A Framework for Specifying Expectations for MBSE, DE, and Digital Twin

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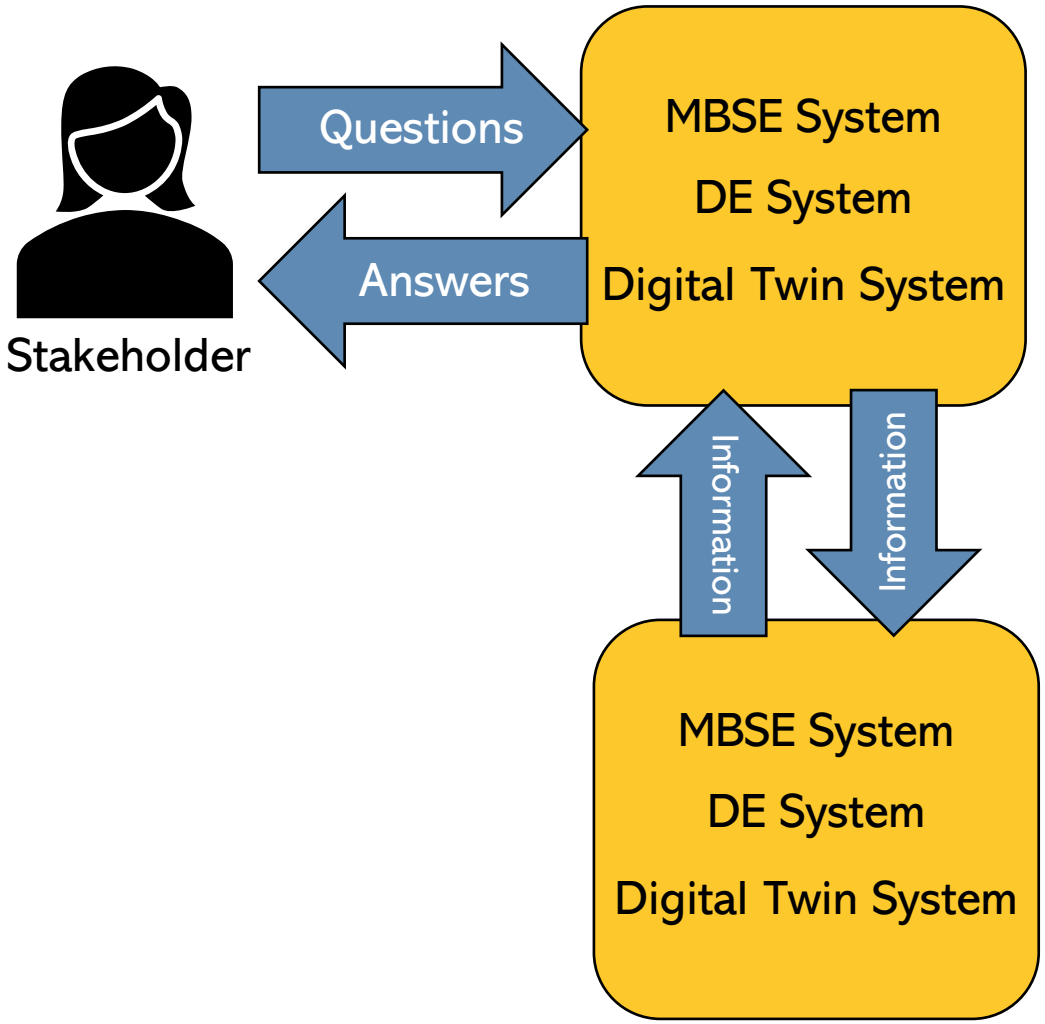
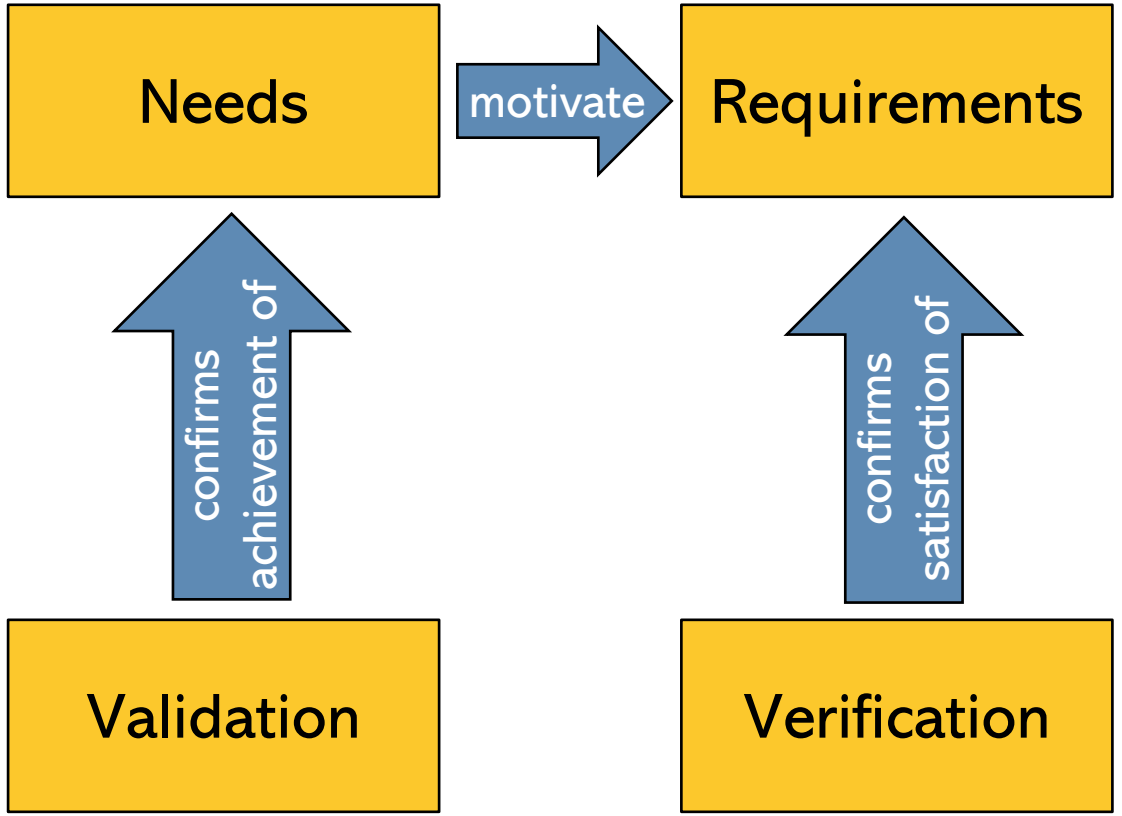
MBSE, DE, and Digital Twins

- Model Based Systems Engineering (MBSE):
  - The modern practice of SE in which ***descriptive models*** replace documents as the ***authoritative embodiment*** of ***SE knowledge***
- Digital Engineering (DE):
  - The digital ***integration*** of ***information*** and ***work***
- Digital Twin (DT):
  - An ***up-to-date*** virtual representation of a physical asset
- Each of these is a ***system***
  - Whose function is to ***answer stakeholders' questions*** about some modeled entity or entities



Needs and Requirements

- Needs:
  - ***Stakeholder*** expectations of the ***outcome(s)*** an acquired entity is intended to satisfy
- Requirements:
  - Expectations of ***characteristics*** the acquired entity ***must have*** to enable it to achieve stakeholders' intended outcome(s)
- (System) Verification:
  - Process of ensuring the acquired entity ***satisfies the requirements*** placed upon it
- (System) Validation:
  - Process of ensuring the acquired entity ***satisfies its intended purpose***



INCOSE. (2022). Needs, Requirements, Verification, Validation Lifecycle Manual.
INCOSE. (2022). Guide to Needs and Requirements.

In practice, validation often occurs very late in the development lifecycle, well after verification

Identify and Refine Needs and Requirements for MBSE, DE, and DT

- Collaboration between model developers and key stakeholders
  - *Elicit, deconflict, and harmonize needs and requirements*
  - *Achieve consensus on vision and priorities*
  - *Focus subsequent model planning & acquisition activities*

Step 1

Problem Framing

Define modeling objectives and scope

- Decisions & milestones
- Questions to be answered
- Model use cases & users
- Model views & products
- Internal models & data
- External models & data

Step 2

Capability Assessment

Define needed modeling capabilities

- Modeling objectives
- Modeling roles
- Modeling competencies
- Model management
- Model development
- Model use
- Model effectiveness

Step 3

Model Requirement Definition

Define needed model artifacts and content

- Define views needed to answer key questions
- Identify model elements, data, tools, etc. needed to create views
- Articulate requirements for models and views

Pre-Award Process and RFP Development

- Market research
- RFP
- Model contract
- Milestone review criteria

DE Tailoring of Government Acquisition

- Acquisition Strategy Plan
- SEP
- TEMP
- Milestone review plan

Government Model Development

- Model requirement specification
- PWS language for model development effort
- Model development plan
- Milestone review model

Capability Maturity Assessment

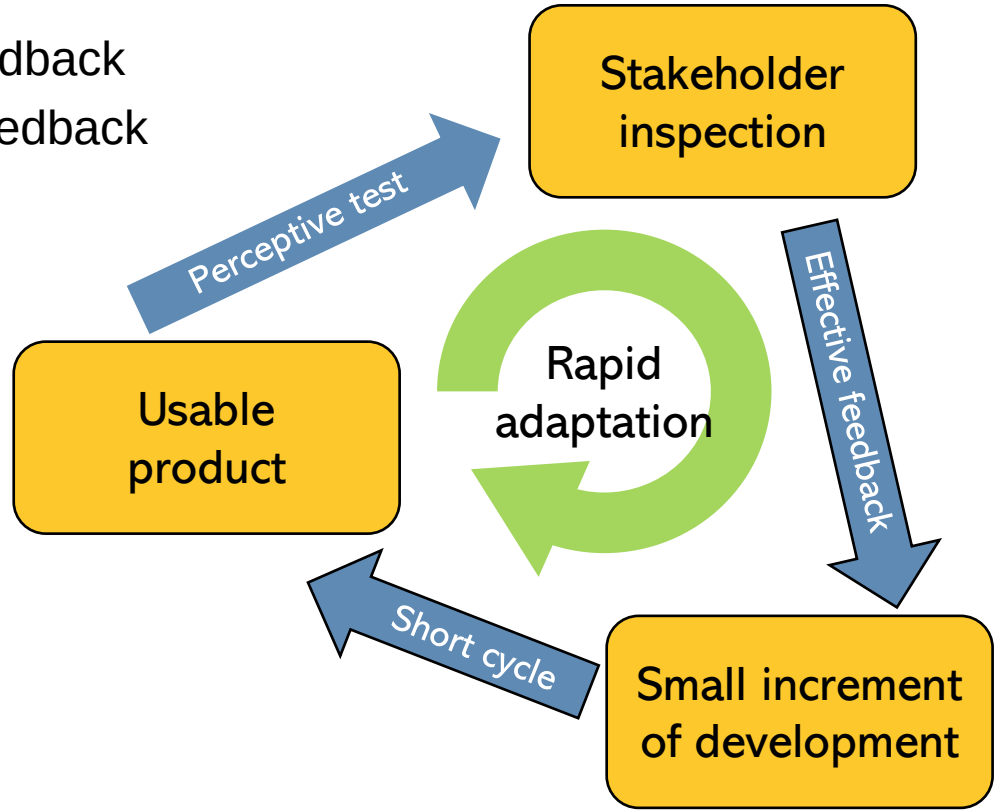
- Achieving the benefits of MBSE, DE, or DT requires the successful implementation and integration of many interdependent capabilities
  - Methods, processes, standards
  - Environments, infrastructure, tools
  - Integration of multiple disciplines and domains
  - Workforce mindset, skills, competency and capacity
- Maturity assessment is essential to planning
  - Identify current level of maturity for each capability
  - Identify necessary state of maturity for each capability
- Can be helpful to perform the assessment in stages
  - Initial assessment addresses broad scope with less detail about each capability to focus strategy and prioritization
  - Subsequent assessments focuses on narrower scope with more detail to support implementation planning

Assess where you are and where you need to be

Agile Planning and Execution

- Agile development methods address problem space uncertainty by adopting three critical tenets:
  - ***Rapid adaptation*** driven by ***real users*** using ***real product***
  - Iterative development in ***small increments*** to ***accelerate*** feedback
  - ***Usable product*** at each increment enables ***effective*** user feedback

- MBSE, DE, and DT can be developed via agile principles to facilitate accelerated learning and adaptation
  - Use the output of Capability Assessment to drive planning
  - Prioritize use cases for the MBSE/DE/DT System
  - Quickly develop and integrate a complete digital thread
    - Enough to answer a meaningful stakeholder question
  - Process stakeholder feedback to steer the remaining effort



MBSE Needs and Requirements

- MBSE is the practice of ***SE*** in which ***descriptive models*** replace documents as the ***authoritative embodiment*** of ***SE knowledge***
  - MBSE provides opportunities to more effectively and efficiently exercise familiar SE processes and achieve familiar SE outcomes
  - All the ***information needs*** for SE (and the ***use cases for SE information***) also apply to MBSE
    - Therefore, you already know what those are, right?

- However, SE practice is often not practiced in a very disciplined and repeatable manner
  - Often processes are well documented, but not practiced consistently
  - Often success criteria for milestone reviews are documented, but at a very high level
    - Misalignment of expectations and inconsistent assessment of compliance are common

- MBSE is less tolerant of inconsistent discipline
  - The intent of MBSE is to remove unnecessary touch labor for activities that can be automated
  - Automation is less tolerant of inconsistency or ambiguity

MBSE Needs and Requirements in the Problem Space

- The problem space of MBSE is the realm of stakeholder value
  - What is the ***value proposition*** for doing MBSE?
  - What improvements to decision support add value to stakeholders?
    - Faster and/or better decisions?
    - More-data-driven decisions?
  - What are stakeholders' ***use cases for the models***?
    - How would the models be used by stakeholders?
  - What ***decisions*** do stakeholders need to make?
  - What ***questions*** need to be answered to inform those decisions?
  - What questions need to be answered to answer those questions?
  - The questions the models are intended to answer are the ***functional requirements*** for the MBSE System
  - The ability to answer the questions are the MBSE System's ***functions***
  - ***Decompose*** the functions (questions) until each can be satisfied by a ***single model view***

Elicit, deconflict, harmonize, and prioritize stakeholder needs

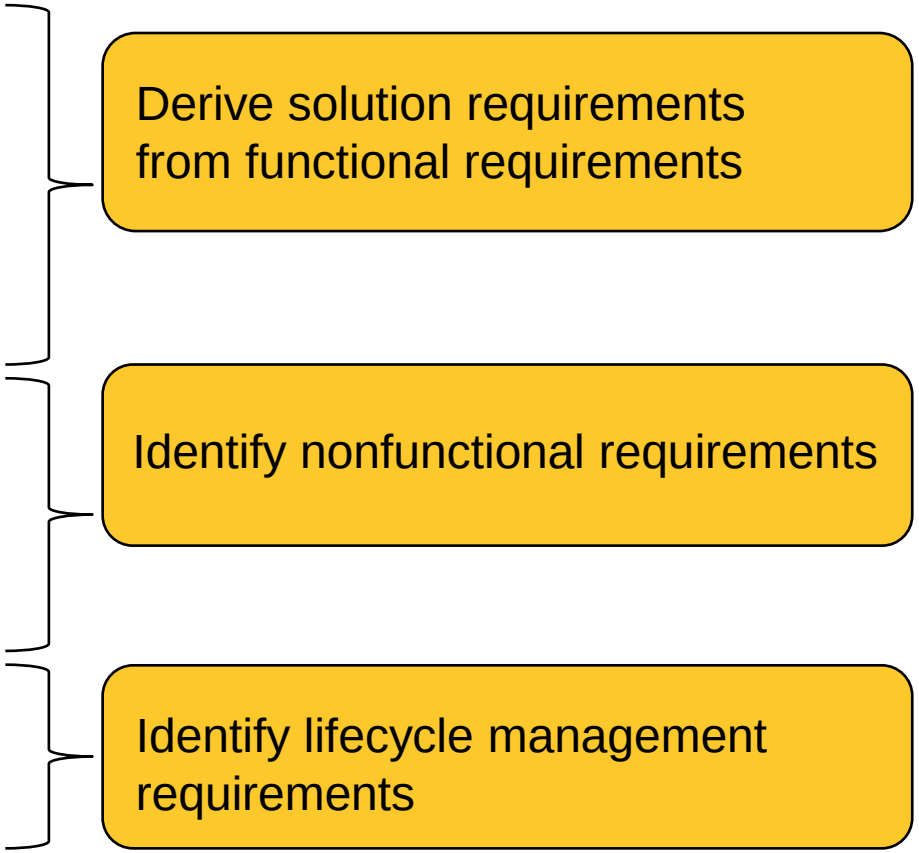
Transform stakeholder needs into functional requirements

Perform functional decomposition to prepare for implementation

Apply results of Problem Framing, Capability Assessment, and Model Requirements Development activities to develop MBSE problem space needs & requirements

MBSE Needs and Requirements in the Solution Space

- The solution space of MBSE is the realm of the systems engineers who are building the descriptive models
  - Model content?
  - Model form (syntax, style, etc.)?
  - Model components?
  - Non-model components?
    - Scripts, plugins, templates, queries, etc.
  - Model views?
  - Model ***interoperability***?
  - Model ***performance***
  - Model ***usability***?
  - ***Quality*** constraints?
  - Metadata or documentation?
  - Model configuration management?
  - Model curation and sustainment?



Apply results of Problem Framing, Capability Assessment, and Model Requirements Development activities to develop MBSE solution space needs & requirements

Verification and Validation of the MBSE System

- Verification of the MBSE System involves assessment of satisfaction of the requirements
  - Some checks may be automated
    - Primarily nonfunctional and lifecycle requirements
  - Most checks will need human inspection and assessment
    - Primarily functional requirements—Does the model (view) adequately answer the question?
    - Questions should be clear enough to be readily verifiable by inspection

- Validation of the MBSE System involves assessment of satisfaction of its intended purpose
  - Largely identical to verification of the MBSE System's functional requirements

- The beauty of this approach is that:
  - Verification and validation are ***largely the same*** activity
  - Verification and validation can be done ***early*** and ***often to facilitate rapid adaptation***

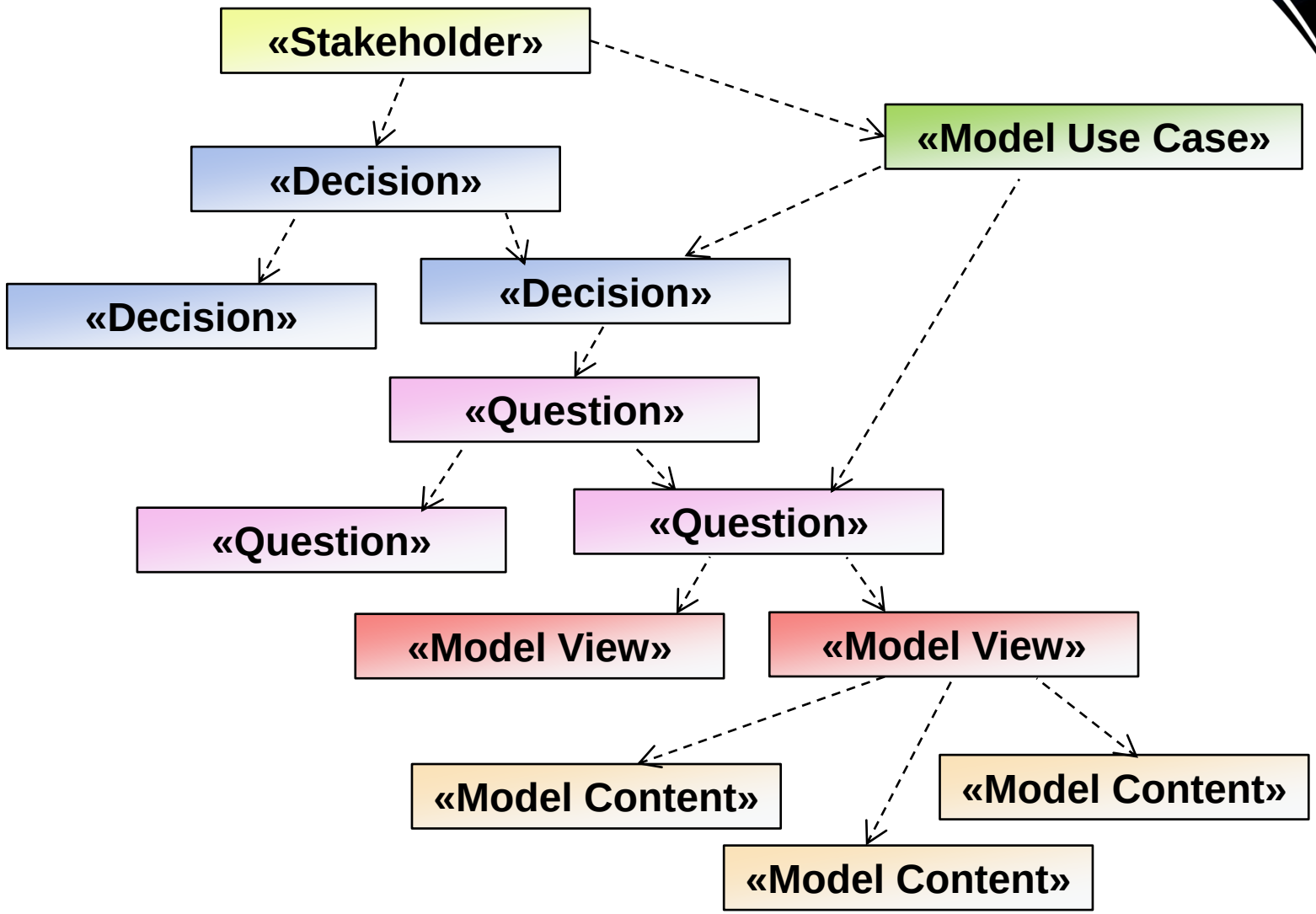
“Are we there yet? ”

- Measuring progress can be readily done in either the problem space or the solution space
- Progress in the problem space $= \dfrac{\text{\# of questions currently answered by the model}}{\text{\# of questions the model is supposed to answer}}$
- Progress in the solution space $= \dfrac{\text{\# of solution space requirements completed}}{\text{\# of solution space requirements}}$
- These “equations” are notional
  - Some questions or requirements may be more difficult than others, so perhaps weight them differently
- For each program milestone, there may be a different number of model requirements to be met
  - Progress can be measured relative to the requirements of each milestone
  - When 100% completion is reached, the milestone has been successfully achieved
    - No need for a milestone review; we’re done—at least with that milestone

Capturing this measurement approach in the DE Measurement Framework v2

Using MBSE to Manage MBSE Needs and Requirements

- Use a descriptive model to capture and trace dependencies between:
  - Stakeholders
  - Use cases for the models
  - Decisions to be made
  - Questions to be answered
  - Model views to answer questions
  - Model content to populate views
- Use the model to manage complexity and traceability
- Analyze the model to identify gaps
- Use the model to support model verification and validation efforts
- Use the model to measure progress toward milestones



MBSE^2 method uses MBSE to manage the architecting, implementation, and operation of the MBSE system

Digital Engineering Needs and Requirements

- Digital Engineering is the digital ***integration*** of ***information*** and ***work***
  - DE expands upon MBSE by integrating other technical and non-technical disciplines
  - Like MBSE, it should be thought of as a system whose function is to answer questions
- Define DE needs and requirements in the problem space
  - Elicit, deconflict, harmonize, and prioritize the use cases for DE and the questions to be answered to inform stakeholder decisions
- Define derived DE needs and requirements in the solution space
  - Model and data content, and (logically) how must they be integrated to form digital threads
  - Model and data integration implementation mechanisms and/or standards
  - Analysis or visualization capabilities to transform input information into answers for stakeholders
- Capture, communicate, and manage DE needs and requirements in MBSE^2 model
  - Greater complexity than with MBSE due to heterogeneous nature of DE components

Use cases for DE—and decisions and questions—should be the key drivers of the model/data architecture

Digital Twin Needs and Requirements

- Digital Twin is an ***up-to-date*** virtual representation of a physical asset
  - It is kept up-to-date by receiving data collected from the physical asset

- DT is a federated set of models, simulations, and data that represents the physical asset
  - Like MBSE and DE, it should be thought of as a system whose purpose is to answer questions
  - Over time, fidelity can increase
    - Stakeholders may expect higher fidelity answers
    - Data from the physical asset enables higher fidelity answers
      - Before a physical asset is built, the design is used as a surrogate
      - After the physical asset is built, collected data can provide higher fidelity than the design
      - Incorporating current state (and history) may be essential to provide higher-fidelity answers
  - DT expands on DE by adding considerations of the physical asset
    - Data to be collected and how that data improves the fidelity of M&S to answer questions
  - Like with MBSE and DE, DT needs and requirements are elicited, deconflicted, harmonized, and prioritized in both the problem space and the solution space

Use cases for DE—and decisions and questions—should be the key drivers of the architecture of the digital twin

Summary

- MBSE, DE, and DT should be thought of as a System
  - Its functions are to answer questions to inform decisions
  - Its functional requirements are those questions
  - Its value results from its ability to answer those questions to inform those decisions

- Elicit and explicitly capture stakeholder needs
  - Identify the value proposition for the investment
  - Prioritize the functions that provide the best value
  - Develop the system using agile principles to accelerate adaptation

- Explicitly capture requirements in both the problem space and the solution space
  - Define sets of requirements applicable to each program milestone
  - Measure progress against those requirements for each program milestone
  - Digital Twin will also have differing requirements for fidelity at different points in the program life cycle

- Use $MBSE^2$ to help manage the complexity of needs and requirements for MBSE, DE, and DT

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