- An MCA review can contain documents, models, and data as its artifacts (IAW contact terms)
- The greater the dependency on models and data for a review (and subsequent reviews), the greater the lower the acquisition risk
- Executing the MCA lifecycle process as a DE-based process lowers the acquisition risk even more because it imposes continuity in the acquisition and SE lifecycle continuum – inserting consistency and greater SE engineering rigor into the MCA lifecycle process



Specific Models Required to Model-Enabled Lifecycle Reviews

- **3 Activity models**

- ***[Persistent must occur first]*** Transformation from document-based to DE-based process*: the process of transitioning document artifacts and non-lifecycle process-specific models to 3-axis traceability-focused models and data – see back-up
- ***[Persistent]*** Acquisition lifecycle process: the progression of program maturity/temporal traceability and include acquisition milestones and SETRs
- ***[Persistent]*** Baseline management process: analogous to change, version, and configuration management (CM) process but applicable to all elements that define a baseline in the DE context, that is, requirements, models, data elements, and interfaces (for future Phase activity)

- **3 Descriptive Data models**

- ***[Persistent]*** Comment Resolution Matrix (CRM) whose data are part of the aligned to the horizontal, vertical, and temporal traceability
- ***[Persistent]*** Horizontal and vertical traceability: traditional requirements "trees" and connecting everything
- ***[Program-dependent]*** Mission thread: models that interconnect data elements from disparate authoritative source of truth (ASOT) data sources that define the mission thread

***Needed regardless whether "born digital" or not**



Context for DE-based, model-enabled lifecycle maturity

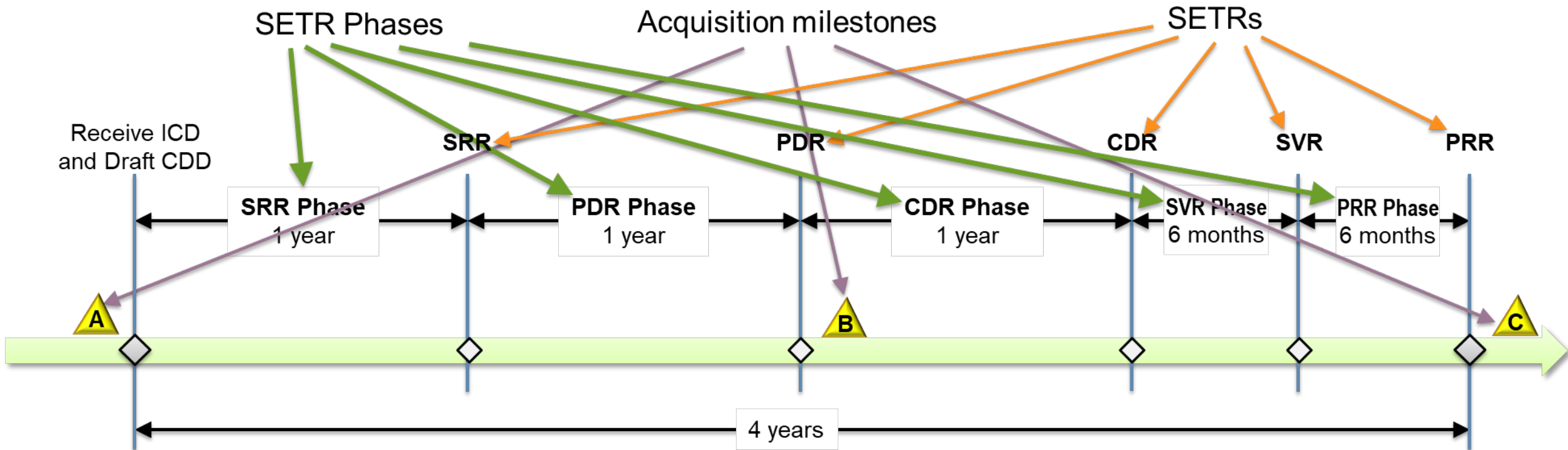
- The SE lifecycle process incorporates SE best practices and rule-based baseline management into the lifecycle process
- The model-based SE lifecycle process is a temporal continuum in which data and models grow, detail, and evolve over time
 - *Top-down model-based systems engineering (MBSE) is concurrently built into the lifecycle process*
 - *Models are purpose-built to enable lifecycle systems engineering*
- Data and model authoritative sources of truth (ASOTs) baselines are defined, retained, and managed as they evolve and mature through the systems engineering lifecycle temporal continuum
- A consistent hybrid-agile SE execution process governs lifecycle maturity to ensure consistent enterprise, portfolio, system, and program lifecycles
- DE-based and traditional MCA process execution DO NOT MIX WELL: the best result will be achieved if an acquisition initiates as DE-based as opposed to transitioning while the acquisition is in progress
- If a MCA for a particular acquisition is in progress and the decision has been made to transition to DE-based acquisition, execution of the transition model must occur **prior** to the beginning of a review phase

Developing and using models within the Acquisition Lifecycle ≠ MBSE Acquisition Lifecycle



Typical Current Lifecycle Process Execution – Milestones A - C

For this exemplar, major capability Milestones A thru C spans 4 years

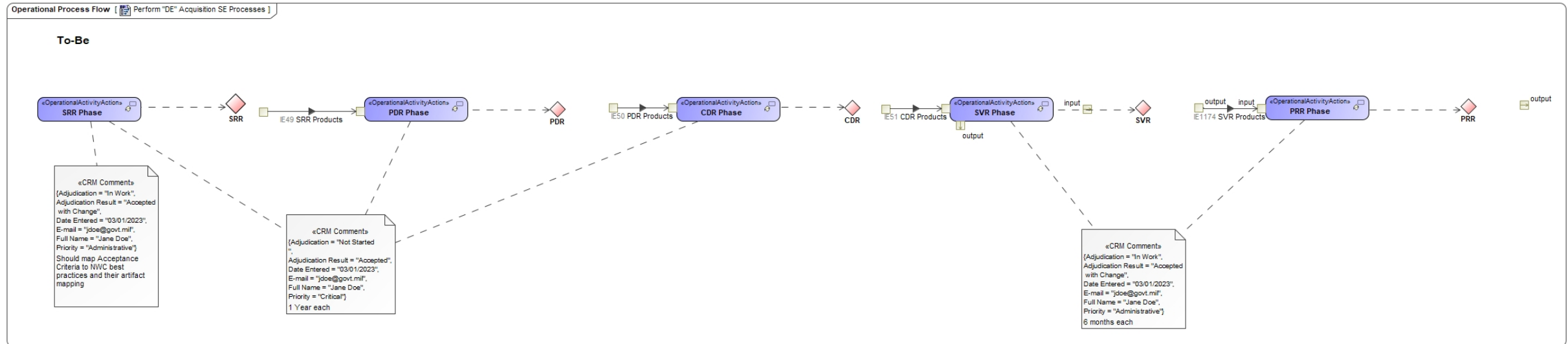


- For simplicity, this exemplar assumes a major capability acquisition where
 - *SRR, PDR, and CDR Phases are 1 year each*
 - *SVR and PRR Phases are 6 months each*
 - *Each SETR involves only 1 event and 1 contractor*

DE-Based Lifecycle Execution

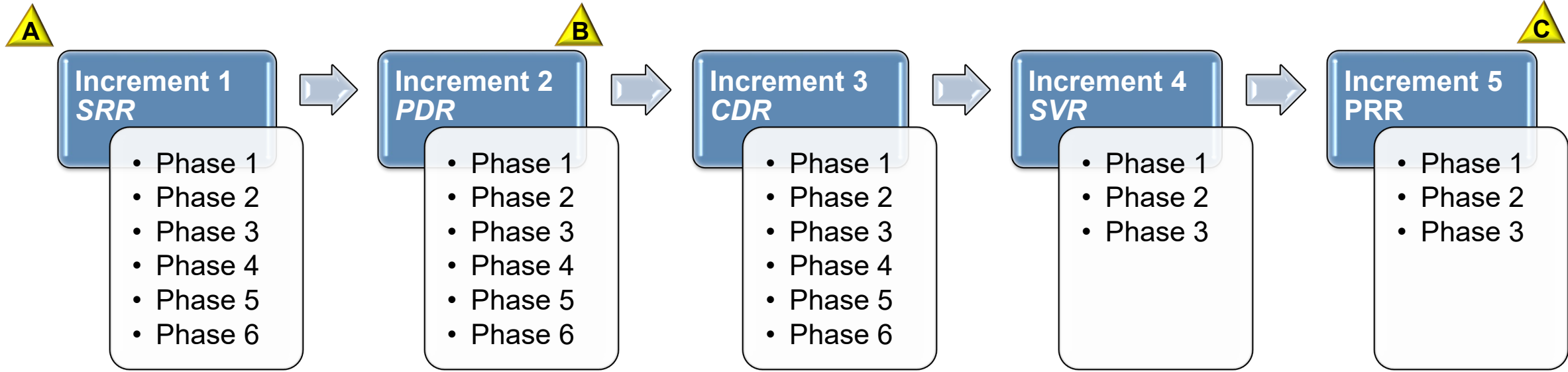
Model-Based

- The DE-based Acquisition lifecycle process is executed in a hybrid/agile process with reviews punctuating each Increment
- This pathfinder covers 5 phases between Milestones A and C as defined in DoD Systems Engineering Guidebook § 3, Figure 3-1 [2022] and other references
 - *Passing reviews ensure that the maturity levels expected at various places in the lifecycle time have occurred*



SE DE-Based Continuous Lifecycle Process between Milestones A and C

Activity model architecture highlights

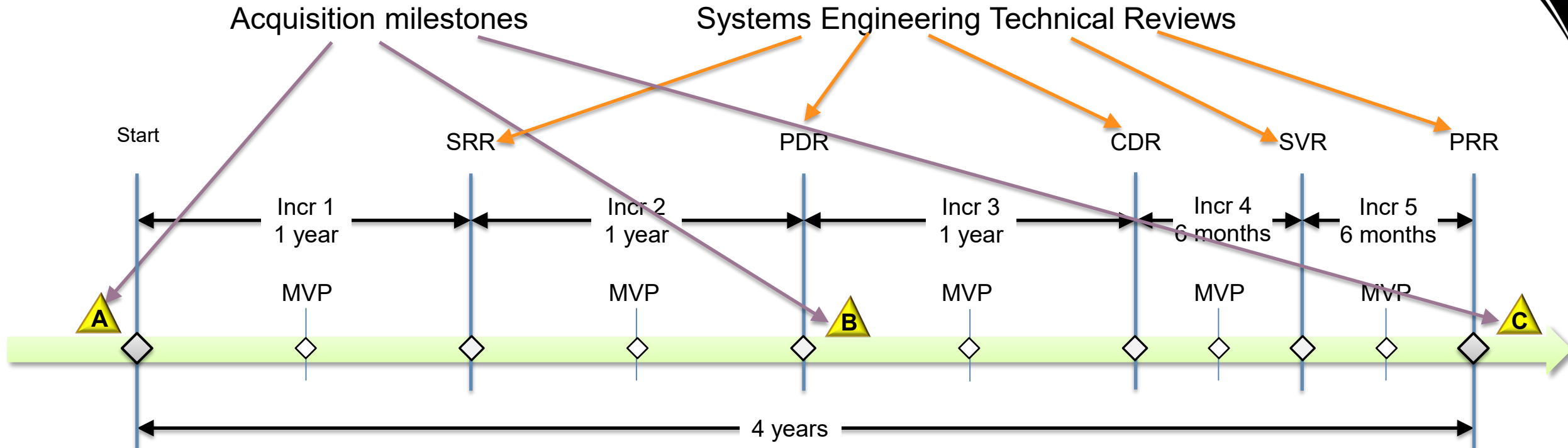


- The DE-based Acquisition lifecycle process is executed in a hybrid/agile process with PTRs punctuating each Increment
- This pathfinder covers 5 Increments between Milestones A and C as defined in DoD Systems Engineering Guidebook § 3, Figure 3-1 [2022] and other reference documents
 - *Passing PTRs ensure that the maturity levels expected at various places in the lifecycle time are true*
 - *In the future, if the Acquisition lifecycle is defined by a hybrid/agile process, PTRs can be replaced by reviews/demonstrations within the hybrid agile cadence*



DE-Based Execution – Milestones A – C (detail)

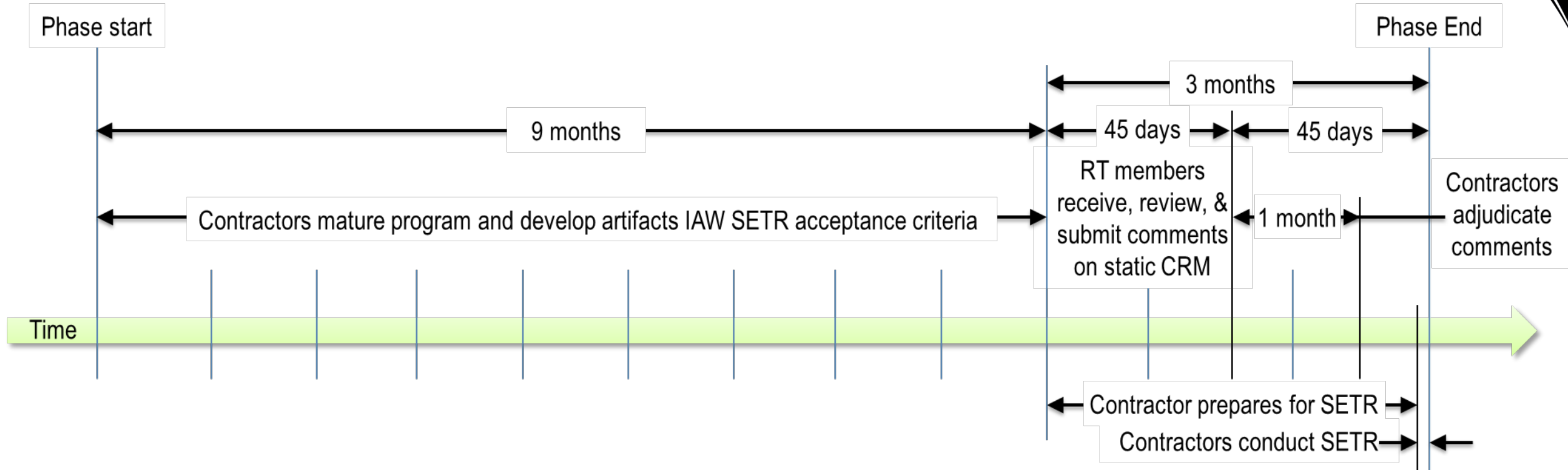
For this pathfinder, major capability Milestones A thru C spans 4 years



- This pathfinder assumes a major capability acquisition where
 - Increments 1, 2, 3 are 1 year each
 - Increments 4 and 5 are 6 months each
- Increment 1 closes with a SRR SETR
- Increment 2 closes with a PDR SETR
- Increment 3 closes with a CDR SETR
- Increment 4 closes with a SVR SETR
- Increment 5 closes with a PRR SETR

Typical Current Lifecycle Process Execution – Maturity Phase Detail

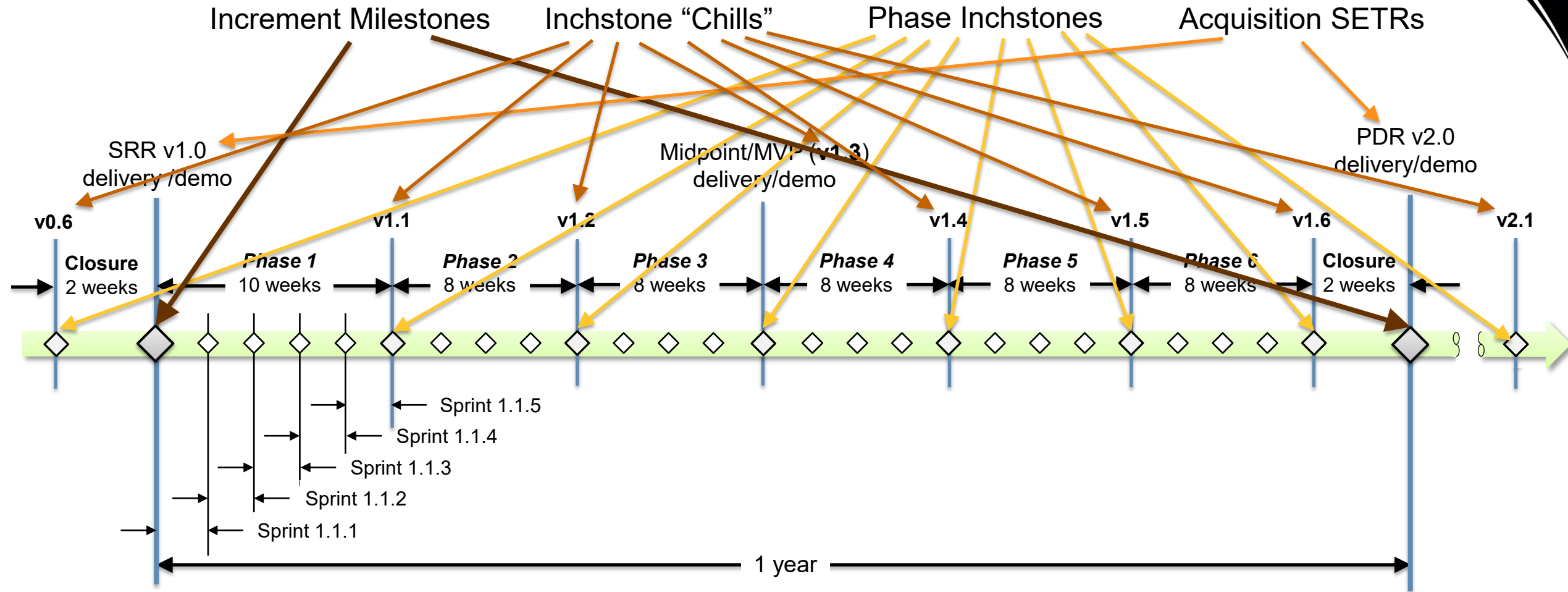
1-year lifecycle phase



- Typically, SETR and Milestone artifacts are not the Phase work products, they are evidence of completion of Phase work products
- Thus with current process, there is a bifurcation between actual work accomplished and evidence that the Phase is successfully passed

Maturity Phase Technical Review Execution with Models and Data

Exemplar: PDR Execution



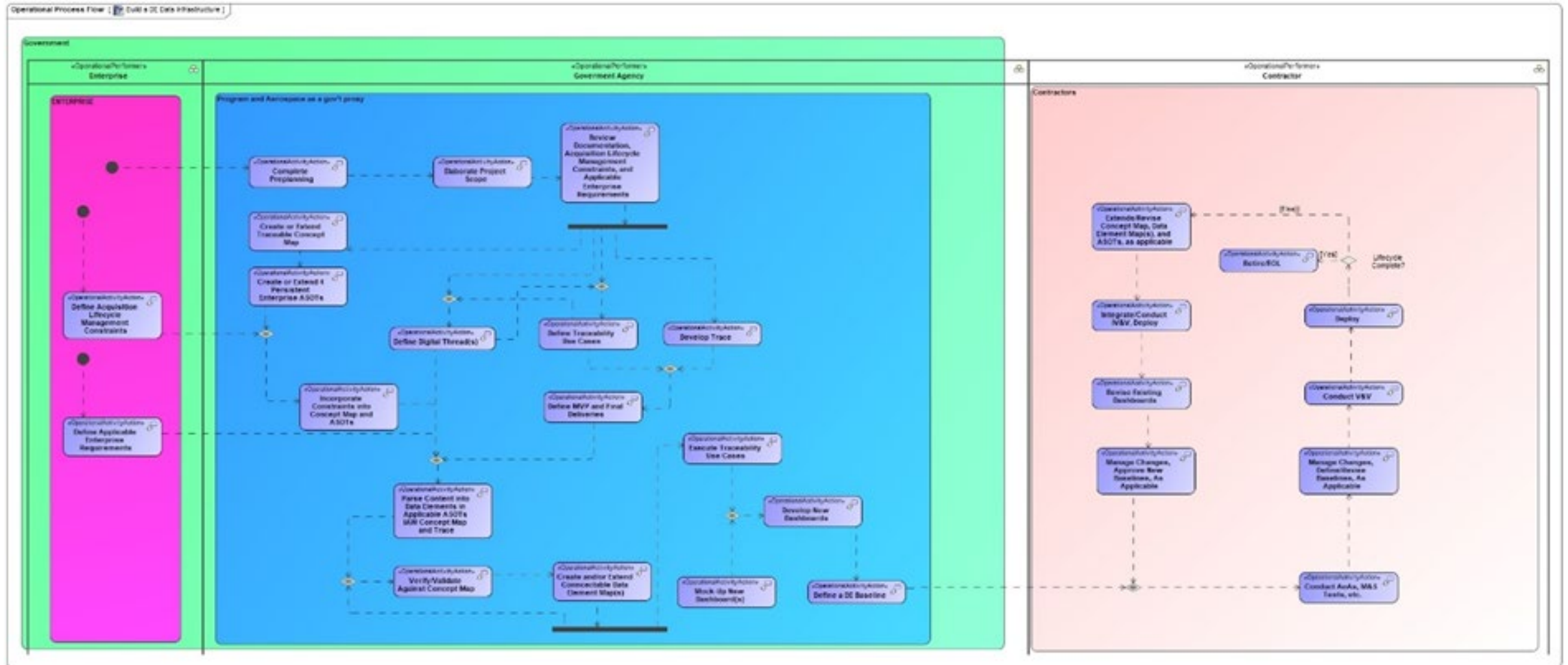
- Each phase

- Concludes with an “Inchstone” event and is identified as vX.Y where X is the previous PTR version # (for Inchstone events leading to SRR, X = 0) and Y is the current phase #
- Delivers a minimum viable product (MVP) at the midpoint of its execution



Transformation Model: From Document-Based to DE-Based

Every Program must transition prior to Start of Phase to establish a DE-based baseline





In Summary....

- The likelihood of acquisition success can considerably improve, and risks can significantly decrease if SE, MBSE and DE-based best practices underpin the acquisition lifecycle
- Incorporate SE best practices for development of maturity artifacts
- Use data and models for lifecycle artifacts
- Apply models to execution of the acquisition lifecycle to ensure continuity and consistency

All are needed for success and all will transform the organization



Thank you



Requirements, Reference Architectures, and CONOPS

Scott Schnee

February 2025



Requirements Management using MBSE

NOAA/NASA Joint Program Examples

Goals

- Trace and model requirements for future NOAA/NASA joint flight programs to define the horizontal, vertical, and temporal relationships
- Carry out the trace using Model Based Systems Engineering (MBSE) tools and techniques as pilot to inform decisions on what tools and methodologies to use for requirements management as these future programs progress through the acquisition lifecycle

Scope

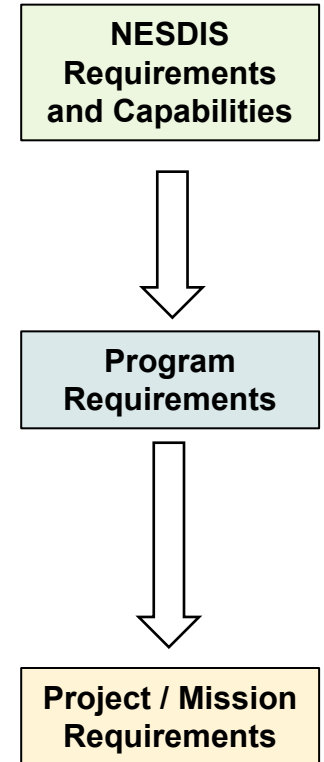
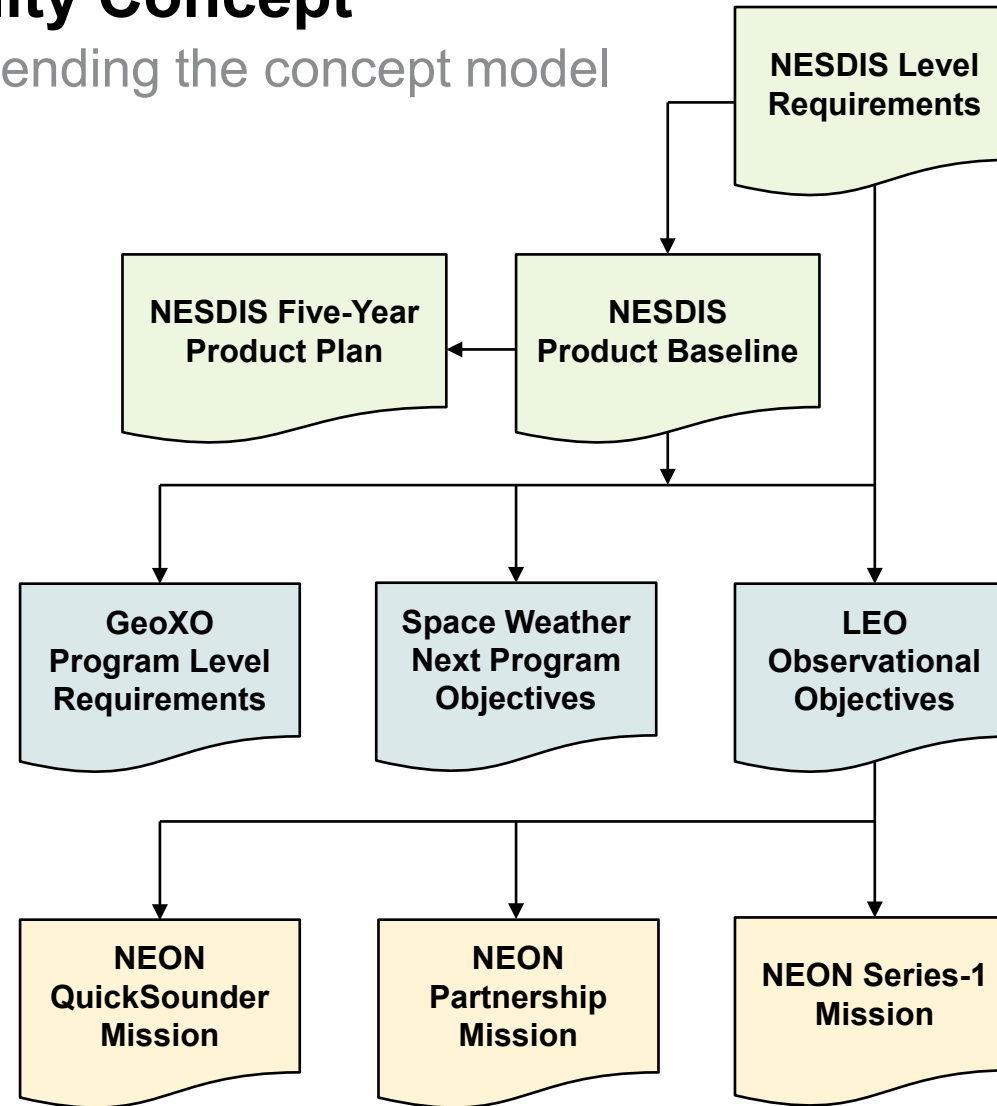
- Geostationary Extended Observations (GeoXO)
 - Successor to NOAA's current Geostationary Operational Environmental Satellites (GOES-R) Series
- Space Weather Next (SW Next)
 - Maintain and extend space weather observations from several orbital regimes
- Near Earth Orbit Network (NEON)
 - Successor to NOAA's current Joint Polar Satellite System (JPSS) series of low earth orbit satellites
- All three (GeoXO, SW Next, NEON) are in formulation and design phases



NESDIS Enterprise Traceability Concept

Vertically and horizontally tracing/extending the concept model

- Model is a user-friendly visualization of the requirements authoritative source of truth (ASOT) with traceability of requirements from NESDIS to each mission
- Model includes high level NESDIS requirements, program requirements for each of the three major flight programs, and some of the project/mission level requirements for the flight programs



Model include SW Next mission requirements; NEON is highlighted for clarity



Trace: Tools Used and Value-Based Artifacts Delivered

- **Platform tools used**

- Requirements/Lifecycle Change Control and management: Jama
- Modeling: Cameo
- Data Broker: Syndeia

- **ASOTs Revised:**

- NESDIS ASOTs
 - Capabilities/requirements
 - Architecture

- **Models revised and created**

- NESDIS overarching semantic data model (revised)
- Data interconnection models (revised/added)

- **Model views revised**

- Relationship diagram
- Project matrix

- **Digital threads revised and created**

- NESDIS Enterprise traceability thread (revised)

- **Use cases developed**

- Bottom-up and top-down enterprise traceability (gaps, overlaps, conflicts)



What we can do or do better than before

Value of Traceability with Modeling

- Requirements reviews are much faster, and requisite changes can also be adjudicated much faster
- Real-time enterprise situational awareness
 - Of current baseline and all previous baselines
 - Because models can relate elements regardless of what they are, the enterprise is more comprehensively defined as relationships not only of requirements to one another, but of all enterprise elements to one another
- Quick identification and resolution of “suspects”
 - Address suspects early to ameliorate their impact further down the program lifecycle
 - Suspects are interconnected with other parts of the program and the enterprise; when mitigating impacts of any given suspect, make sure to include analysis of the impact(s) to other program and enterprise elements; while mitigating
- More consistent configuration management (CM) and baseline management
- Open and neutral model interfaces enable re-use of data: requirements and model data can be read into other applications and data from other application can be read into the model
- Enables adoption by NOAA/NASA program offices and integration into the broader NASA Digital Transformation
 - <https://www.nasa.gov/digital-transformation/>

Enables the NOAA and NASA systems engineers to do their work faster and with fewer errors



NASA Adoption of Digital Engineering

Connection with NOAA/NASA program efforts

- NASA has adopted a digital transformation strategy, which the requirements management pilot efforts described above fit into
 - NASA's digital transformation strategy: <https://ntrs.nasa.gov/citations/20230002095>
 - Digital Transformation is housed within NASA's OCIO (Office of the Chief Information Officer) with OCE (Office of the Chief Engineer) as a primary stakeholder
 - NASA offers training via its SATERN Digital Academy to develop job-based digital competences as well as common enterprise-wide digital literacy practices
 - Pilot studies show how to “Streamline critical workstreams within the domain”
 - Eliminate, Optimize, Automate workflows to address process bottlenecks & redundancies
 - Evolve from paper-centric to integrated data/model-centric approaches
 - Maximize shared services & role-based access to enable geographically agnostic Future of Work
- NASA's Jet Propulsion Laboratory recently decided to switch from DOORS NextGen to Jama as the institutionally-supported requirements management database
 - <https://ieeexplore.ieee.org/document/10520996>
- GSFC DE effort also includes requirement management, with Jama support
 - <https://ntrs.nasa.gov/citations/20230006041>

Jama requirements for SW Next, GeoXO, and NEON fit within broader NASA and GSFC digital strategy



Expanding the NOAA/NASA Requirements Model

Next steps

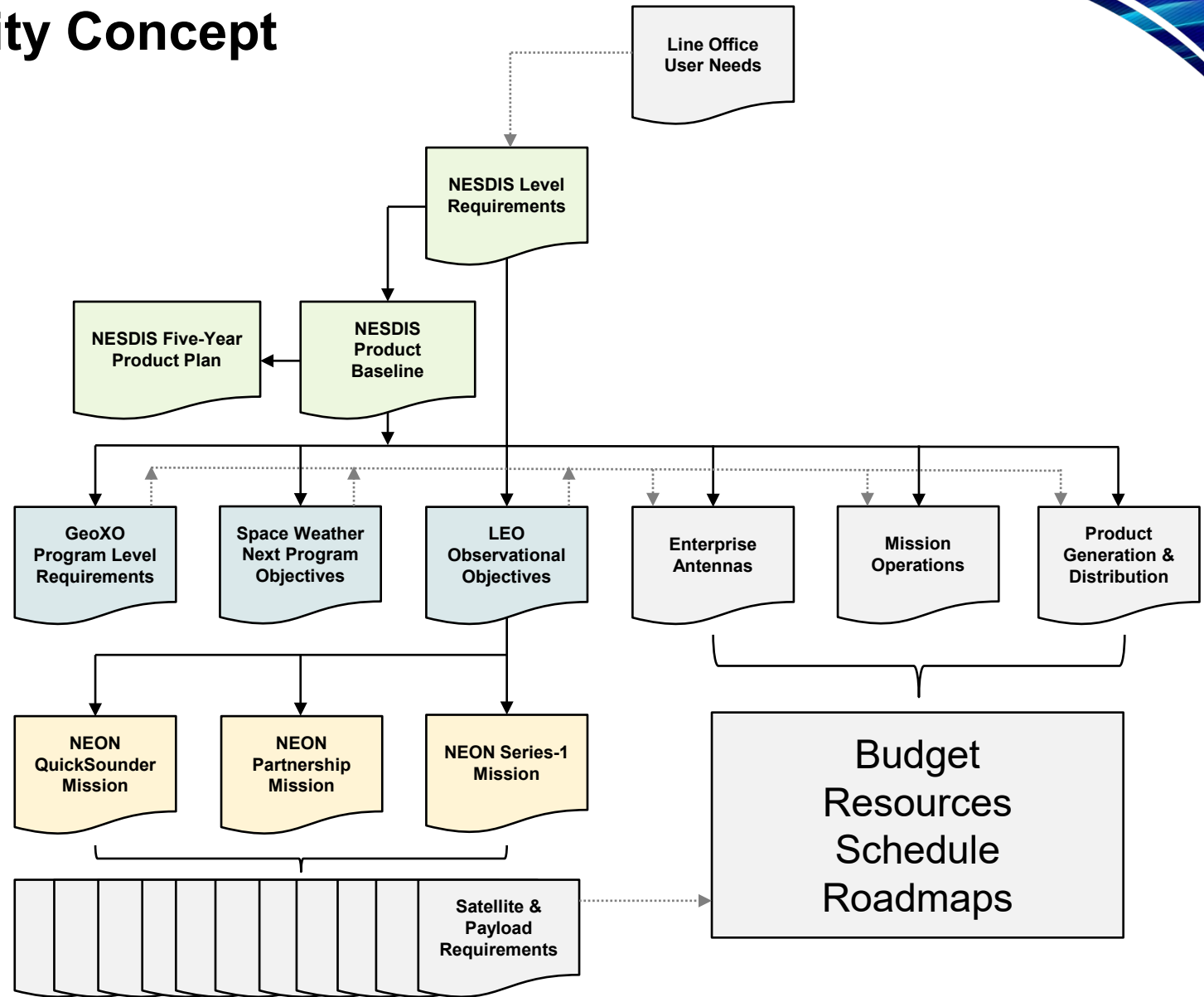
1. The Office of Space Weather Observations is building upon the requirements model to allow a CONOPS model
2. Adding ground programs to the model
 - Enterprise antennas
 - Mission operations
 - Product generation, distribution, and archive
3. Connecting requirements to user needs
 - User needs are passed to NESDIS by the other NOAA line offices
 - NOAA Marine & Aviation Operations, NOAA Marine Fisheries Service, National Ocean Service, Office of Oceanic and Atmospheric Research, and the National Weather Services
 - NESDIS' Office of Systems Architecture and Engineering creates the program level requirements
 - Other offices within NESDIS are given responsibility to satisfy the program requirements
 - E.g., the Office of Space Weather Observations leads the Space Weather Next program
 - The flight programs (LEO, GEO, Space Weather) are joint with NASA
 - Need to find a way to connect the efforts across offices and agencies

Next steps are to build on the pilot efforts and coordinate future development across stakeholders and networks

NESDIS Enterprise Traceability Concept

Expanding the Requirements Model

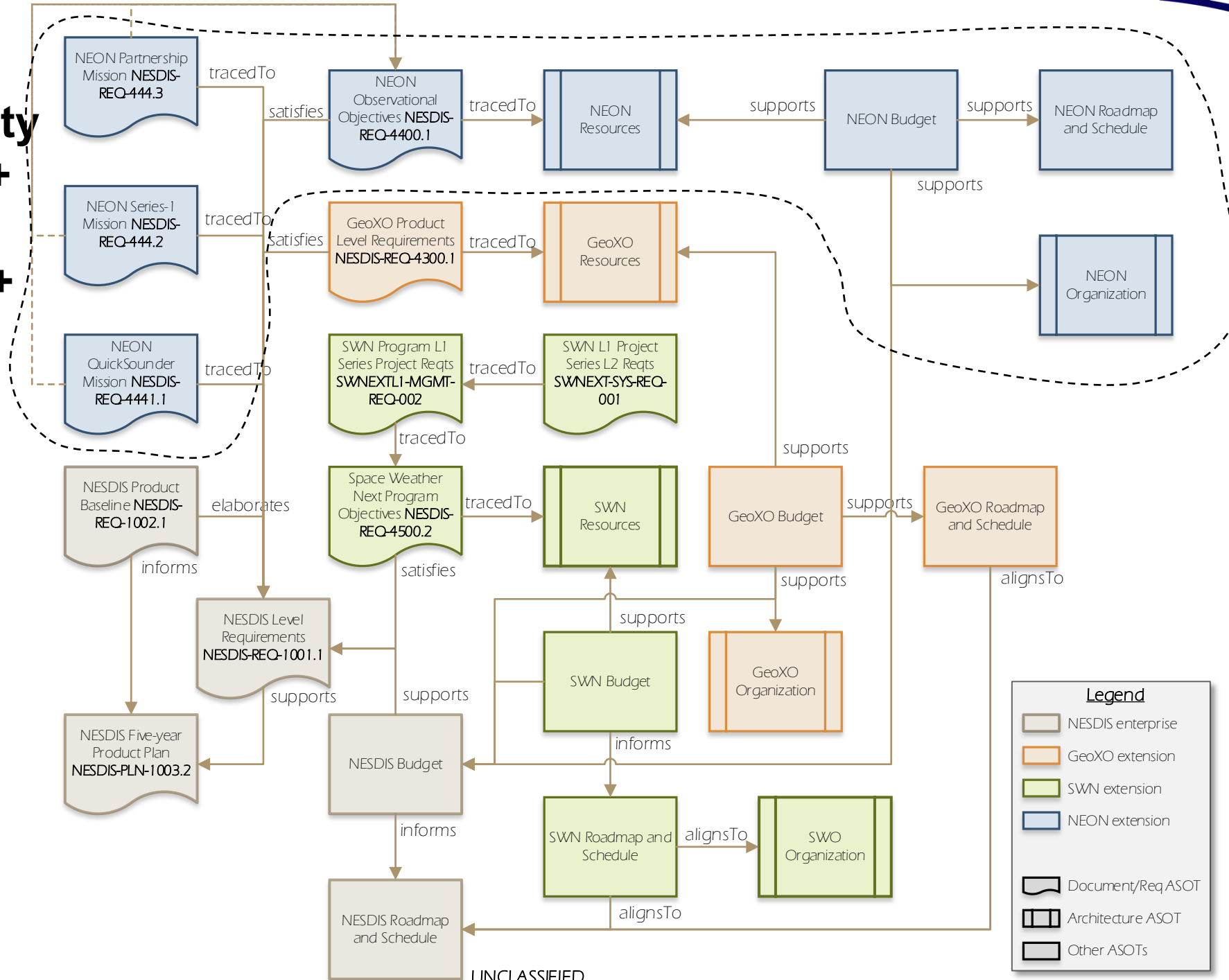
- Expand the model up to include user needs
- Expand the model down to capture lower level (e.g., spacecraft and payload) requirements
- Expand the model horizontally to include NOAA enterprise ground systems
 - Receiving requirements from the flight programs and from NESDIS
- Find a way to maintain the model and connections across many stakeholders



Understanding NESDIS enterprise interconnectedness through illustrating relationships of the paper documents



NESDIS Traceability Concept + GeoXO + SW Next + NEON



UNCLASSIFIED





Reference Architecture, Analysis, and Visualizations

Building a digital model to visualize the baseline and impacts of “what if” alternatives

Portfolio Decision Support Tool

- PDST is a model-based visualization and data exploration tool that can be applied to systems engineering problems
- Users can model the schedule, costs/budgets, requirements, risks, and interdependencies between organizations, projects, and physical systems.
- A wide variety of interactive, customizable visualizations can be used to explore, present, and build this model
- PDST is typically used with architecture-level models to explore effects on an acquisition-level timescale; typically, the lowest-level system modeled is a satellite payload, and the smallest time increment considered is one day.
- Creating a PDST model requires expertise in the modeled domain and in PDST, but once the model is created, PDST provides an easy-to-explore, encyclopedia-like interface that non-experts can explore on their own to understand the content and implications of the model.

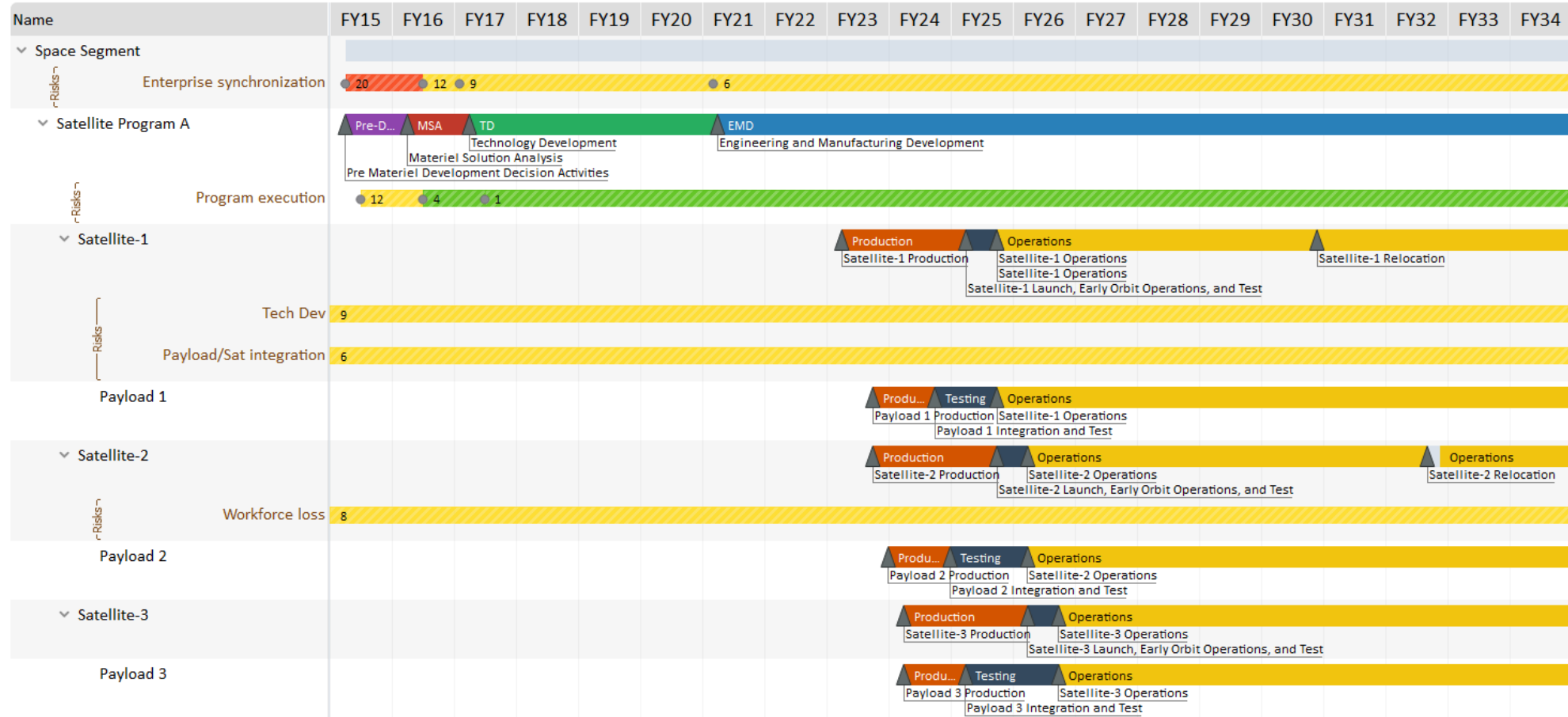
Digital engineering enables informative, data and analysis-driven decisions

Reference Architecture, Analysis, and Visualizations

Portfolio Decision Support Tool (PDST)



Example Schedule for Notional Program

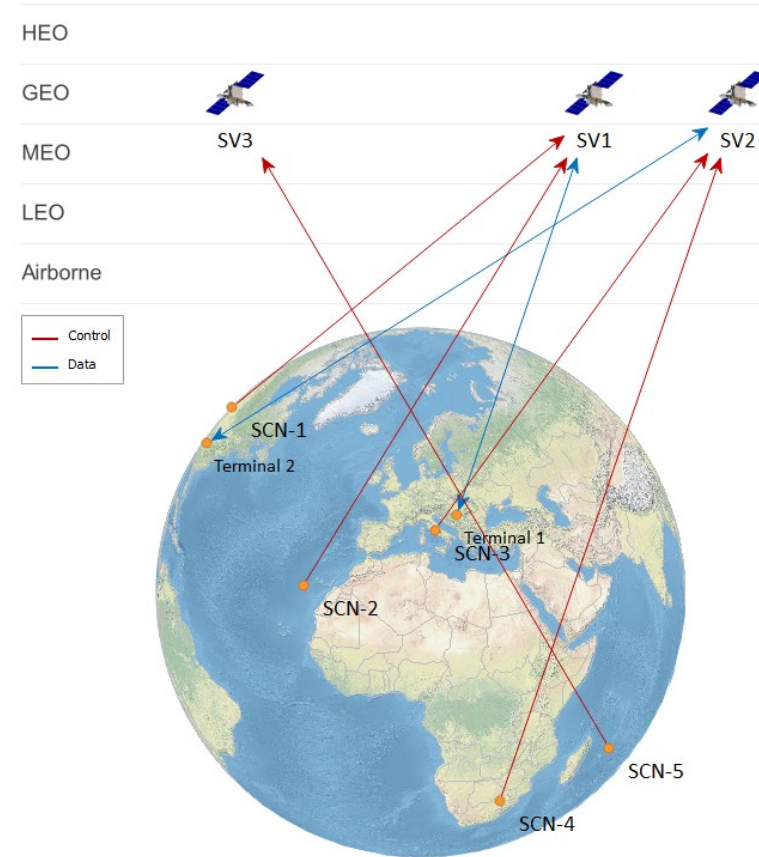
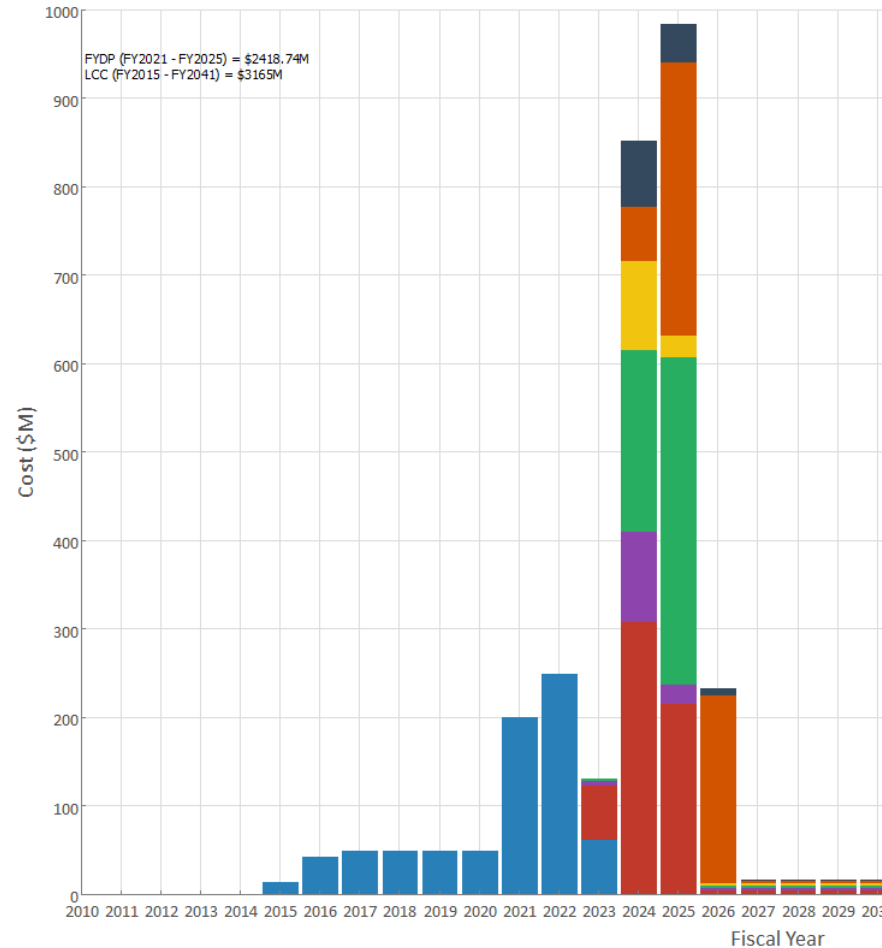


PDST enables visualization and on-the-fly adjustments of program schedules

Reference Architecture, Analysis, and Visualizations

Portfolio Decision Support Tool (PDST)

Example Cost Profile and Communications Paths for Notional Program



Changes in schedule are immediately updated in view of program cost profile

PDST enables visualizations of the space-to-ground communications connections as a function of time

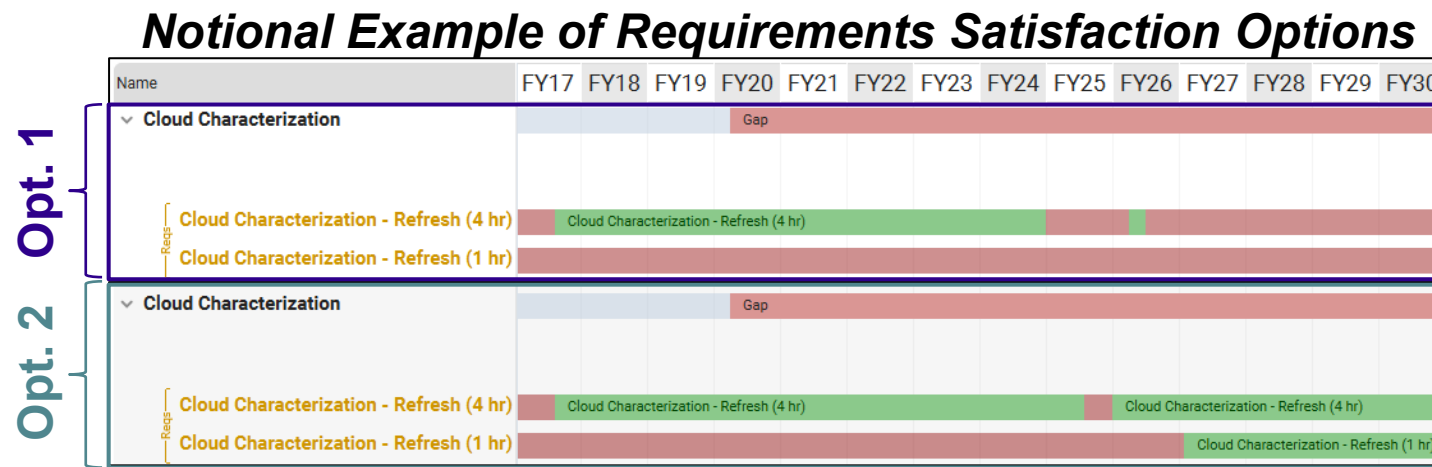


Reference Architecture, Analysis, and Visualizations

Building a digital model to visualize the baseline and impacts of “what if” alternatives

“What if” example analyses carried out in support of NOAA/NASA joint programs using PDST

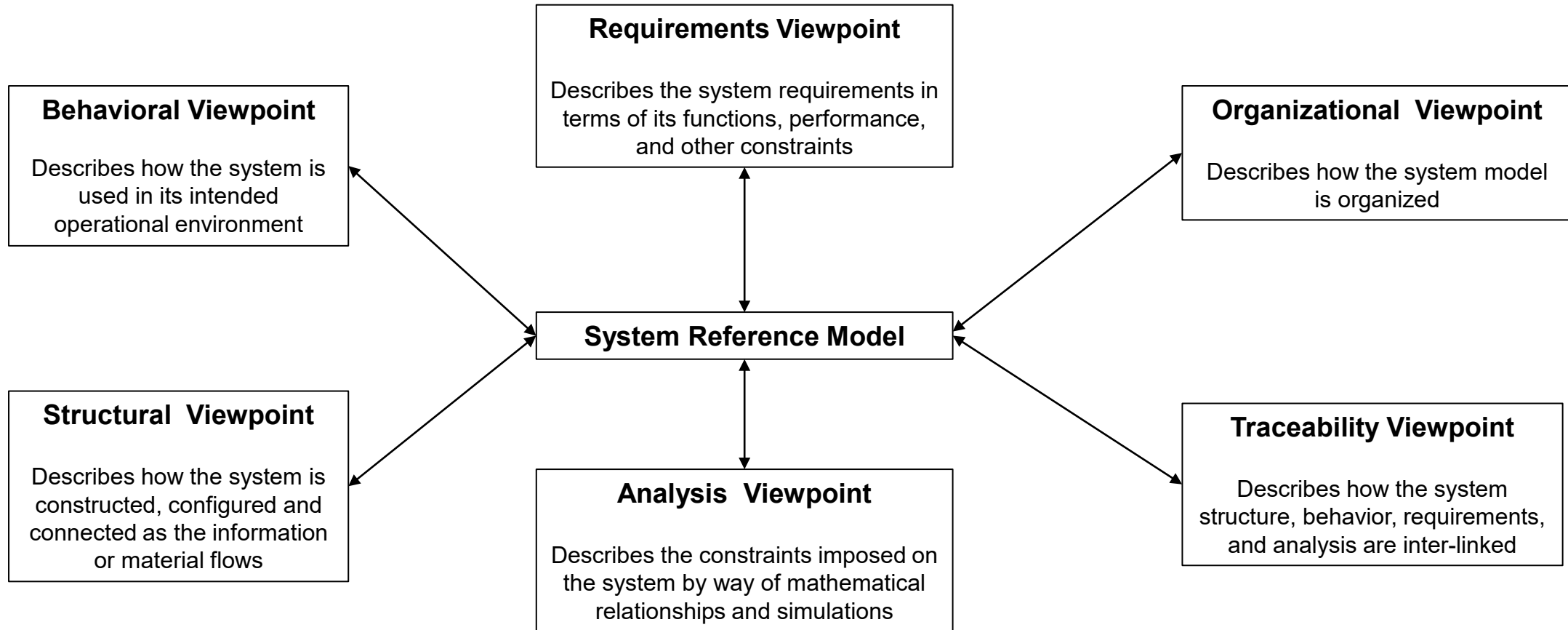
- What are the impacts to the program launch schedule and cost profile if we change the design life of the satellites in the constellation?
- What are the impacts to the program launch schedule and cost profile if we change the number of payloads hosted on each satellite bus?
- If the budget changes, how can we adjust the schedule to stay within the new budget cap and what are the impacts on constellation availability and overall performance?



PDST enables on-the-fly visualization and assessments to narrow down the trade space for further analysis

System Reference Model

Using MBSE to visualize many aspects of a program



One Reference Model, Multiple Viewpoints of Concerns



Example Reference Model

- Goal
 - Build a reference model of the particular imaging capability of a customer satellite that illustrates the power of MBSE to aid requirements development, satisfaction, and validation
- Methodology
 - Aerospace's Concept Design Center (CDC) used MBSE methods and tools to develop a Spacecraft Reference Model for the project
 - SRM was expanded to include the Operational Concept for the imaging capability
- Result
 - Model tied together requirements, generic spacecraft architecture, and Operational Concept
 - Model allowed testing of OpsCon to validate requirements can be met (e.g., latency)
 - Model can be adapted validate vendor designs when they are submitted

Use of MBSE to develop requirements and test vendor solutions



Adoption of Digital Engineering

How to move from pilot studies to adoption, NASA as example

- NASA is undertaking digital transformation across multiple domains
- Aerospace (and many others) are working with NASA/GSFC to adopt digital engineering so that
 - Missions are not delayed by having to learn new tools and methodologies
 - Missions can minimize rework resulting from starting using one set of tools and then adopting new DE tools
 - Missions are able to both choose the right tools for themselves and also exchange data between missions
- NASA/GSFC is using digital engineering to
 - Minimize the complexities of exchanging information while protecting sensitive/proprietary information
 - Reduce the time it takes to go from concept to operations
 - Reduce the time from Request For Proposals (RFPs) to contract award
 - With greater insight and definition of scope
 - Reduce the number of design errors which surface late in the design, test, and certification phases

Use of MBSE to develop requirements and test vendor solutions



Thank you



Digital Engineering Sandbox Overview

Michael Alba

February 2025

Agenda

- What is a Digital Engineering Sandbox?
- Sandbox Implementation and Use Case
- Video Demonstration
- Challenges
- Summary and Return on Investment



What is a Digital Engineering (DE) Sandbox?



Environment for Customer DE Prototyping

- Enables safe environment to develop DE capabilities and processes with complex tools that customers can leverage
- Enables collaboration between stakeholders in a common environment
- Enables lift-and-shift to different networks

Testbed for Digital Fluency Training

- Introduction and exposure to engineering toolsets and capabilities
- Developed as a testbed for developing engineering workflows
- Documents lessons learned to share with customers

Digital Engineering Operational Environment

- Serves as a pathfinder for customer DE environments
- Utilization of integrated engineering toolsets to efficiently execute workflows
- Enables access to engineering capabilities for day-to-day use

Sandbox environments should replicate enterprise production environments to accurately inform development of new capabilities, provide realistic scenarios, and streamline deployment

Pathfinding DE Implementation for Aerospace and our Customers

National Nuclear Security Administration (NNSA) Digital Engineering Sandbox

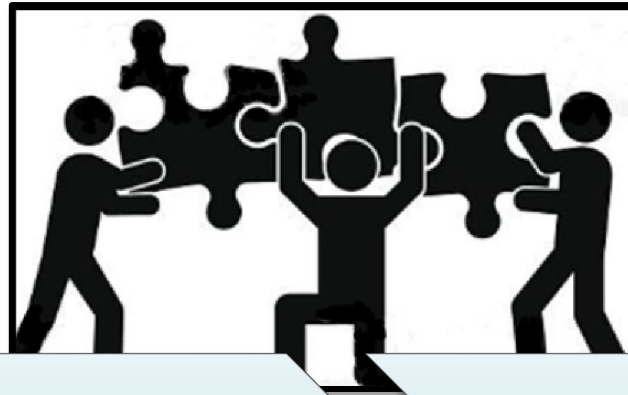


- ☐ Use Case/Workflow
- ☐ Network/Classification
- ☐ Software
- ☐ Data



Problem Framing

- NNSA rebranded their cloud approach (ESN Hub)
- Investing hundreds of millions toward their cloud environment; need an integrated environment for training/testing



Integration First Approach

- NNSA primarily focused on collaboration and business use cases with limited, initial tool set
- Have not fully deployed complete engineering tool suites in the cloud

Prototype Workflows

- Target specific use case(s)
- Develop prototype environment to execute use case(s)



Deployed Capability

- Deployment to Amazon Web Services to inform ESN Hub
- Publish specification document with lessons learned for broader adoption



DE Sandbox Enables Pilot Development

Leverage Amazon Web Services (AWS) cloud virtual machines to test tool and data interoperability

Practical use of digital engineering in safe development environment to significantly enhance the implementation of new digital engineering tools and processes

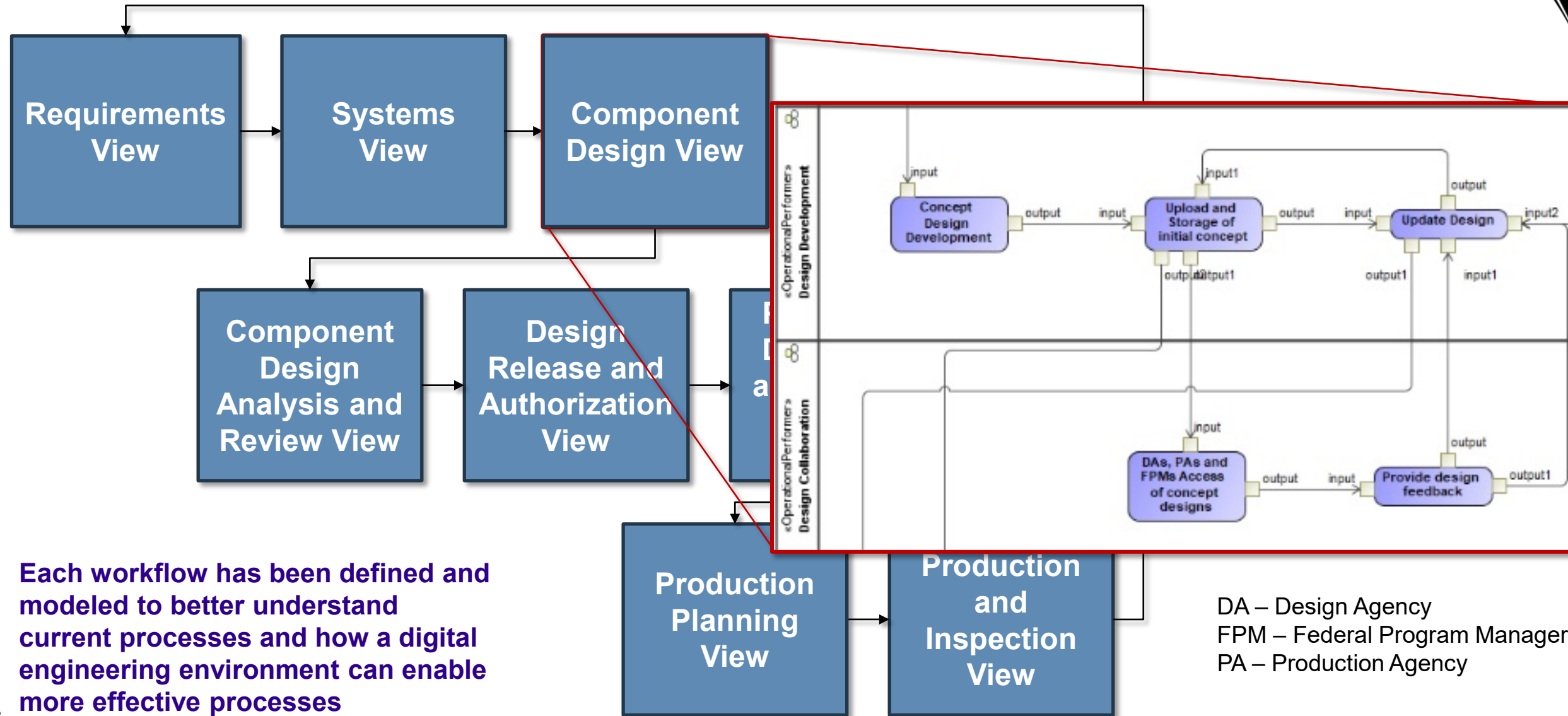
Sandbox environments allow for development and exploration of engineering problem sets in a manner that does not put enterprise data and resources at risk

Targeted use case within the DE sandbox: digital thread demonstrator

- Informs decision makers throughout a system's lifecycle by providing the capability to access, integrate, and transform data into actionable information
- Data elements involved in the digital thread use case include requirements, design, testing, analysis, production, and inspection
- Digital threads have significant benefits for acquisition programs:
 - Enhance gate reviews by having all data present, integrated, and current
 - Enable near real-time access to data and models
 - Reduce preparation time for design reviews
 - Sustain the source of truth throughout program execution

Tool and data interoperability enables and streamlines data-driven decisions

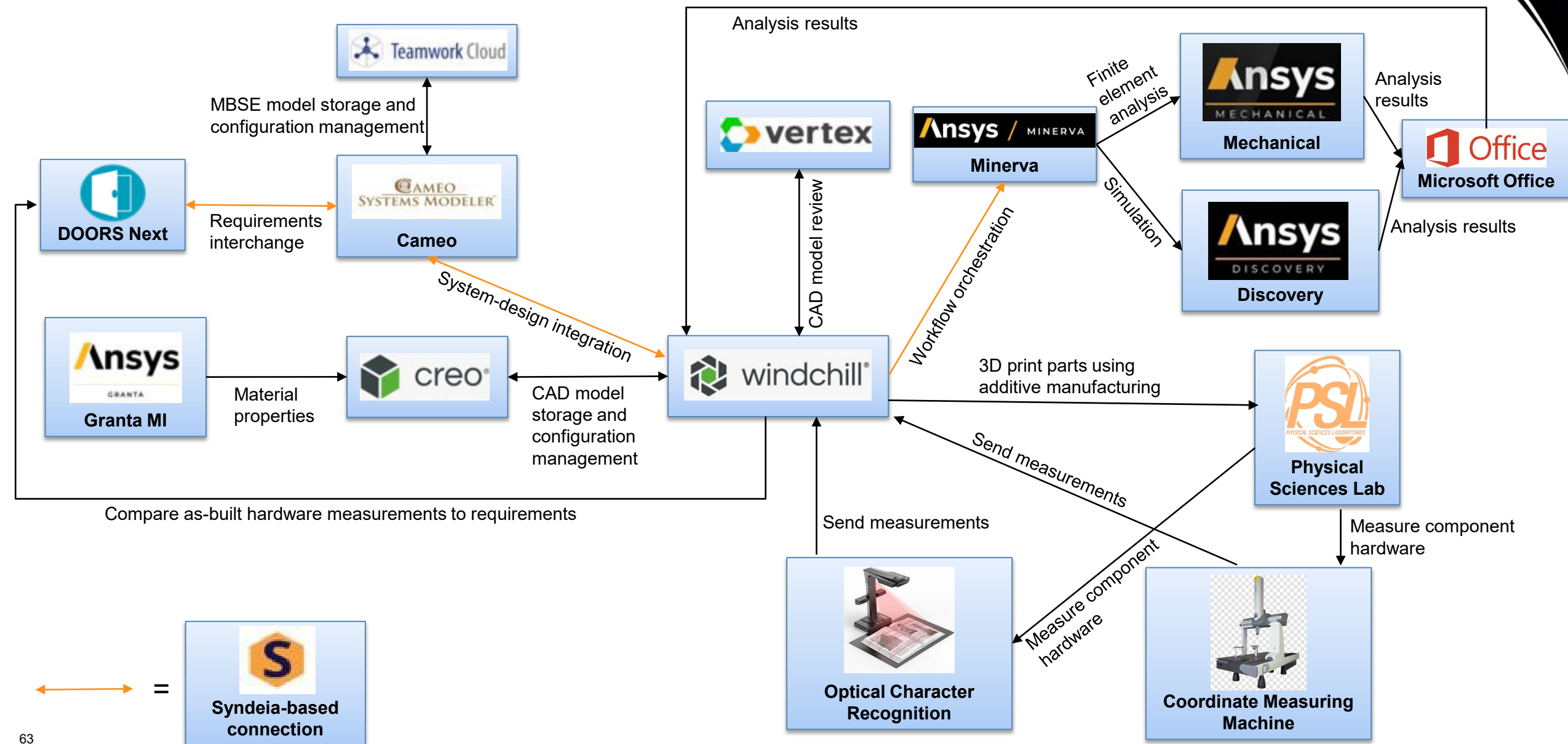
Component design feedback loops enable concurrent engineering between designers and producers



Each workflow has been defined and modeled to better understand current processes and how a digital engineering environment can enable more effective processes

Digital Thread Activity Workflows within DE Sandbox

Product realization activities and their interfaces in the digital thread demonstrator



Video Demonstration





User Roles

Data access based on stakeholder role

- **Federal Entity**

- Federal Program Office (FPO) - manage program's cost, schedule, scope, risk and all activities executed throughout the program
- Tool integrator
- Cloud admin

- **Design Agency**

- Designer
- Checker
- Systems Engineer
- Analyst
- Configuration Management
- Program Manager

- **Production Agency**

- Product Engineer
- Process Engineer
- Quality Process Engineer
- Configuration Management
- Program Manager
- Procurement
- Purchase Product Engineer
- Tool and Gauge Designer
- Manufacturer
- Inspector

Incorporate varying permissions based on user role and need-to-know authorization



Challenges

- Each cloud provider has different deployment processes, different terminology, and various nuances that are unique to their ecosystem
- Minimal out-of-the-box standardization across tool suites and environments
 - Ontology and common object model could drive standardization
- Tool Interoperability
 - Most of the tools don't have direct connections to integrate with each other
 - Identify native connections that exist versus building customized integrations with a data broker or script
 - Lack of containerization and cloud-native applications made getting tools functional on AWS a challenge
- AWS WorkSpace functionality
 - Software that requires extensive visualization cripples standard WorkSpace deployments
 - Deploying a graphics processing unit (GPU) WorkSpace mitigates this issue but increases costs for individual WorkSpaces

Not trivial to implement a DE sandbox solution



Summary/Return on Investment with Impact on Programs

DE Sandbox enables deep exploration of constructs such as the digital thread

- Acquisition lifecycle activities will be enhanced because of a DE sandbox
 - For the digital thread use case specifically:
 - Presenting source of truth design data during gate reviews can show associated datasets (analysis, requirements, and more), reduce presentation preparation time, and eliminate “design freezes”
 - Data is integrated to analyze program decisions downstream effects on cost, schedule, and risk
 - Stakeholder feedback loop enhances the design process and enables concurrent engineering
 - Traceability of data from historical versions allows configuration management of digital artifacts
 - The DE sandbox is a safe development environment for pathfinding DE prototyping capabilities before deploying to a production environment
 - Enables concurrent engineering, reduces rework, enables higher quality of engineering across programs, facilitates training the userbase in novel engineering tools and processes
- AWS and software license investments
 - AWS GovCloud: ~\$1,750 monthly for virtual machines, compute services, and database instances
 - Increased cost required for enterprise-scale deployments (increased data storage needs, additional virtual machines, increased compute power, etc.)
 - Licenses for commercial-off-the-shelf tools

Initial and continued investments are worth the value a DE Sandbox brings for programs and enterprises



Thank you



The Role of Cost in Digital Engineering

Mary Covert

February 2025



Section Outline

The Role of Cost in Digital Engineering

- Cost ASoTs
- Cost Data Elements
- Cost Estimating in a DE Environment
- Discussion



Cost ASoTs

Characteristics

- Contain cost, schedule, **and technical** data
 - *Technical program attributes must be linked to the provided cost and schedule information*
 - *Often “snapshots” of a program are taken at major milestones (PDR, CDR, &etc)*
- Consistent with the program’s organizational structure
 - *Follows the program WBS (which hopefully follows a standard WBS)*
 - *Bookkeeping costs at a lower level is important to enable requirement trades independent of an individual program*
- Data is input through a controlled process
 - *Normalization processes are implemented and may include*
 - Standardized collection templates
 - In/deflation or budgetary phasing considerations
 - Adjustments for quantity
 - Scope consistency is enforced through use of a standard WBS and definitions
 - *Also includes narrative outlining major program or data issues*
 - *Data access is permissioned/limited based on role, need, or NDA*
- Major cost ASoTs also include direct connection to analysis and visualization tools
 - *Often through an internal web interface*

Proper data structure is a backbone for successful DE implementation

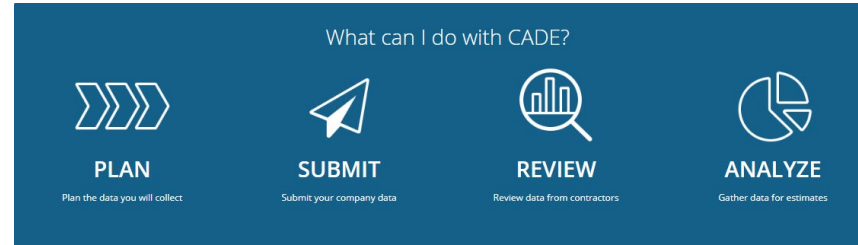
Cost ASoTs

Examples

- Office of the Secretary of Defense

- [Cost Assessment Data Enterprise \(CADE\)](#)

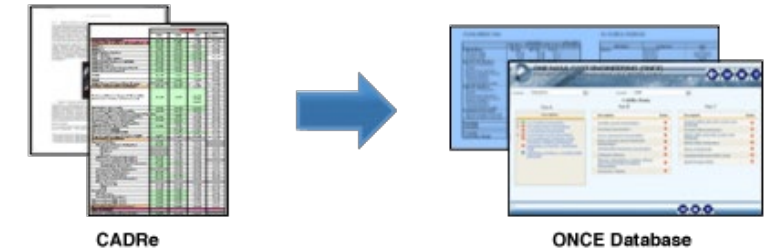
- “The Authoritative Source for Defense Cost Data”
 - Developed and maintained by OSD Cost Assessment and Program Evaluation (CAPE)
 - Includes contractor cost data reports (CCDRs), cost analysis requirements descriptions (CARDs), software resource data reports (SRDRs), and Selected Acquisition Reports (SARs)
 - Also provides cost-related policy and guidance documents



- National Aeronautics and Space Administration (NASA)

- [One NASA Cost Engineering \(ONCE\) Database](#)

- Developed and maintained by the Office of the Chief Financial Officer (OCFO)
 - Includes query, export, analysis, and visualization functions for Cost Analysis Data Requirements (CADRe) documents
 - Also provides cost-related policy and guidance documents as well as a download point for NASA cost models



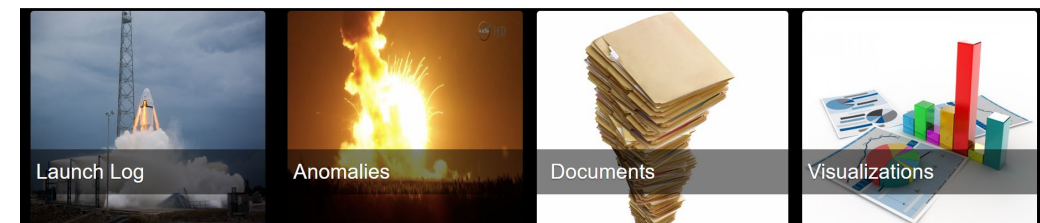
- The Aerospace Corporation

- [Acquisition Support and Systems Engineering Toolset \(ASSET\)](#)

- *Internal clearing house which houses data and artifacts from across the space enterprise*

- Such as Launch Log, Anomaly Database, Communications Satellite Catalog, program documentation

- *Provides direct interface to a set of web-based analysis tools*





Cost Data Elements

Definitions

- ASoTs cited on the previous page follow the standard WBS for their respective organizations
 - *BUT may have a space or military hardware focus*
 - *A functional enterprise ground WBS has historically been challenging to develop due to*
 - The variety of ground functions
 - *Every space vehicle needs power, propulsion, etc. but not all ground systems need to have standard functions; in some cases, major functions (such as C2) may be handled by another system*
 - A ground system has historically been tailored to the asset it services
 - Ground systems almost never start from a green field (program leverages a legacy or enterprise system)
- Define cost elements for a study based on study needs. WBS must support the tradespace and scope of available data.
 - *Examples:*
 - Use high-level breakouts for an early-phase concept study, such as spacecraft, instruments, ground, O&M.
 - Phase A estimates may account for cost by subsystem or function.
 - Typically, estimates aren't performed at the line-item level until a design is mature (PDR or later)
 - *Architecture vs. business model trades*
 - Business model trades include build/fly sensor vs. data buy, or in-house vs. commercial services. WBS must enable cost comparison between completely different paradigms.
 - Architecture trades include transfer of requirements from one orbit or mission to another, or onboard vs. on ground processing. WBS must capture cost deltas at the right level of granularity.

Cost element breakout must support intended estimate type and use for the project's life cycle phase



Cost Estimating in a DE Environment



Cost Questions that DE May Facilitate

Design Level Trades Linked to Requirements

- DE links requirements to performance and budget/cost
 - *Without an implementation of a requirement, there's nothing to estimate. DE enables concurrent creation of system and architecture design options that meet requirements, and estimates of performance and cost of those designs.*
 - Cost alternative architecture designs to meet requirements. ...
 - Explore the business alternatives to meet that requirement or performance level
- The cost component of interconnected analysis in a DE environment enables portfolio level decisions from an affordability standpoint
 - *Flight Architecture Study example: Some architectures barely missed requirements. If we relax requirements and admit these architectures, what kind of cost savings will we see? The performance hit may be minimal, but the cost savings great.*
 - Value modeling would be a next step
 - *NESDIS Ground Enterprise Study (NGES) example: Study proved continuing today's ways of doing business becomes unaffordable as performance improves and data volume grows. If a different business model offers significant cost savings, can we buy more performance with those savings? Or does unaffordable performance simply become affordable?*

The digital environment links requirements, designs, performance, and cost for efficient trade analysis

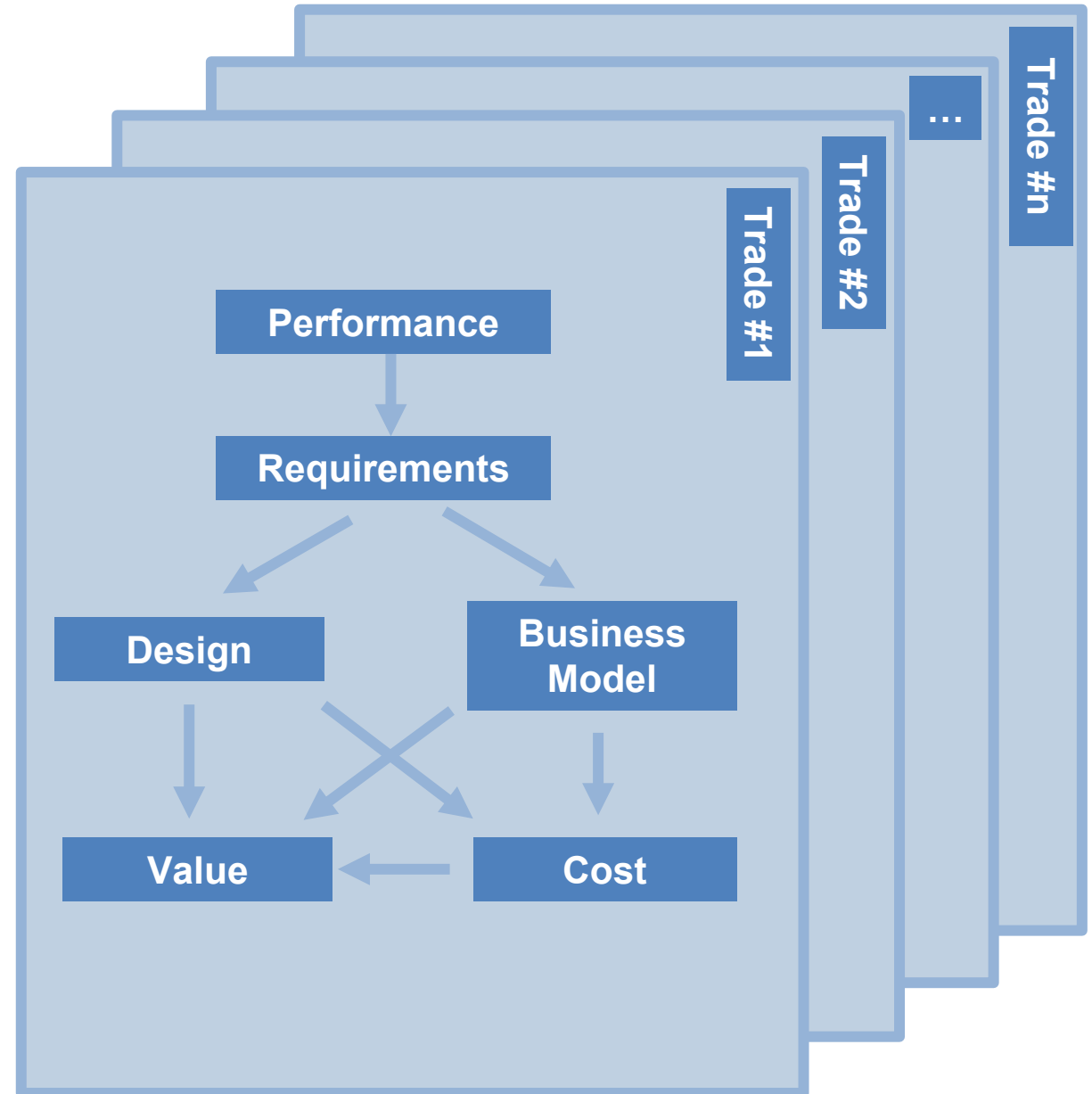


Digital Engineering Process

“Then”... or perhaps “Now”

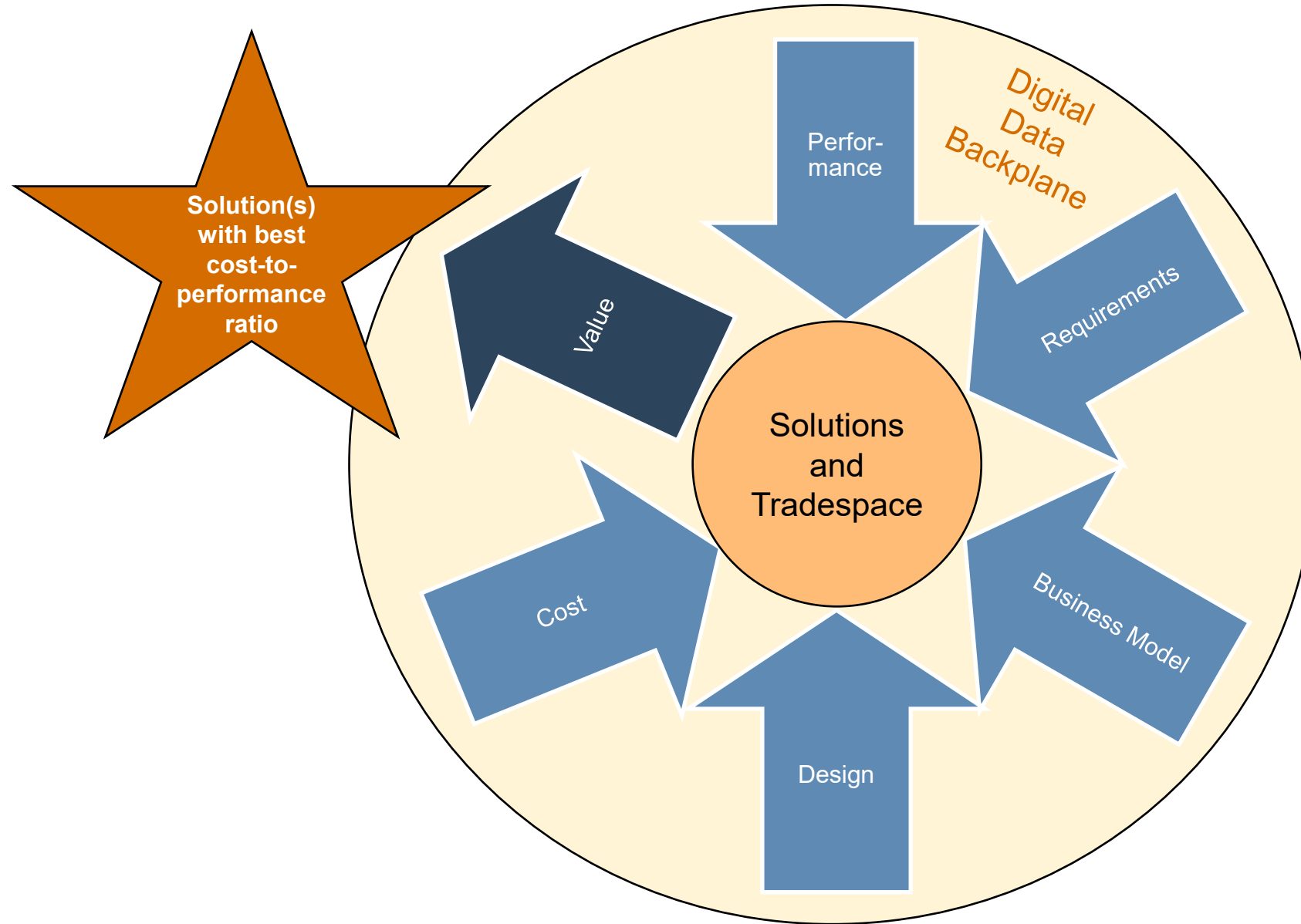
- Many current portfolio studies rely on outdated spreadsheet-based and manual processes
- Difficulties include:
 - *Multiple disparate, potentially inconsistent data sources*
 - *Serial process that requires repetition for each architecture*
 - *Manual processes require hands-on attention in each area*
 - Introducing the possibility of transcription and association errors

Picture of now ... and future DE





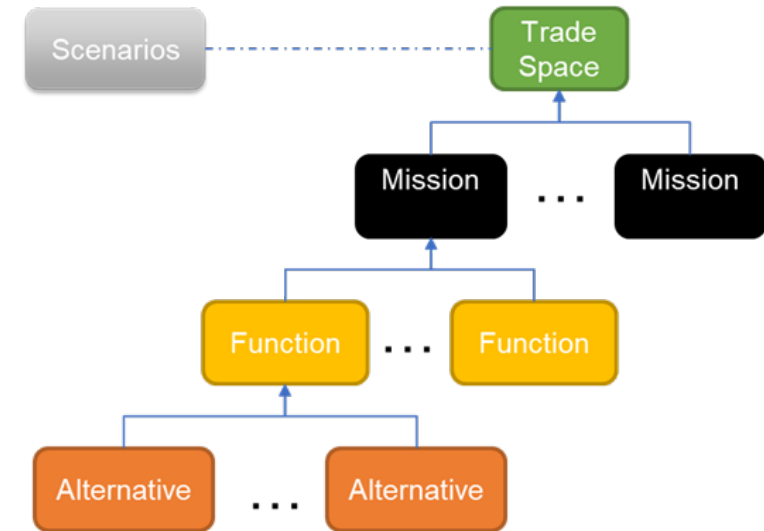
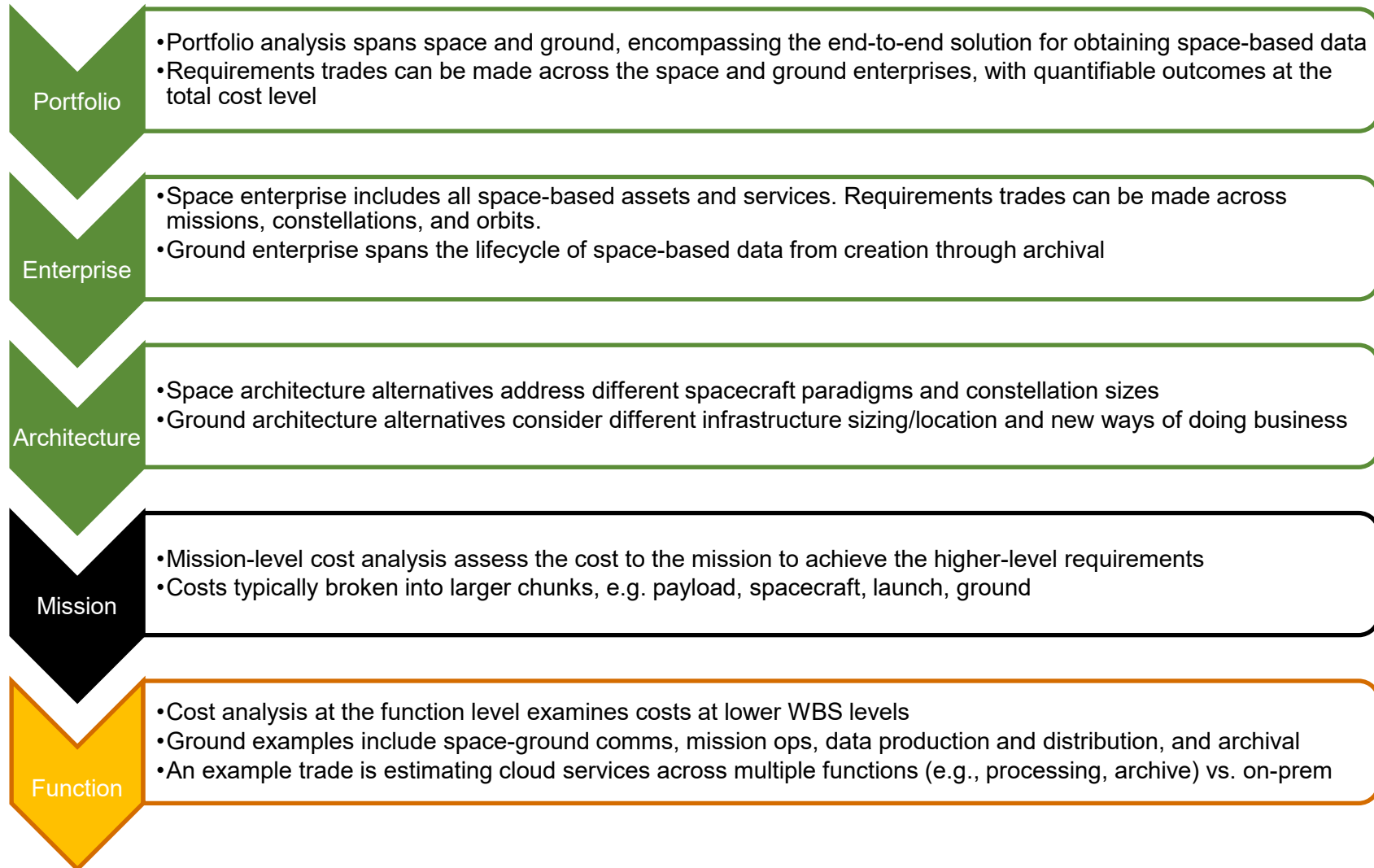
Integrating Cost into the Digital Engineering Process



With all models leveraging the same ASOTs, analysis is more efficient, and metrics can be tied to performance

Levels of Estimation

Analysis Hierarchy





Enterprise-Level Estimating

Aerospace-Supported Example

- Aerospace developed a standard ground enterprise WBS around which an extensive cost model was built as part of the NESDIS Ground Enterprise Study (NGES)
 - *Six functions:*
 - Space-ground comms
 - Mission operations
 - Science
 - Data production, delivery, and archive
 - *Ten elements: hardware, software, labor, facilities, commercial services, data handling, systems engineering, program management, PMO, and legacy system O&M*
 - *Elements recur within each function for comparison across functions and roll-up of elements to the enterprise level*
 - *Alternatives allow for business model trades across functional areas within the same cost element structure*
- Value modeling combined cost estimates with other key metrics to determine which functions within the enterprise might gain the most benefit at reduced cost using different business model alternatives
 - Illustrates how trades paired with cost and measures of benefit (performance) lead to informed decisions

NESDIS - National Environmental Satellite, Data, and Information Service O&M – Operations and Maintenance

Cost models are complex and independent of value models today, making analysis serial, iterative, and cumbersome



Modeling Costs with DE

Future Processes

- Within a digital environment, estimated costs move with architecture trades so that the costs of each architecture are immediately understood
 - *Fosters understanding of higher-level cost drivers*
- Costs are linked to requirements, which is foundational for cost-benefit analysis key to high-level decisions
 - *This is an aspirational future capability*
- Aerospace taking strides in DE direction
 - *NOAA 15-Year Antenna Study: Aerospace developed a VBA tool that pulled inputs from the study's source data templates, ran the cost and cost-risk models, and produced a uniform output. This enabled the estimation of 10s of ground antenna architectures in 15 minutes each, vice day(s).*
 - *PROPHET: Aerospace-developed tool used for the conceptual design of space vehicles to support feasibility analyses, analysis of alternatives, and design/cost trades*



Role of Cost Estimating in Portfolio Management

Design-level Trades Linked to Requirements

- Portfolio management examines performance against objective-level requirements
 - *Today, the preferred performance level is selected for inclusion in the space asset request for proposal*
 - *Then, the ground solution is built to suit the chosen performance level*
 - *This serial approach precludes cost-benefit optimization of the ground solution with respect to space segment decisions*
- Ideally, cost-performance trades should be understood at the holistic portfolio level, which DE would foster
- Estimated costs and value should be integral when making high-level decisions to ensure alignment between performance and affordability
 - *Within a digital environment, estimated costs move with architecture trades so that the cost of each architecture is immediately understood*
 - *Fosters understanding of higher-level cost drivers, which in turn informs the tradespace*
 - *Enables cost-benefit analysis at the decision level, not at lower levels of estimating typical today*

Linking costs to requirements is foundational for cost-benefit analysis and key to high-level decisions



Discussion

Digital Maturity Model

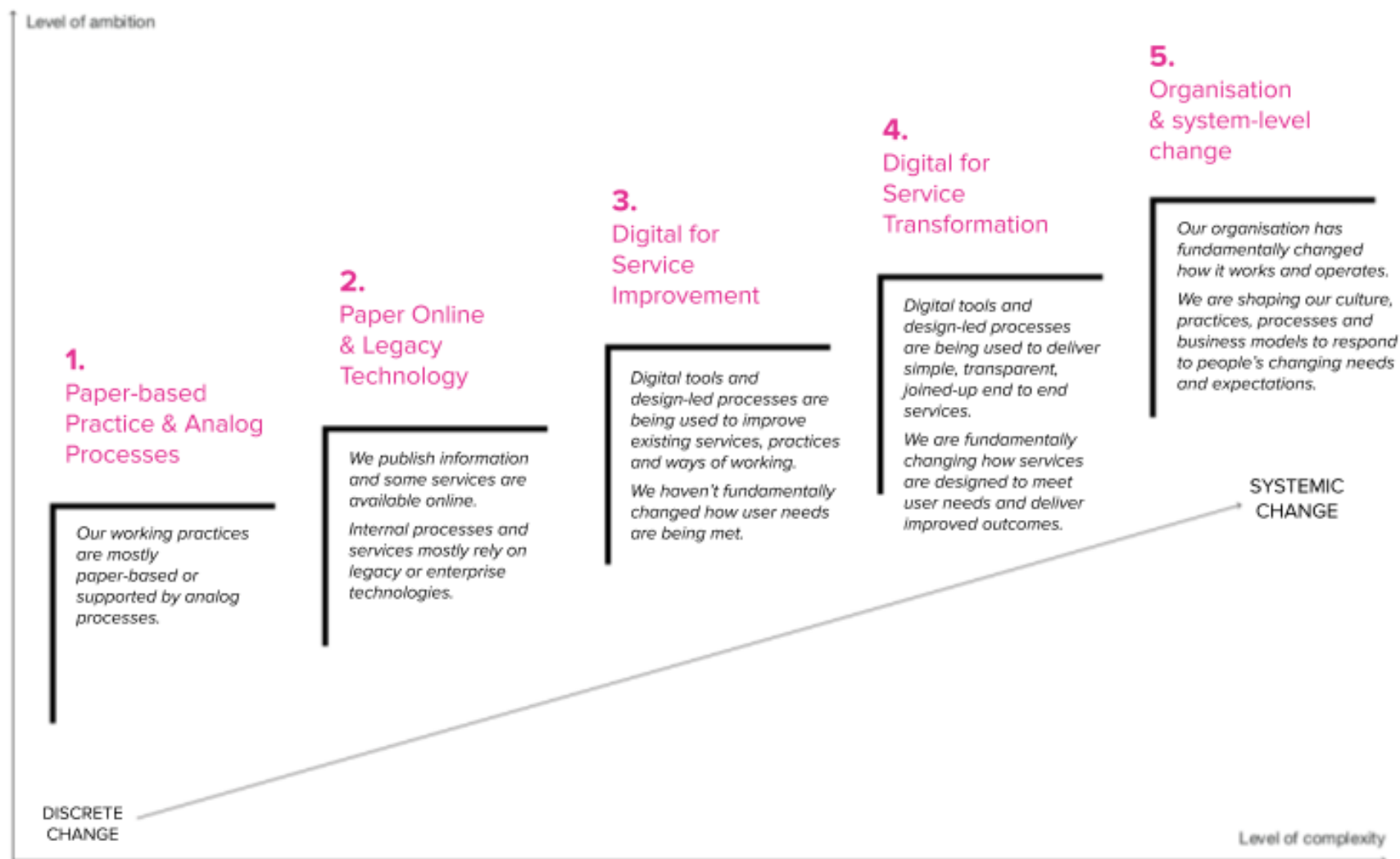
Process



<https://www.linkedin.com/pulse/digital-maturity-model-vital-strategy-thriving-automated/>

Digital Maturity Model

Levels of Adoption





Discussion Questions

A discussion of cost analysis support to an acquisition lifecycle management process in a digital engineering environment will illustrate the benefits and importance of cross-mission costs in portfolio management, and an interactive discussion of the current implementation state of DE among contractors will lend to understanding how DE may streamline estimating practices and reporting requirements to result in oversight efficiency.

- How mature is your organization's DE infrastructure today?
 - *How long do you estimate it will be before your organization reaches Level 4?*
- Can you quantify the resources (time, people) currently involved in DE development?
- Is your organization currently planning to incorporate cost analysis into their DE process?
 - *If actively doing so, can you quantify the resources (time, people) working on the cost aspect?*
 - *How long do you estimate it will take to complete the incorporation of cost analysis?*
- What challenges or obstacles does your organization face regarding developing and implementing DE?
- What advantages might your organization realize from incorporating cost into their DE environment?

- ❖ What specific advantages and efficiencies do you believe including cost in DE will afford?
- ❖ Can current cost reporting requirements be met with new DE process?
- ❖ What CDRLs may no longer be needed?



Thank you