JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Digital Twin of an Acquisition Program

Engineering Decisions

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Outline

- Problem
- Case Studies
  - A. Modeling Functional Organization Process
  - B. Digitalization of Documents into Models
  - C. Cross Functional Data Model
  - D. Connecting Decision to Data to Process
- Solution
  1. Digital Engineering Strategy
  2. Data Model
  3. Decision Support System
- Recommendation
- Conclusion

Problem

P-8 Inc 1/2/3, or F/A-18 A/B/C/D/E/F, or B-52, etc.

- The regulatory environment of a Defense MDAP changes throughout its life cycle, forcing generations of leaders to be custodians of corporate knowledge.
- Programs make decisions that span and impact the organization, often without a comprehensive view of factors influencing their programs.
  - Information is often sequestered in functional silos.
  - The pedigree and reliability of data is often not established or readily apparent, which can contribute to reduced trust and rejection

We can make better organizational decisions with the data we already have (e.g. CDR) to construct a shared mental model that becomes the basis for more consistent and efficient decision-making.

Grieves, M. (2002)

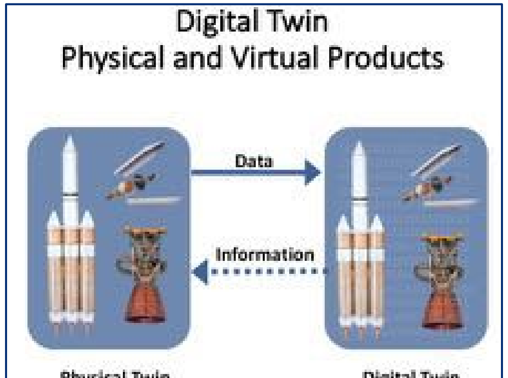


Figure 2

Better logistics decisions, using PLM in model

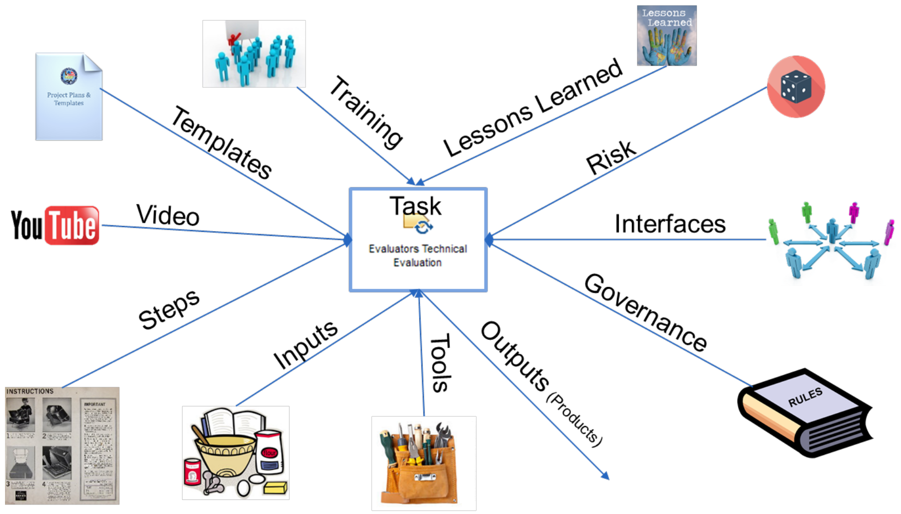
1. Virtual model of a real thing
2. Real data updates the model
3. IoT connection
4. Useful over lifecycle

Can program decision making be digitally transformed by applying principles of decision science (DS), theory & methods of systems engineering (SE), and practices from business program management (BPM), to *engineer decisions*?

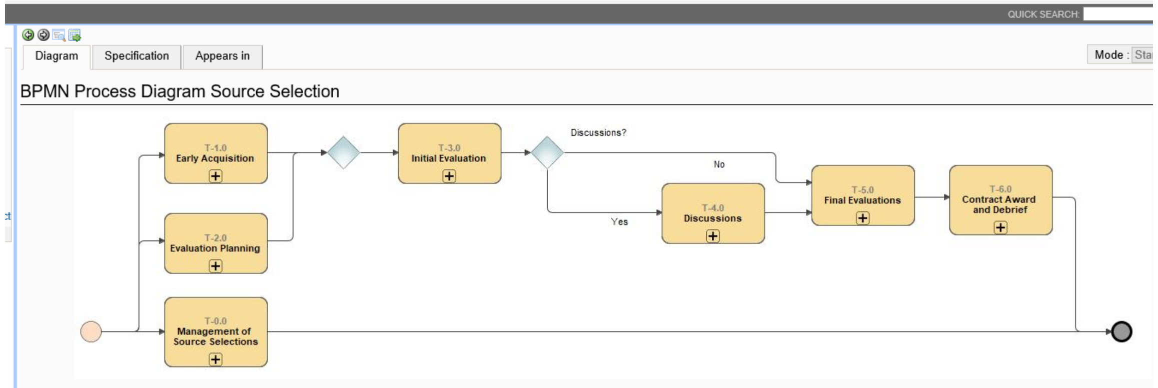
Case Study A

Improving Source Selection for a SYSCOM

- Core concept:
  - Every step in process is governed by constraints, I/O, protocols

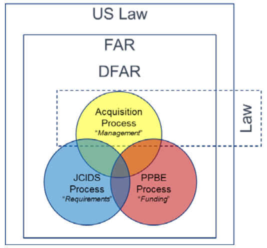


- Modeled the business process in BPMN
  - Created instances for small programs & MDAP



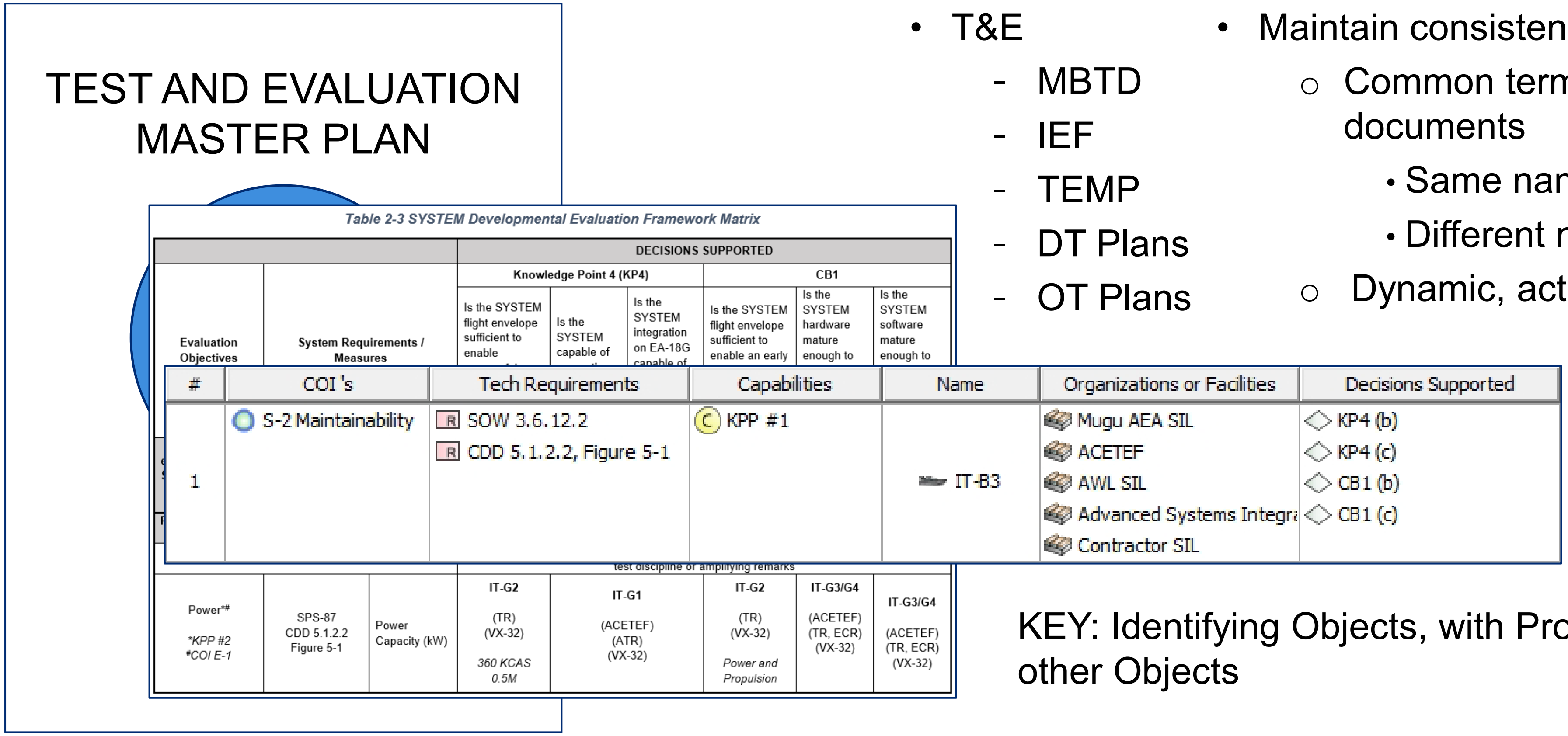
- Exposed that the process was largely governed by tribal knowledge
  - Many products were unicorns or orphans
  - Process was disconnected from FAR/DFAR

Modeling a Business Process like a Mission Computer



Case Study B

Transform Common Documents into Object-Oriented Databases



- T&E
  - MBTD
  - IEF
  - TEMP
  - DT Plans
  - OT Plans

- Maintain consistency across T&E
  - Common terms of reference across documents
    - Same name for same thing
    - Different names for unique things
  - Dynamic, active links across documents

KEY: Identifying Objects, with Properties, related to other Objects

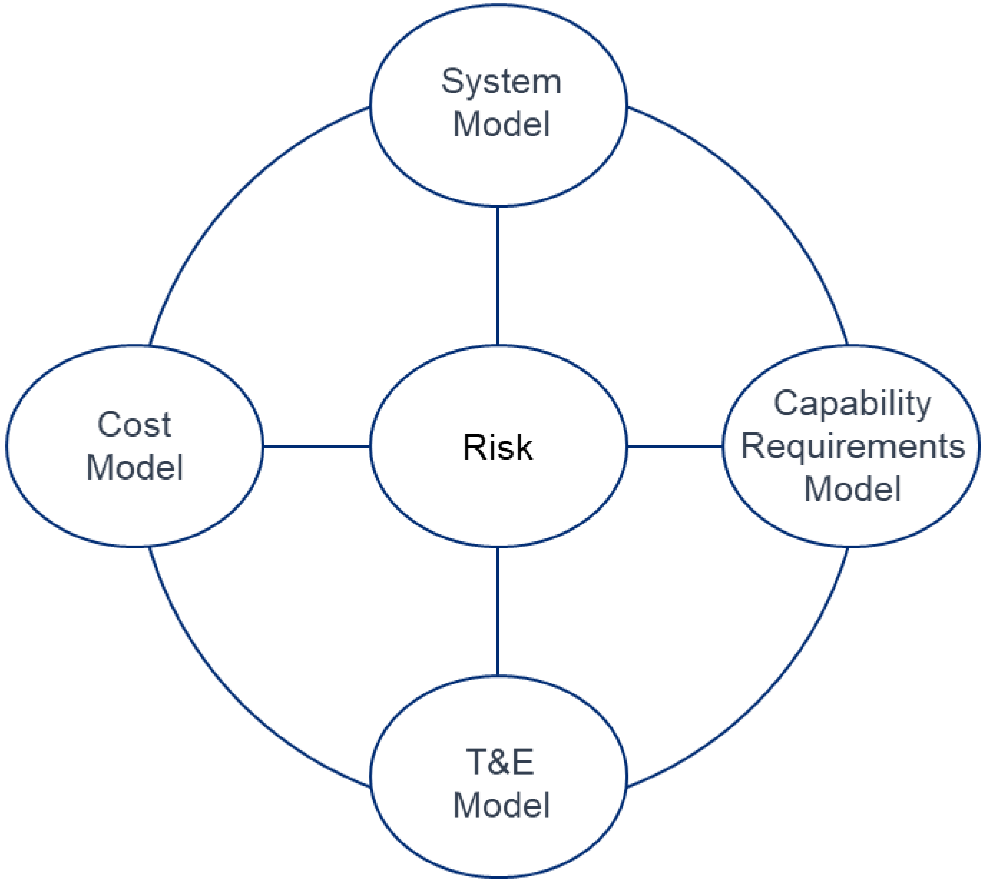
Digital Transformation of Documents into Models

Case Study C

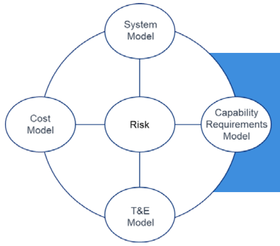
Decision Support System (DSS) for ACAT Program

Achieved objectives:

- ✓ Decision Support System (DSS) in a single, object-oriented environment.
- ✓ Integrated 5 component models as analytical products for alternative comparison.
  - ➢ Classic DoDAF: CV, OV, SV, etc.
  - ➢ Requirements documents and repositories
  - ➢ Cost Estimates and Items
  - ➢ Risk
  - ➢ CBT&E, MBTD, IEF, Cyber
- ✓ Enabled program functions to operate independently while retaining coherence.
- ✓ Remains a queryable database for subsequent analysis.



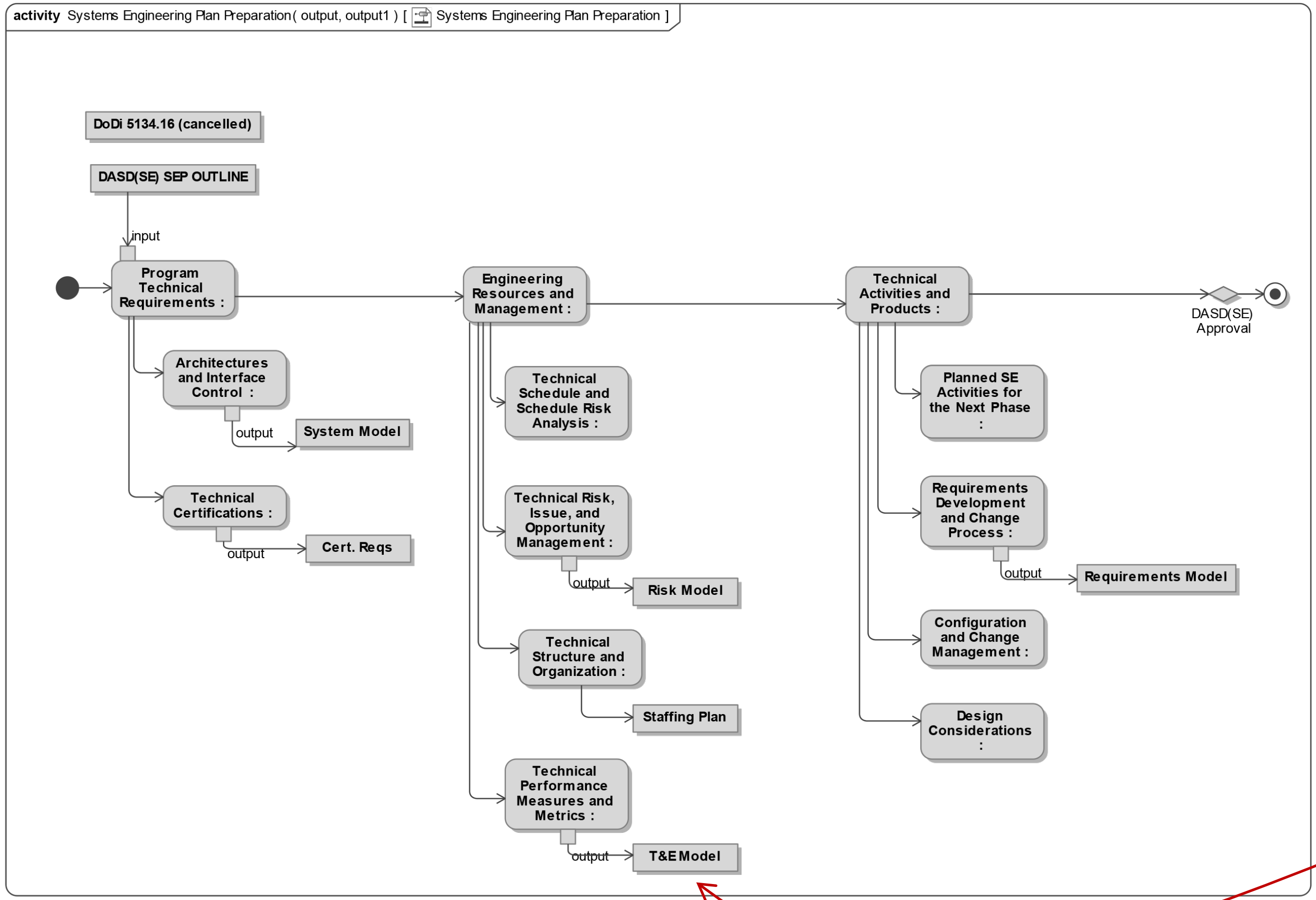
New Conceptual Framework & Exemplar

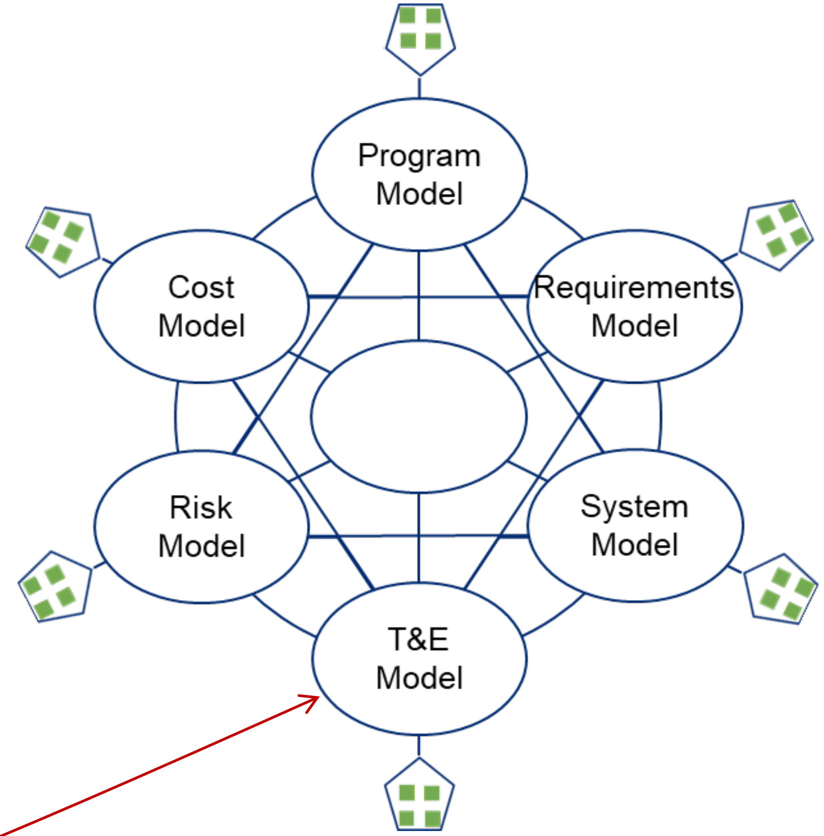


Cross Functional Data Model

Case Study D

Digital SEP with DSS for Next Gen Capability





Connecting Decisions to Data to Process

Solution

Lessons Learned

A. Workable Business Process Models
B. Digitalization of Documents
C. Cross Functional Data Models
D. Connect Decision to Data to Process

Digital Twin Attributes:

A. Has a physical twin
B. Can change in real-time
C. Consists of connected products
D. Digital thread
   - Lifecycle connectivity
   - Data exchange between physical / digital

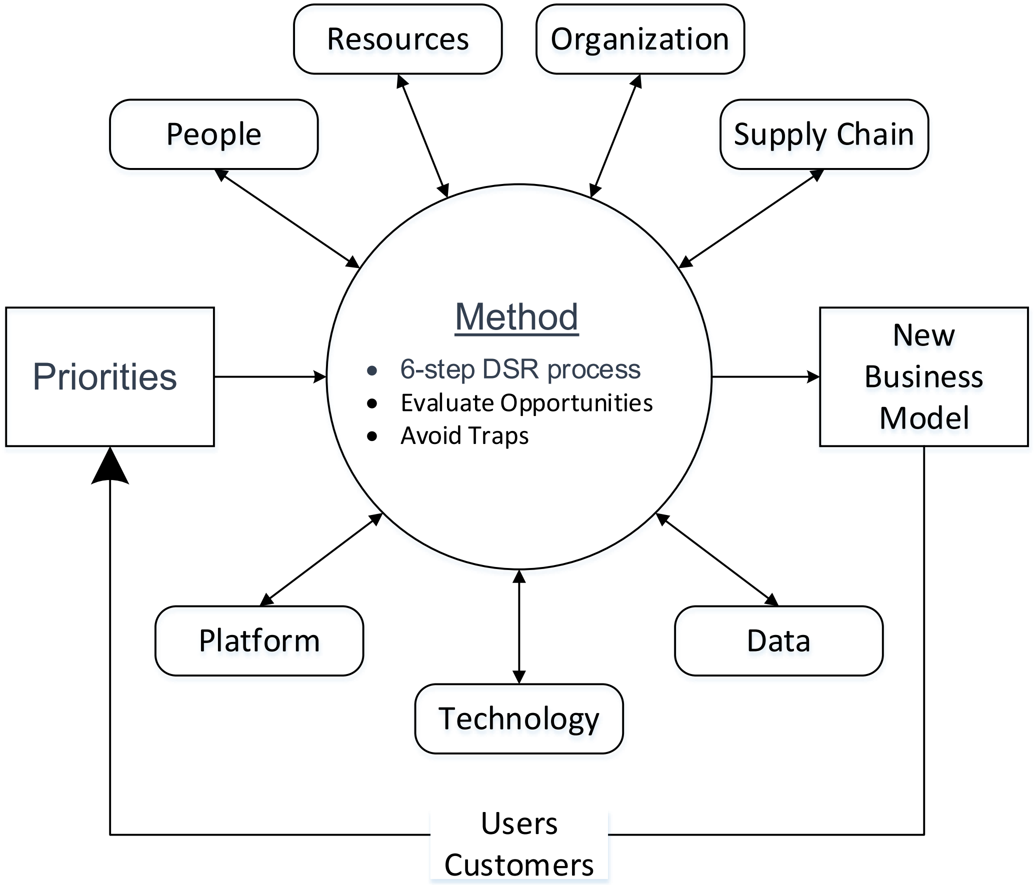
Digital Twin of the Program Office is Possible

1. Establish a framework for characterizing information sources and processes across all program functions (engineering, test, logistics, cost, risk, etc.), with specific attention to *decisions they feed and how.*
2. Using that framework, develop a program data model in the context of those decisions.
3. Using that data model, construct a dynamic decision support system that can respond to changes in the program's acquisition strategy and goals throughout its lifecycle.

Solution #1

Digital Engineering Strategy: Priorities, Ecosystem, Technology, & Method

1. Degree of Change:
   Refine, or Innovate, or Transform
2. Lean Impact Target:
   Process, or Product & Service
3. Circular Economy:
   Data Transformation, Resource Optimization, Data Flow Process, Reuse
4. Industry 4.0 Design Principles:
   Flexibility, Real-Time Capability, Decentralization, Modularity
5. Avoid over-digitization
   Delimit eligible processes



Program Goals feed Priorities, Ecosystem constrains Technology options, Method defines execution, New Business Model delivers efficiencies, Feedback supports continuous improvement.

Solution #2

Model Data Required by Decisions: e.g. Milestone ‘C’ (DoDI 5000.85)

DoDI 5000.85, August 6, 2020

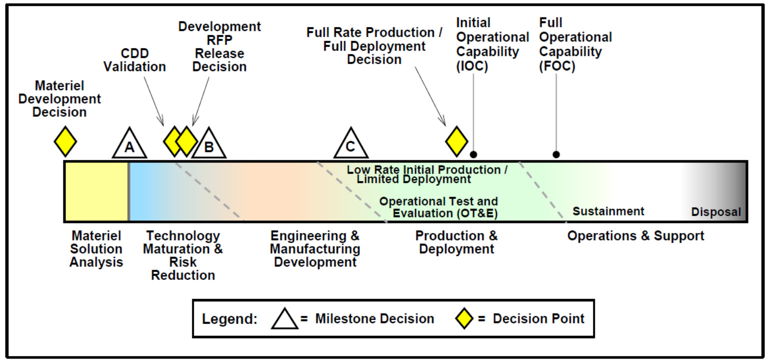


Figure 2. Major Capability Acquisition Model.

3.12. MILESTONE C

DoDI 5000.85, August 6, 2020

3.12. MILESTONE C.

a. Purpose.

Milestone C is the point at which a program is reviewed for entrance into the P&D phase.

b. At the Milestone C Review.

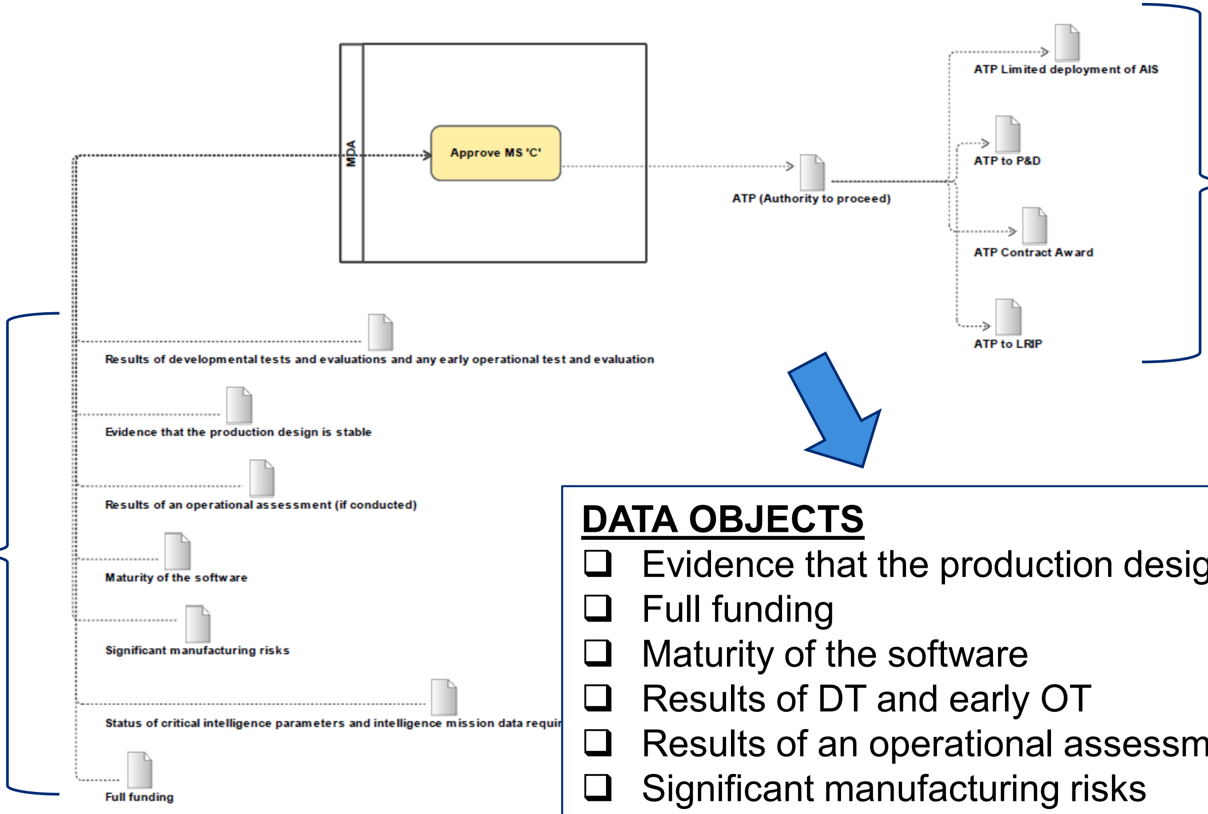
The following information will typically be considered: the results of developmental tests and evaluations and any early operational test and evaluation; evidence that the production design is stable; the results of an operational assessment (if conducted); the maturity of the software; any significant manufacturing risks; the status of critical intelligence parameters and intelligence mission data requirements, relative to fielding timelines; and full funding.

c. Decisions.

The MDA’s decision to approve Milestone C will authorize the program to proceed to the P&D phase, enter LRIP, or begin limited deployment for AISs, and award contracts for the phase.

SECTION 3: MAJOR CAPABILITY ACQUISITION PROCEDURES 16

Data Required



Data Produced

DATA OBJECTS

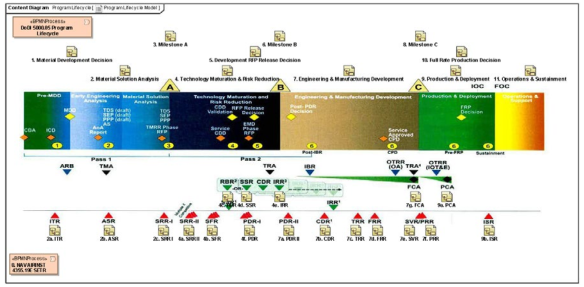
- ❑ Evidence that the production design is stable
- ❑ Full funding
- ❑ Maturity of the software
- ❑ Results of DT and early OT
- ❑ Results of an operational assessment (if conducted)
- ❑ Significant manufacturing risks
- ❑ Status of critical intelligence parameters
- ❑ ATP (Authority to proceed)
- ❑ ATP Contract Award
- ❑ ATP Limited deployment of AIS
- ❑ ATP to LRIP
- ❑ ATP to P&D

Solution #3

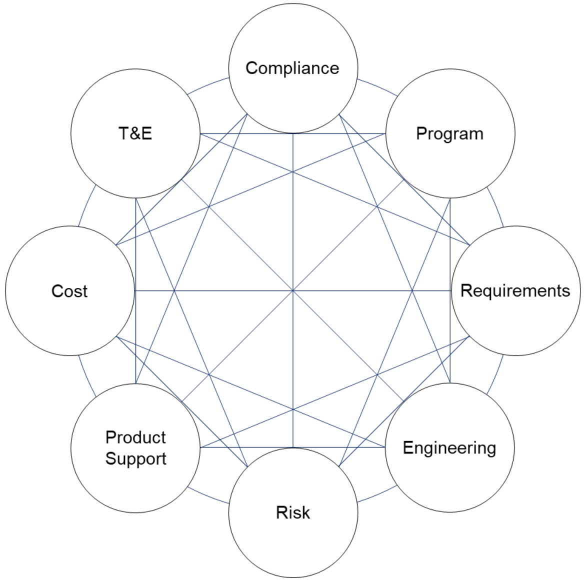
Decision Support System (DSS)

- Single *source of truth that features*
  - Cross-functional program data access with requisite controls and protection
  - Connectivity with internal and external processes that manage, produce or require it
  - decision aids tailored and accessible to the enterprise

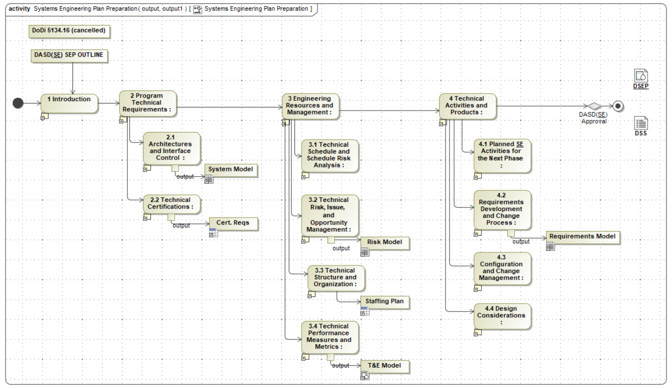
➢ Data segmented to allow internal fluidity while retaining external relevance
  - ➢ I can manage my data & process at will
  - ➢ I can see your data & relate my data to yours
  - ➢ I cannot change your data or process



New Decision Aids



New Data Model



New Digitalized Processes

Recommendation

Establish a Strategy, Develop a Data Model, Construct a Decision Support System

Strategy

1. Set priorities
2. Define the ecosystem & technical options;
3. Describe method to assess opportunity and risk;
4. Plan for the result: new processes using new data models that enable better decisions;
5. Provision for feedback: internally from users and externally from customers

Data Model

- Decision context (information requirements)
- Data format requirements
- Eligible processes

DSS is a platform to

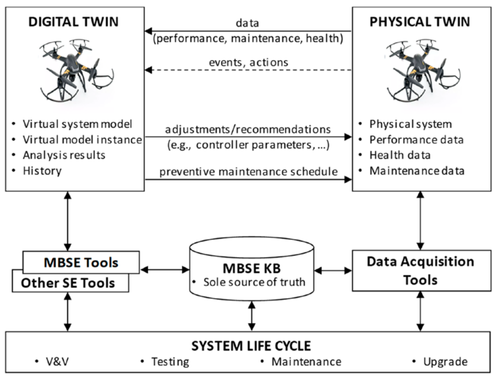
- Serve prioritized program manager needs,
- Ingest, transform, and harmonize data,
- Democratize the data environment using data services and business intelligence toolsets,
- Provide scalable and sustainable data/analytics products to accelerate time to value

Know *why* you do work, *how* you do work, and *what* you get out it

Process → Data → Info → Knowledge → Decision

Conclusion

Digital Twin of a Program: virtual model conjoined with real program



Madni et al (2019)

Digital Twin

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4. Digital thread
   - Lifecycle connectivity
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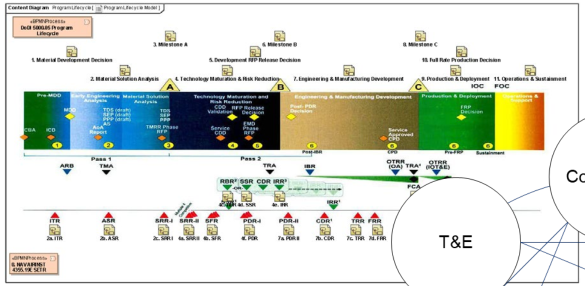

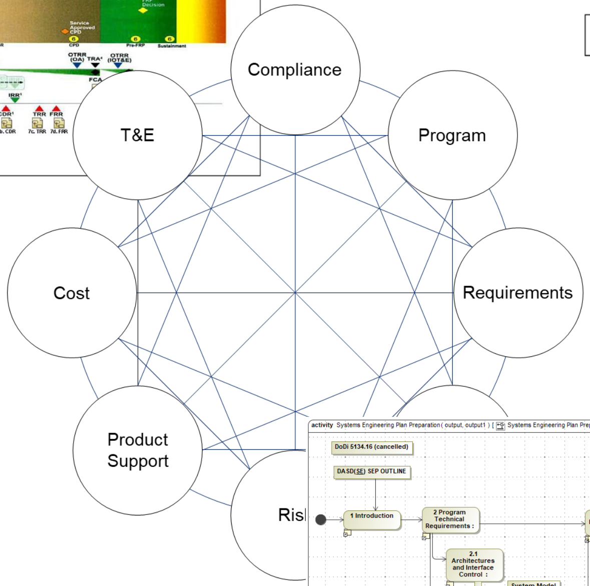

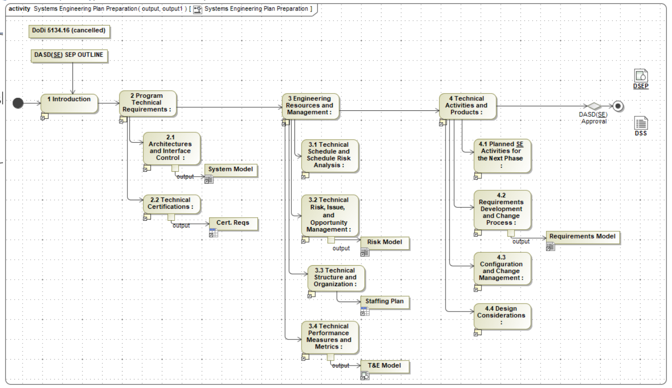

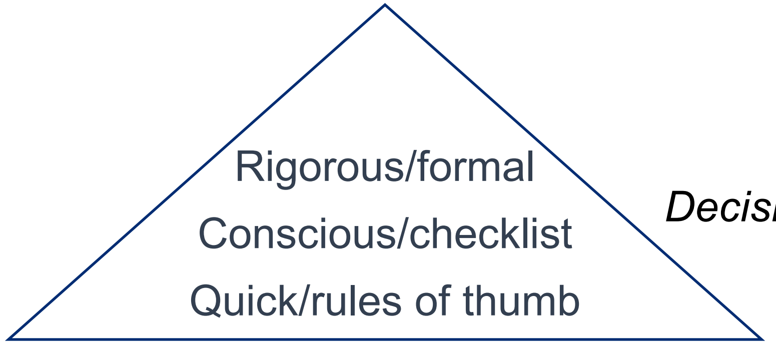

Decision making hierarchy

A program digital twin supports decision engineering: it identifies decision points, data required for those decisions, and processes necessary to produce the data.

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Data Objects Derived From

- DoDI 5000.85
- NAVAIRINST 4355.19E

Data Objects

1. Coded
2. Themed
3. Synthesized

Ability To Achieve KPP's
Ability To Achieve KSA's
Acceptance Test Procedures (ATP)
CSI And CSA Test Planning
CSI And CSA Testing
Data Collection, Reduction, Analysis; Test And Deficiency Reporting
Flight Test Requirements
Flight Testing Certifications
Initial Assessments Of Operational Effectiveness
Initial Assessments Of Suitability
Initial Assessments Of Survivability
Live Fire T&E (As Appropriate)
M&S Plan
M&S Role In Testing
M&S Validation
Remaining Tests Planned
Results Of OA
Results Of DT

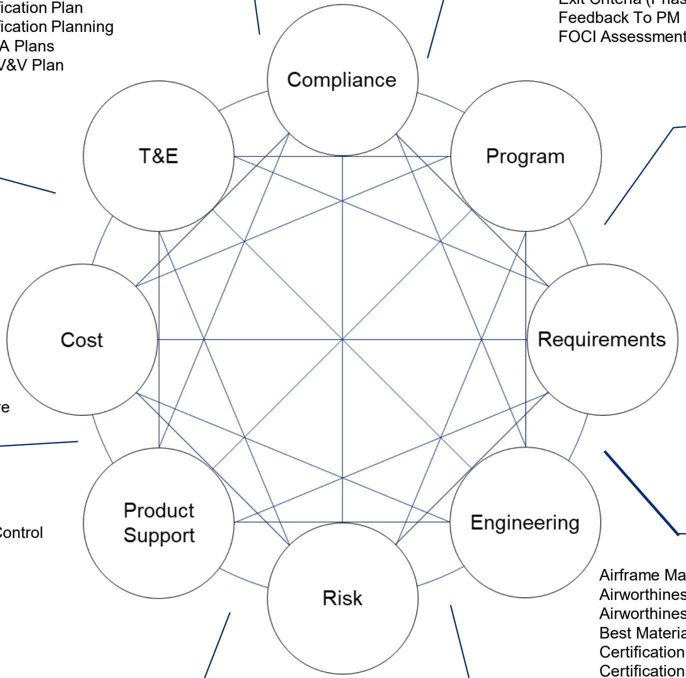
Software Integration Testing
Software Test Plan
Sprint Testing Results
Test And Data Processing Procedures
T&E Accomplishments
T&E Master Plan (TEMP)
Test Facilities Planning
Test Planning
Test Plans
Test Procedure
Test Requirements
Test Results
Test Strategy
Test Verification Plan
V&V Methodology
Verification Plan
Verification Planning
VV&A Plans
SIL V&V Plan

Public Law
FAR
DFAR
DODI
SECNAVINST
NAVAIRINST
FAA Regulations

Acquisition Phase Of Entry
Acquisition Program Baseline (APB)
Acquisition Strategy
ADM
AoA Study Guidance
AoA Study Plan
ATP (Authority To Proceed)
Business Approach
Business Strategy
Capability Trade Space & Priorities
Contract Incentives
Entrance Criteria (Phase)
Exit Criteria (Phase)
Feedback To PM
FOCI Assessment

Framing Assumptions
Initial Review Milestone
Integrated Master Schedule (IMS)
IP Strategy
Key Government And Contractor Interfaces
LRIP Quantity
LRIP Quantity Approval
Milestone Approval Criteria
Milestone Documentation
OAG Priorities
Open Action Items
Options Matrix
Organization Structure
(Phase) Acquisition Plan
(Phase) Strategy

PM Waiver Requests
Program Decisions
Program Goals Approval Memorandum
Program Protection Implementation Plan
Program Protection Plan (PPP)
Program Security
RFP
RFP Release Approval
Senior Leader Guidance
SOO
Source Selection Criteria
SOW
Competition Strategy
Subcontract Strategy



Affordability Analysis
CARD and/or Cost Estimates
Cost Data
Current Execution Year
Earned Value Data
Fiscal Assumptions
Full Funding
Funding
Future Years Defense Program
ICE
Pending Execution Year
Planned vs. Actual Resource Curve
Should Cost Targets

Affordability Requirements And Program Goals
Capability Development Document (CDD)
Capability Production Document (CPD)
Initial Capabilities Document (ICD)
Contractor System Specification
Requirements Document
SRD
SRS
Contracts Data Requirements List (CDRL)
Technical Performance Measures (TPM)
Key Performance Parameters (KPP)
Key System Attributes (KSA)
Measures Of Effectiveness (MOE)
Measures Of Performance (MOP)
Measures of Success (MoS)
Measures Of Suitability (MOS)
Critical Intelligence Parameters
Integration Planning
Maturity Of The Software

Mission Profiles
New Mission Capability
Product's Compliance With Contractual Requirements
Requirements Baseline
Requirements Trace
Requirements Verification Matrix
Requirements, Certification
Requirements, Design And Functional
Requirements, Engineering Data
Requirements, Functional
Requirements, Manufacturing
Requirements, Performance, Safety
Requirements, Producibility
Requirements, Product Support
Requirements, Quality
Requirements, Safety Critical Software
Requirements, Security, Cybersecurity
Requirements, Software
Requirements, System Level
RFP Requirements
Threat Environments
Threat Projections

Allocated Baseline
Functional Baseline
Performance Baseline
Product Baseline
Bulletin Technical Directives
Certifications Required For Fielding
CM Procedures
CM Process
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DMSMS
Evidence That The Production Design Is Stable
Fatigue Life
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Industrial Production Capabilities
Integrated Information Dissemination Processes
IPS Elements
LCC, TOC Evaluation Methodology
Life Cycle Sustainment Plan
Life-cycle Mission Data Plan
Logistics Footprint Assessment
Manufacturing And Production Strategy
Manufacturing Plan
Manufacturing Process Control
PCA Results

Performance And Reliability Metrics
Production Quality Deficiency Reports
Producibility, Manufacturing Process, And Process Control Analysis
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Quality Control Plan
RCM And IMP
RCM And IMP Staffing
Release Cycles
Release Schedule
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Technical Publication Deficiency Reports
Training Strategy
NATIP
NATOPS
NARIIP

Risk Management Process
Risk Management Plan
Risks
- Causal Factors
- Consequences
- Mitigations

Programmatic Risk Assessment
Manufacturing Risks
System Risk Assessment
System Safety Hazard Risk Assessment

Airframe Management Board Status
Airworthiness Criteria
Airworthiness Criteria Changes
Best Material Approach(es)
Certification Plans
Certifications and/or Flight Approvals
Communication, Navigation Systems
Computer Resource Utilization Metrics
CSI And CAI
CTE
CTE Candidate
CTE Maturity
CTE TRL Verification
CTE, Software
CTE, Systems And Subsystems
Cybersecurity Controls
Cybersecurity Strategy
Design Process
Design Analysis
ECP
ECP Status

EI
Effective Combat Capability
Engineering Data Artifacts
Flight Clearance
Flight Clearance, Interim
Hazard Analysis
Hazard Material Reports
Hazard Reports
Integrated Architecture (CV, UC, OV, SV)
Integration Planning
Integration Point Complexity
Interface Design Documents
Interface Design Maturity
Interoperability
ITRA
Mishap Reports
MOSA
Physical System
Rework Quantification
Safety Assessment Reports Status
Safety Engineering Investigations

SDP
SEMP
SEP
Software Backlog Allocation
Software Backlog User Stories
Software Certification Plans
Software Development Execution Metrics
Software Development Plan
Software Development Strategy
Software Documentation
Software Integration Plan
Software Plans
Software Trouble Reports Status
Subsystem Level Analysis
Subsystem Level Safety Analysis
System Design
System Level Analysis
System Performance
System Software Interfaces
System Technical Interfaces
Systems Integration Plan
Technology Maturation Plans (TMP)

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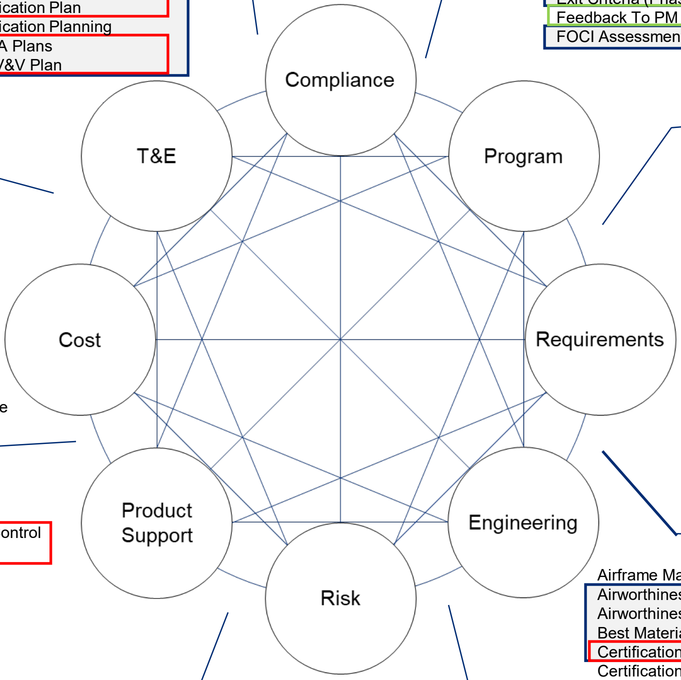

T&E

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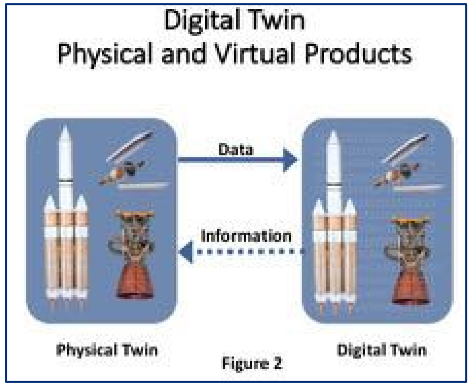
Integration Point Complexity
Interface Design Documents
Interface Design Maturity
Interoperability
ITRA
Mishap Reports
MOSA
Physical System
Rework Quantification
Safety Assessment Reports Status
Safety Engineering Investigations

SDP
SEMP
SEP
Software Backlog Allocation
Software Backlog User Stories
Software Certification Plans
Software Development Execution Metrics
Software Development Plan
Software Development Strategy
Software Documentation
Software Integration Plan
Software Plans
Software Trouble Reports Status
Subsystem Level Analysis
Subsystem Level Safety Analysis
System Design
System Level Analysis
System Performance
System Software Interfaces
System Technical Interfaces
Systems Integration Plan
Technology Maturation Plans (TMP)

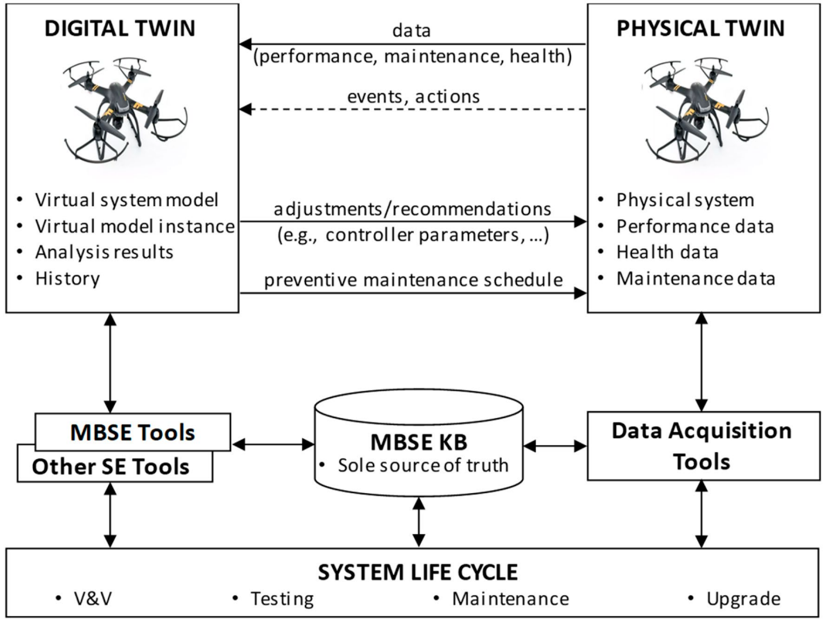
Background - Digital Twin

Virtual models conjoined with real systems in feedback loops

- A digital twin requires a physical twin for data acquisition and context-driven interaction.
- The virtual system model in the digital twin can change in real-time as the state of the physical system changes (during operation).
- A digital twin consists of connected products, typically utilizing the IoT, and a digital thread.
- The digital thread provides connectivity throughout the system's lifecycle and collects data from the physical twin to update the models in the digital twin.



Grieves, M. (2002)



Madni et al (2019)

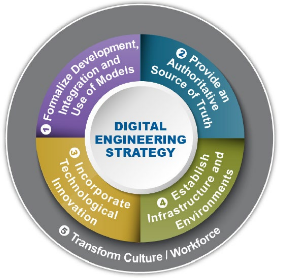
Forecast health, remaining life, probability of success, response to events, mitigation of damage, recommend changes

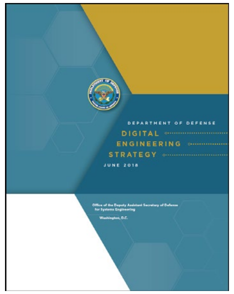
Background - DE

Digital Engineering (DoD Strategy)

<u>Problem</u>

- Greater efficiency in procurement is a national priority (National Defense Strategy, 2018).
- Reforming the business processes is a key strategic goal (National Defense Business Operations Plan, 2018).
- DoD lags industry on digital transformation solutions (DoD Digital Engineering Strategy, 2018).





<u>DoD Digital Engineering Strategy Goals:</u>

- Formalize the development, integration and use of models to inform enterprise and program decision making
- Provide enduring, authoritative source of truth
- Incorporate technological innovation to improve the engineering practice
- Establish a supporting infrastructure and environments to perform activities, collaborate, and communicate across stakeholders
- Transform the culture and workforce to adopt and support digital engineering across the lifecycle

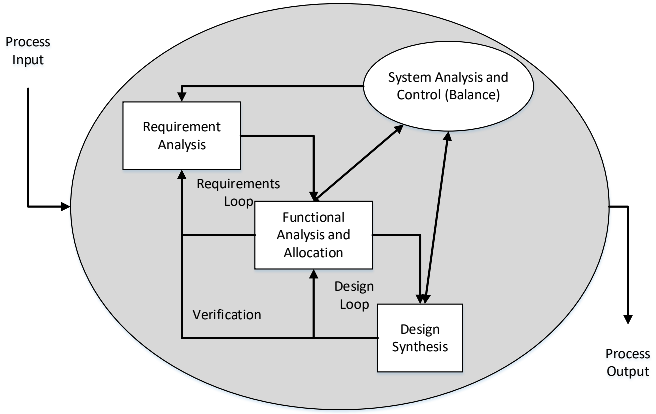
"DE is an integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support life cycle activities from concept through disposal." - DAU

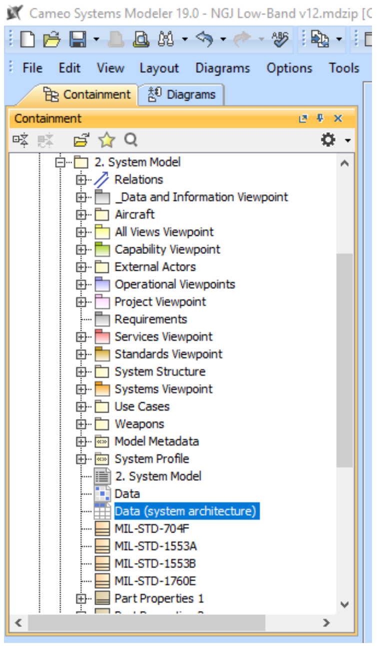
Does not answer [WHAT] or [HOW] to implement digitalization

Background - MBSE

Model-Based Systems Engineering

- “Model-based systems engineering is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.”
  - INCOSE SE Vision 2020
- “In contrast to document-centric engineering, MBSE puts models at the center of system design.”
  - Shevchenko, N. (2020)



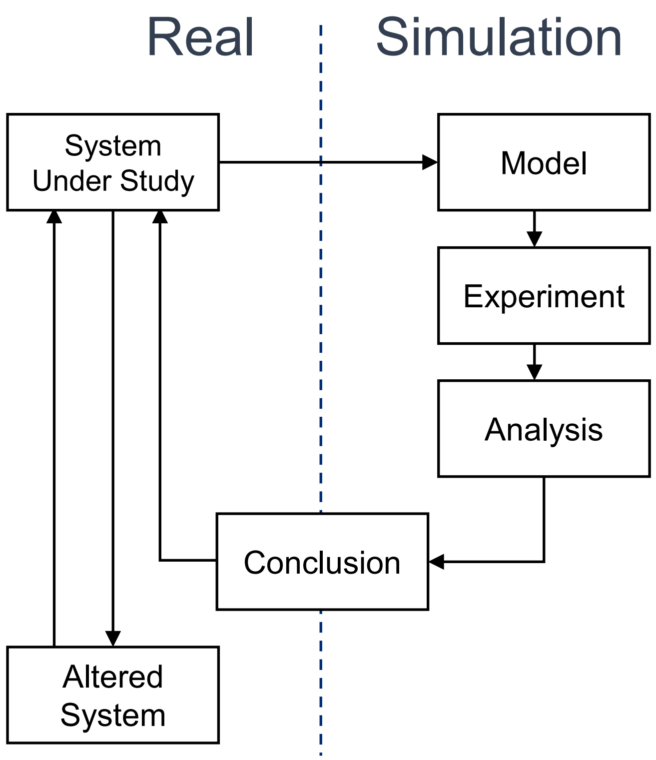


MBSE can be done in any of several languages, in many tools

Background – M&S

Modeling & Simulation

- Model:
  - a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process
  - a close approximation to the real system, incorporates most of its salient features
  - to promote understanding of the real system
- Simulation
  - a method for implementing a model *over time*
  - the operation of a model of the system
  - enabling one to perceive the interactions that would not otherwise be apparent because of their separation in time or space



Note: Adapted from Maria, A. (1997)

Background - BPM

Business Process Modeling

Business Process Management (BPM)

- the art and science of overseeing how work is performed in an organization to ensure consistent outcomes and to take advantage of improvement opportunities.

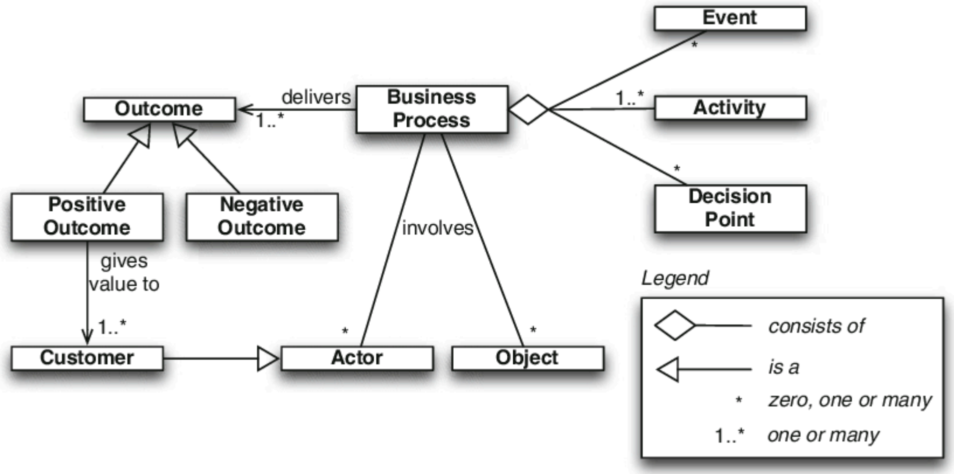
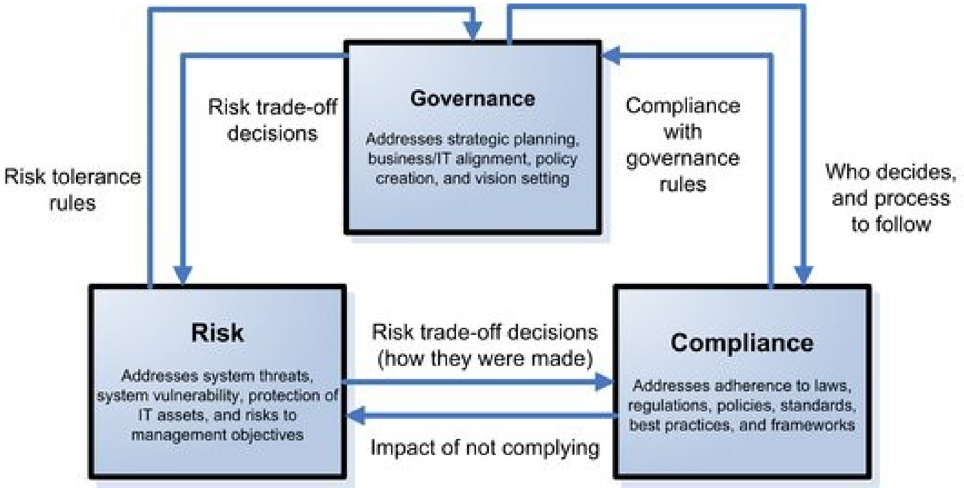


Fig. 1.1 Ingredients of a business process

Dumas, M., et al. *Fundamentals of Business Process Management*. Germany. Springer-Verlag Berlin Heidelberg, 2013

Governance, Risk, and Compliance (GRC) is a type of software that business uses to

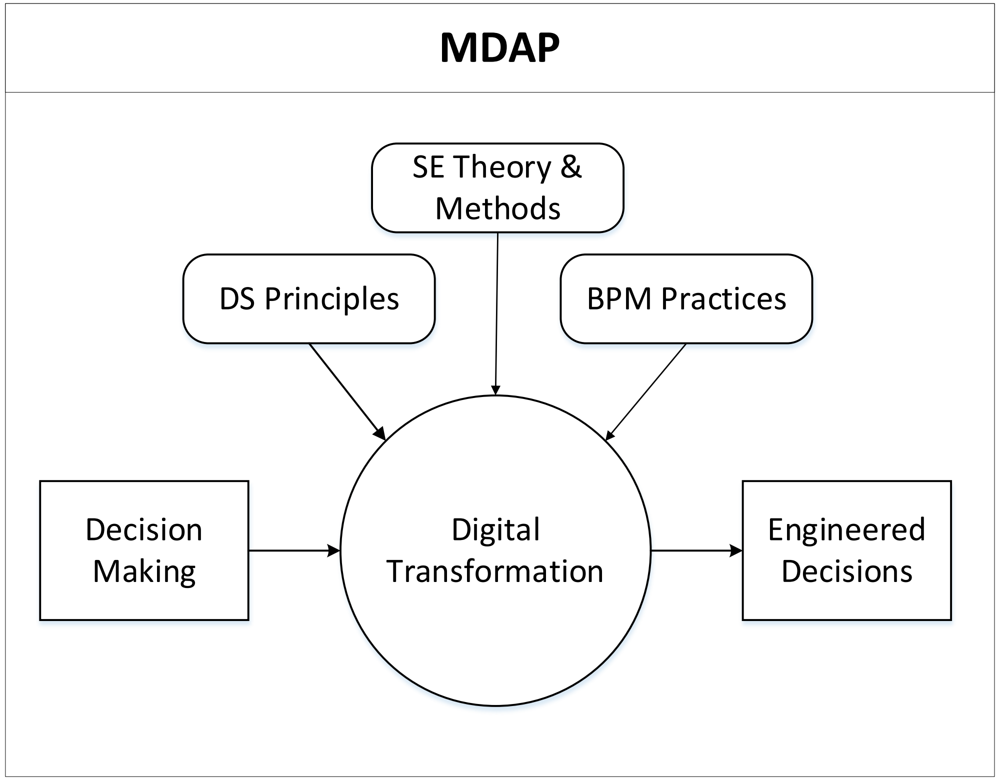
- Meet BPM goals by governing processes
- Keeps processes compliant with changing regulations
- Allow only authorized amounts of risk



Source: Microsoft

Research Question

- Can program decision making be digitally transformed by applying principles of decision science (DS), theory & methods of systems engineering (SE), and practices from business program management (BPM), to engineer decisions?
- Figure reflects this question using the theoretical framework of General Systems Theory



Future Research

Does Decision Engineering reduce errors?

H_1 - Decision Engineering reduces Type I errors	(false positive)
H_2 - Decision Engineering reduces Type II errors	(false negative)
H_3 - Decision Engineering reduces Type IIII errors	(wrong problem)
H_4 - Decision Engineering reduces Type IV errors	(wrong action)
H_5 - Decision Engineering reduces Type V errors	(inaction)
H_6 - Decision Engineering reduces Type VI errors	(unsubstantiated inference)
H_7 - Decision Engineering reduces Type VII errors	(system of errors)
H_8 - Decision Engineering reduces Type VIII errors	(incorrect implementation)
H_0 - Decision Engineering does not reduce errors.	

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