Decision Engineering and the Digital Twin of an Acquisition Program a Cumulative Case Study

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Abstract

The regulatory environment of a Major Defense Acquisition Program changes throughout its life cycle, challenging generations of leaders to be custodians of corporate knowledge, and make decisions across an enterprise, sometimes without a comprehensive view of factors influencing their programs. Tools such as Digital Twins, Digital Engineering, Model-Based Systems Engineering, and Modeling & Simulation have utility, but their value to managers is often illusive. This paper explores if program decision making can be digitally transformed by applying principles of decision science, theory & methods of systems engineering, and practices from business program management, to engineer decisions. This cumulative case study describes the background, purpose, method, and conclusions from four projects. A digital twin of a project can be constructed by modeling organization processes, digitalizing documents, linking live cross functional data, and connecting decisions to data to process. The resulting system has transparent processes, dynamic and relevant data models, and useful decision aids. This repository is an enduring, usable body of knowledge, linking decisions to the data required, and the business processes that create it. A program digital twin supports decision engineering: it identifies decision points, data required for those decisions, and processes necessary to produce the data.

Keywords
Decision Engineering, Digital Twin, Strategy, Data Model, Decision Support System

Executive Summary
The regulatory environment of a Major Defense Acquisition Program (MDAP) changes throughout its life cycle, challenging generations of leaders to be custodians of arcane corporate knowledge, complicating decision-making across organizational levels and functions, often without a complete, common operating picture. Data critical to decisions may be inaccessible, and the processes that generate it may not be transparent. Tools and approaches such as Digital Twins, Digital Engineering (DE), Model-Based Systems Engineering (MBSE), and Modeling & Simulation (M&S) are being applied in an attempt to address this challenge, but their value to program managers may be illusory. Four case studies demonstrate a digitally transformed program can create a digital twin of itself: a shared repository of data and analytics to excel at decisions. This repository is an enduring, usable body of knowledge that links management decisions to the data required, and to the business process that creates the data. The program can have the data it needs, when it needs it by engineering decisions: identifying the likely decision points, the data required for those decisions, and the processes necessary to produce the data.

The decisions are identified by a strategy, designed into a data model, and instantiated in a Decision Support System (DSS). The strategy identifies the priorities on program data, eligible processes, the ecosystem the model will reside in, the technology options/constraints, and a feedback loop. The data model drives transformation by digitalizing existing documents, combining existing cross-functional data, and modeling necessary processes. Once populated, this digital transformation results in a shared DSS with digitalized processes that are transparent, data models that are internally fluid and externally relevant, and accessible decision aids. With a digital twin of the program, managers can forecast health, remaining life, probability of success, response to events, mitigation of damage, and recommend changes.

1. Introduction
Many programs are a layered set of MDAPs with multiple, complex, related but unique programs passing through milestones in rapid succession. These programs will strain the highly specialized staff and managers, and their ability to make decisions and execute. Compounded with the other programs in a program office, the challenges are magnified further. Providing the staff and managers a mechanism to control the processes that generate the products necessary for making better decisions is essential. A construct for such a mechanism combines Department of Defense (DoD) standards with commercial practices in an innovative framework.

1.1. Problem Statement
The number of policy mandates imposed on a MDAP is so high it is unknown (Gansler et al, 2015). It is difficult to accurately count the layers of stakeholders empowered to impose new constraints on complex programs, let alone discern the directly applicable constraints from those indirectly affecting while avoiding those actually not applicable to a specific program or activity.

At the same time, executing plans in a predictable, fully resourced manner is challenging when the processes are often undocumented, unconstrained, or have unknown triggers, unspecified inputs or undefined outputs (Bolten et al, 2008). Processes executed purely based on the expertise of the process owners can fall prey to slowing shifting tribal knowledge and become untethered from legitimate regulation. Processes or activities that do not generate specified products essential to a decision of a given program should not be required, but may be imposed out of habit.

Managers of program make decisions continuously on a variety of levels, in a variety of functions, across an enterprise, usually without a complete, consistent understanding of the context around a given problem (Fast, 2010). For example, a problem that arises in an early developmental test may not be fully appreciated for its secondary impact on a risk related to the lagging schedule of a system component, simply because when the team meets to discuss the discrepancy they may be unaware of a related program risk, documented in a separate repository. In a different vein, a program may struggle to collect the products necessary to successfully pass a program review without a detailed understanding of what information that decision maker requires or will consider satisfactory.

1.2. 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 1 reflects this question using the theoretical framework of General Systems Theory (Von Bertalanffy, 1972).

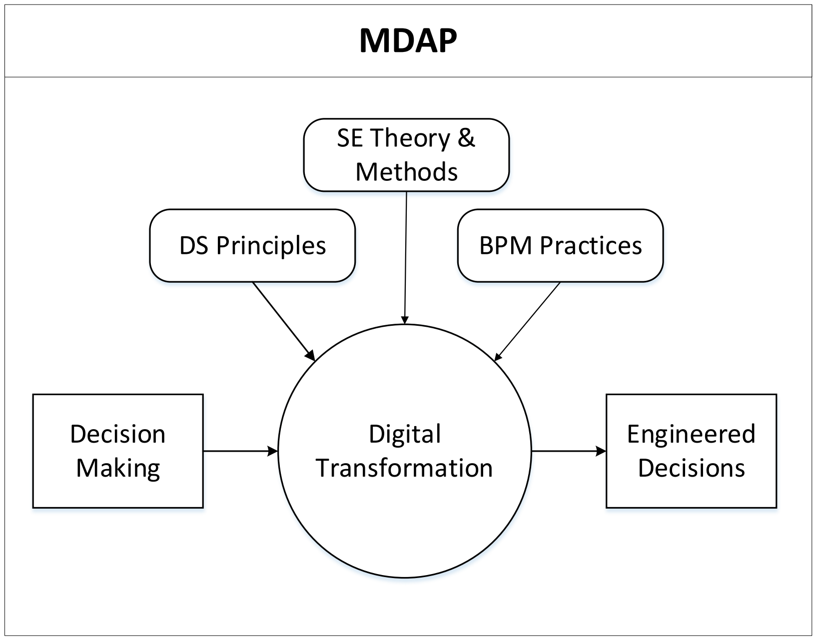

Figure 1. Research Question

1.3. Purpose

We assert that by constructing a digital twin of a program, the organization will be able to look into its own processes that define it, how it collects, processes and presents information across the decision-making spectrum, from executive to operational personnel. A digital twin can trace decisions to program objectives and goals – and how they were set. Additionally, this modeling can enable the organization to critically evaluate individual roles' inputs into the process, looking for which decision-making strategies are used when and for consistency. This provides the organization knowledge tools that level-set the values across the organization to get the results desired, and document the processes to achieve those goals.

2. Background

In order to better understand the problem space and case studies, the paper will review six key tools and their contribution to decision making. Those include modeling and simulation, model-based systems engineering, digital twins, digital engineering, business process modeling, and decision science.

2.1. Modeling & Simulation (M&S)

M&S is a commonly used term, if slightly misunderstood. A model has three characteristics. It is a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process (Maria, 1997). The model is a close approximation to the real system, and incorporates most of its salient features. A model is used to promote understanding of the real system. There are many valid types of model, from wooden ship hulls to a full-scale mockup of the Space Shuttle, or an Activity Diagram of software. A model is an abstraction of a real thing, from a perspective, with utility.

Simulations are a model with a twist. Simulation is a method for implementing a model over time (Coolahan, 2003). A simulation demonstrates the operation of a model of the system. A simulation enables an experimenter to perceive the interactions that would not otherwise be apparent because of their separation in time or space (Gupta & Grover, 2013). A simulation allows repeated tests of a system over time, in different configurations or under different conditions (Figure 2).

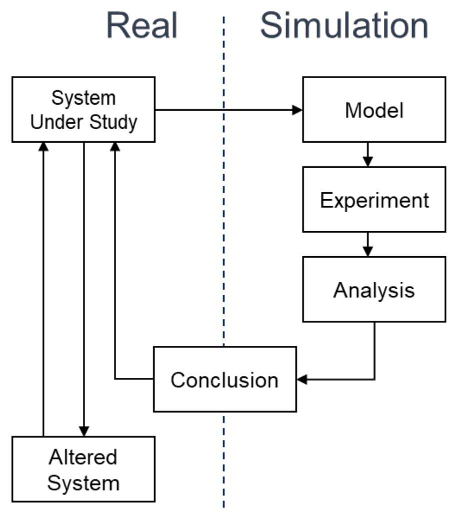

Figure 2. Simulation Study Schematic
Note: Adapted from Maria (1997)

2.2. Model-Based Systems Engineering (MBSE)

MBSE is a method of visualizing the systems engineering process: a top-down process of decomposing requirements into functions, then to designs that are verified against the requirements (INCOSE, 2007). Mandates for DoD Architecture Framework (DoDAF) views at program milestones reflect the same progression (i.e. Use Case, Operational Views, and System Views) (SYSCOMINST 4355.19D). However, there is no DoD requirement (or established method) to connect those System Views to test events, risk items, cost items, or staffing and schedule. Nor is there a connection to the processes that create them or use them.

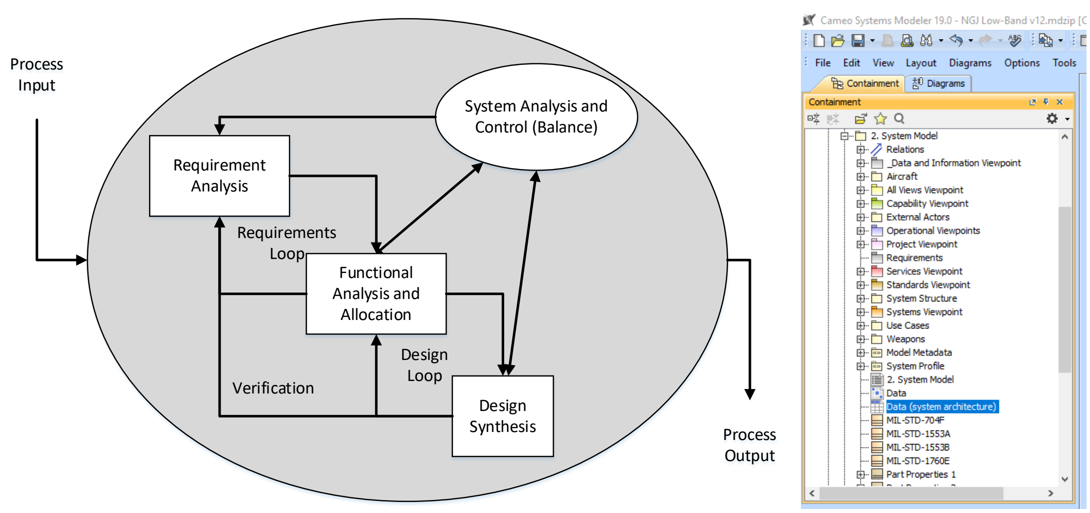

Figure 3. Systems Engineering Method and a SysML Model

Reference Architectures are pattern models at a level of generality that provide some degree of reuse, while a contractor 'solution architecture' portrays the relationships among all the elements of something that answers a problem (OASD/NII, 2010) (Figure 3). Effectively, they are two sides of the same coin (what you want vs. what they sell). DoDAF is a framework for visualizing them, often using the Systems Modeling Language (SysML) (DoD, 2003).

2.3. Digital Twin

The concept of digital twins first arose in discussions of product lifecycle management (PLM) (Grieves, 2002). It has evolved since then, with extensive commercial use and continued research, such as Madni et al (2019). 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 Internet of things (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.

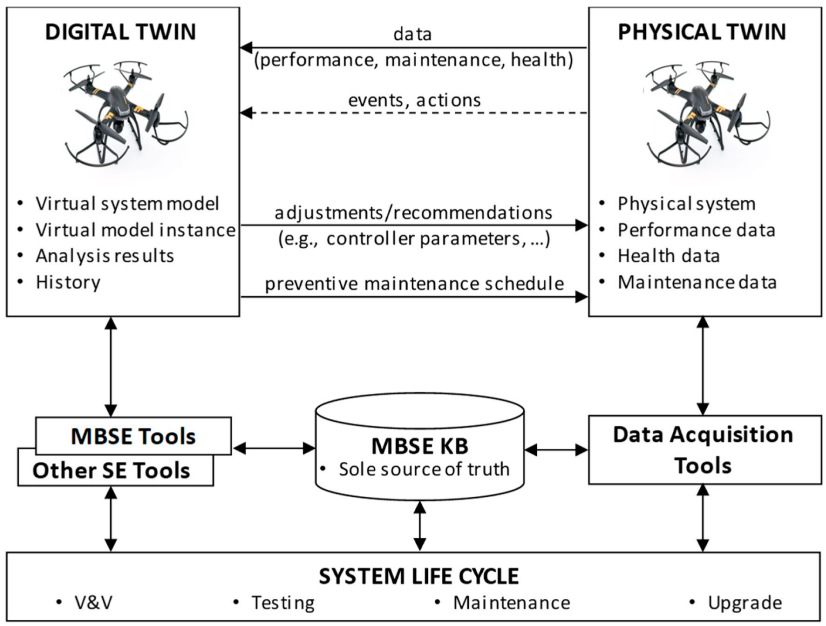

Figure 4. Digital Twin

Note: From Madni & Purohit (2019)(Figure 4). No changes were made to the author's diagram.

2.4. Digital Engineering (DE)

The Defense Acquisition University defines digital engineering as "…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, n.d.). DoD published its Digital Engineering Strategy in 2018, followed in 2020 by the Naval Digital Systems Engineering Transformation (DSET) Strategy (DoD, 2018, DASN RDT&E, 2021). Both have the same five goals, but neither gives direction on what or how to digitalize. The FY20 Defense Authorization defined DE in federal law. In §230 it defined DE as "…the creation, processing, transmission, integration, and storage of digital data, including data science, machine learning, software engineering, software product management, and artificial intelligence product management."

DE is often confused with MBSE, but the DE policy goals go far beyond the familiar DoDAF perspectives, or the Government Reference Architectures (DoD, 2003, OASD/NII, 2010). DE is not a new interdisciplinary branch of engineering, like systems engineering (SE) is a branch of industrial engineering (SEBoK, n.d.). At this time, DE has no distinct scientific principles applied to build particular things, no unique processes, methods or protocols; it is only a policy. However, the commercial world embraced digitalization out of necessity and has realized great opportunities that government can leverage (Carucci, 2020).

2.5. Business Process Management (BPM)

Business Process Management (BPM) is the art and science of overseeing how work is performed in an organization to ensure consistent outcomes and to take advantage of improvement opportunities (Dumas et al, 2013). Each system command (SYSCOM) implemented various BPM efforts that resulted in numerous products that have value, such as standard work packages (SWP). While the processes that have been mapped can be improved, they are not necessarily directly connected to the products they use or create.

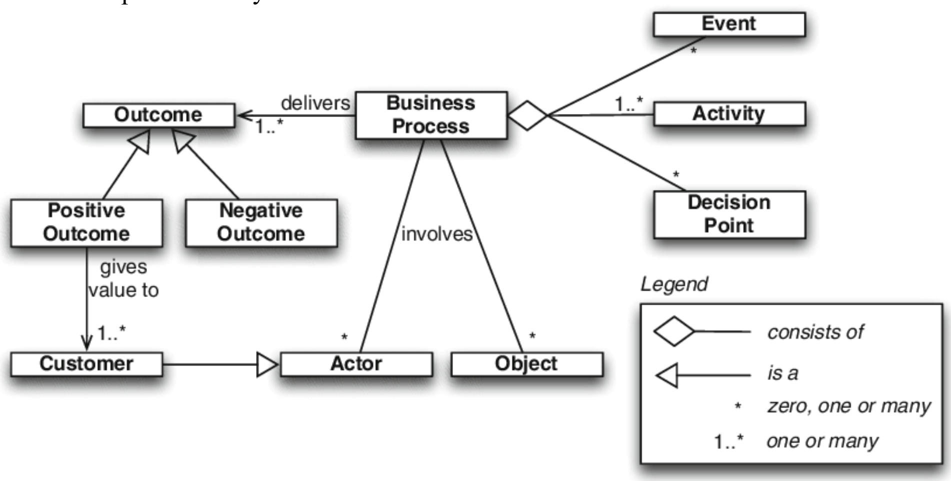

Figure 5. Ingredients of a Business Process
Note: Adapted from Dumas et al (2013)

Because of the "dot com" bust and the subsequent Sarbanes-Oxley legislation (Figure 5), the financial technology industry had to reshape operations (Senate, 2003). Global companies may find themselves financing a loan in Kentucky through a subsidiary in Virginia from a headquarters in New York using funds from the United Kingdom. Such a transaction crosses multiple jurisdictions and must comply with the laws of each, while achieving the intended business goals, satisfying the customer needs, and managing overall risk. As a result, several corporations offer Governance, Risk, and Compliance (GRC) software that keep business processes compliant with changing local, state, federal and international regulations while remaining easy to execute with defined inputs and formatted outputs to meet business goals and allowing only authorized amounts of risk (financial or reputational) (OCEG, 2016).

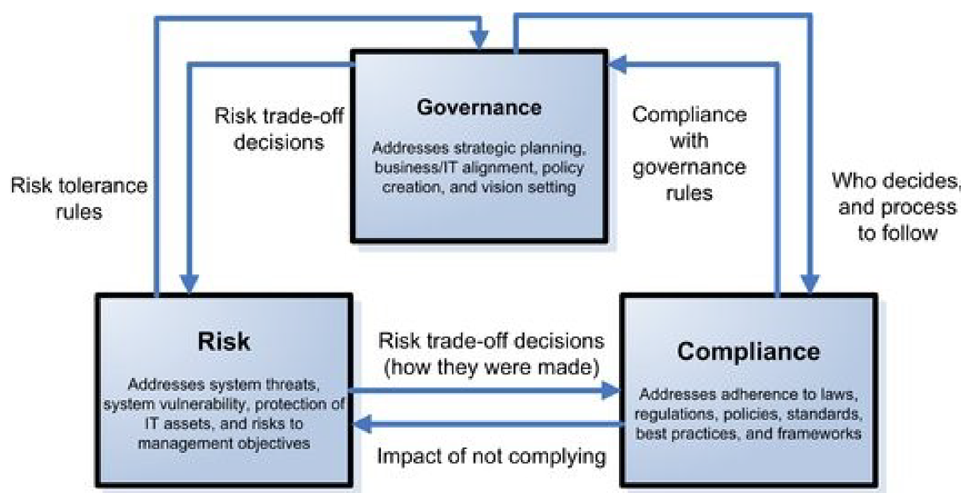

Figure 6. Governance, Risk, and Compliance (GRC) Relationships
Note: Adapted from Microsoft (2008).

Recent research suggests designing decision support systems to treat a decision as the end of a process (Figure 6), and reverse engineering the process from it (Carrucci, 2020). In other words, start by identifying the decisions to be made, who will make them, connect the governance groups, and build in quality control. This came to light in the course of four independent research projects. Each project demonstrated a principle that is essential to building effective decision support systems.

2.6. Decision Science (DS)

The theoretical foundations of decision making include classical, judgement, organizational, and naturalistic methods. Organizational Decision Making (ODM) is focused on decision making as an element of organizational behavior, specifically decision making behaviors in individuals when acting as a member of an organization (Hester & MAcG, 2017). DS has been defined as "(t)he application of the scientific method by intra-disciplinary teams to problems involving the control of organized (man-machine) systems so as to provide solutions which best serve the purpose of the organizations as a whole." (Ackoff, Sasieni, 1968). "The decision sciences … [depends on] strong ties to the professional schools (especially business, public policy, public health, medicine), to the engineering school, to the departments of economics, psychology, government, mathematics, statistics, philosophy, and especially to the school of education." (Raiffa, p.68) This is an acquisition programs concern, where individuals have the authority to make decisions that affect the organization (Hester & MacG, 2017).

Decision making happens at different levels across an organization, specifically executive, management and operational. (Simon, 2013). Although classical decision theory is rigorous and strives to be the most accurate, having all of the information, being able to assign occurrence probabilities, and ultimately define and evaluate ultimate utility, is nearly unobtainable. Organizations can be defined the decisions and decision processes that people make. For an organization to effective and efficient, the decisions that are made at the executive level need to be communicated in an understandable manner through the management level, enabling the operational personnel to meet the objectives and goals.

More information can be helpful if it brings deeper understanding to the options' attributes, however, more information about additional alternatives may increase uncertainty, making tradeoffs more difficult (Bettman, et.al., 1998; Schwartz & Schwartz, 2004). When looking to collect and process information, understanding how the decision-maker(s) process information is important. Many strategies are available and used when making a decision, singularly, and/or in combination. Applying one strategy in the early stages of problem solving to narrow the field focuses the information needed to process before switching to another for the final choice. Individuals make their choice based on the total amount of information processed, selectively processing information by attribute, amount of information of an attribute, etc. An individual's selectivity is based heavily on the information's salience to the chooser, and the decision-maker's pattern of gathering and evaluating information, i.e. breadth vs. depth across options and attributes, and order in which the information is consumed influences the final decision based on their decision-making strategy (Bettman, et.al., 1998).

Within a program office, quantifying those values which are to be applied to the execution of the program will enable clear guidance and consistency in decision and choice-making. The use of utility theory as related to multi-variate analysis within decision theory expresses the decision-maker's preferences to performance measures of chosen, key attributes, and the range in which trade-offs are acceptable. This allows the program office to make comparison across the different attributes in a holistic manner. Leading the decision-maker body (singular or group) through this process provides the human to model translation on the front side, and offers the tailored view of the model's results in a way that is understandable and tractable through consistency of value statement. (Garrett, 2011).

3. Method

Four case-studies are presented in this paper, each reflecting an aspect of a separate DoD acquisition activity. Each case study is a review of an independent research project. The paper will briefly cover the background, purpose, method and conclusions for each. The background describes the context and motivation for the project. The purpose of developing/implementation will be explained. The method will provide a description of the design and implementation of the project and how it incorporated best practices. Finally, the conclusions from each development/implementation case will be stated.

The Source Selection process is considered first, where the associated case study demonstrates the utility of modeling-to-understand in the context of policy and process, and highlights the merits of a product-centric approach. The management of Test & Evaluation through digitalization of test plans is considered next, with a focus on linkages and interdependencies that introduce complexity and program risk. The assembly of a Decision Support System through federation of models (e.g., system, requirements, T&E activities and projected cost) is reflected in the third case study. The fourth and final case study explores the transformation of the mandated Systems Engineering Plan (SEP) into a model that establishes traceability and connectivity from decisions back through process to requisite knowledge products and pedigreed, relevant data.

4. Findings

4.1. Modeling a Business Process like a Mission Computer

4.1.1. Background

One of the critical functions of each systems command (SYSCOM) is to procure goods and services. This is largely accomplished by contracting for those goods and services, and those contracts are largely competitive. Source selection is the process by which a SYSCOM awards competitive contracts. At one such SYSCOM, a single functional office is chartered to supervise the source selection process for every procurement within the SYSCOM above a nominal value threshold. Over time that process had grown unpredictably long and expensive, without clear explanation.

4.1.2. Purpose

The SYSCOM asked JHU/APL system engineers to help improve the source selection process, so the engineers approached it like designing a mission computer.

4.1.3. Method

The core concept was that every task in the business process is governed by inputs, outputs, constraints, and protocols. The figure below shows the relationships (Figure 7).

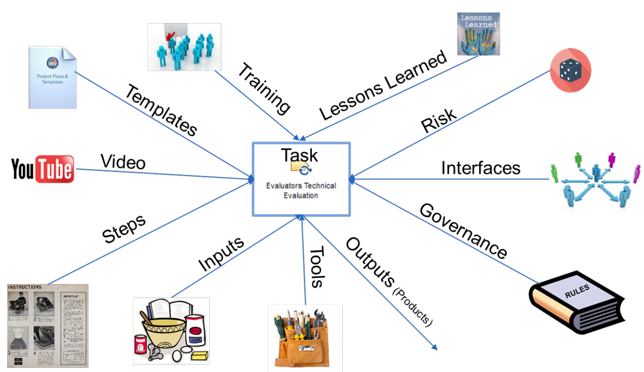

Figure 7. Task Analysis

Initially the process was modeled in Vitech CORE, then IBM Rational Method Composer, with some experiments in Bizagi Modeler. As the sponsor saw promise in the application, the project grew to include a graphic user interface that could be reproduced and tailored for subsequent competitions at a variety of scales. This required integration of several applications, and the project migrated to an IBM Rational Team Concert environment. The project used a variety of modeling languages, including one proprietary IBM language. For process modeling, the team switched from the familiar SysML to the more appropriate Business Process Model Notation (BPMN). When it was ready, a pilot source selection was conducted by government staff using the prototype system for a small competition. The competition was completed on schedule, within the planned staffing resources.

Over the course of these iterative evaluations, the JHU/APL team came to the realization that there were core elements of the source selection process that were ripe for digitalization. Key to this was the clear definition and documentation of the final products required at the conclusion of each source selection. These were all documents, and could all be traced to either Federal, DoD, service, or SYSCOM policies. With this traceability, it was possible to decompose the products into processes that produced them. This transformed the team's thinking of the project from one of data management into one of data generation.

Thinking of the source selection process in a way in which a production engineer might think of a factory, the team was able to approach the problem from a viewpoint that was substantially different than that of the sponsor. Using this viewpoint, the team evaluated each step of the process for the value it added to the source selection, with the ultimate requirement being to satisfy the output requirements defined by the external policies. Conveniently, the vast majority of the work of a source selection is documentary and this simplified the analysis of the core data of the process to allow the team to think about value in terms of creating, editing, and approving documents.

This methodology ultimately allowed the JHU/APL team to identify the actual value flows within the convoluted source selection process being used by the SYSCOM. The flow was redesigned to clearly show the steps that added value (as defined by the requirements) and suggested the elimination of unnecessary steps. As an additional benefit of this approach the team was able to recognize that the fundamental building block of source selection process value was a paragraph of text. It was possible to watch value flow through the process by tracing what happened to a paragraph of text as it was initially written by an evaluator, edited and approved by a team leader, consolidated with other paragraphs by source selection officials, and ultimately summarized for various required documents. This realization allowed the JHU/APL team to more accurately model the overall process and, more importantly, suggested a pathway to process efficiency through digitalization.

While much of the efficiency gained in this project was due to the value analysis and process streamlining, there was also a substantial interest in moving to a digital framework in which future source selections could be conducted. At the outset of the project, this was a complicated endeavor; however, it was greatly simplified when the team identified the core data element. More importantly, there was no interest from the sponsor in using digital technology to dissect the paragraphs produced by humans via data analytics, machine learning or any other means. This meant that the digitalization of the process was analogous to a logistics system. Humans would ultimately add all the value in the source selection, and the digital system could locate, move, and collate data and notify the humans when there was data upon which they could add value. There are many systems available in the marketplace today that offer the digital functions required to perform all of these tasks, and this provided a variety of excellent options to satisfy the requirements of the project without the development of unique source selection management software.

4.1.4. Conclusions

This case study exposed that the source selection process was largely governed by tribal knowledge, disconnected from Federal and Defense Acquisition Regulations (FAR/DFAR), and many data products were unicorns or orphans (inputs from no apparent source, or outputs unused by subsequent steps). The process model stabilized after many iterations, and instances were created for major defense acquisitions and small service competitions. Of key consequence in this project was the identification of the core data element, and the subsequent redesign of the process that resulted. In addition, it would not have been possible to apply digital toolsets for data control effectively without this understanding.

The sponsor was so pleased with the results of the pilot competition they ordered a final version for delivery that they could replicate and repeatedly use. It was at that point when JHU/APL system engineers discovered financial tech industry GRC software, and after quick discussions recommended the government use their funds instead to purchase licenses of GRC software from a major vendor. In an ironic twist, while they had sufficient funds, the source selection office could not award a contract for the software they needed because they did not have a Pentagon-validated requirement for it.

4.2. Digital Transformation of Documents Into Models

4.2.1. Background

A major program office (Acquisition Category (ACAT) 1) test team was struggling with a Master Objective Matrix (MOM) of over 1,000 requirements that were verifiable by many methods at numerous sites by a variety of staff. The complexity of test programs such as this example, are further complicated by the sheer volume and specialization of the physical test resources required (specific aircraft, M&S systems, test support equipment and facilities, etc), as well as test personnel with unique skills and qualifications (such as developmental test pilots, test conductors, data analysts, etc). Further, the test organization in this case was also required to track massive amounts of data associated with each of several hundred tests conducted, and the deficiencies discovered in the tests. The test team ultimately created a spreadsheet of several hundred thousand possible dependencies to track this manually, which proved difficult. It was observed that an object-oriented database might solve the problem.

4.2.2. Purpose

The program office wanted the MOM converted into a SysML database. Also, the program office requested some form of visualization to verify the information that was more user-friendly and less prone to error than a massive spreadsheet. The test organization wanted a means to manage test processes, execution, resourcing, and reporting.

4.2.3. Method

The SYSCOM had recently selected Cameo NoMagic as their DoDAF standard tool, so it was readily available. Using it first required converting from document-based to model-based requirements, modeling the verification methods, sites, equipment, and staffing, then relating them appropriately. SysML is provisioned for some of this so it offered a good starting point. Quickly completed, the sponsor asked if a developmental test plan could be digitalized, which required customized profile diagrams and stereotypes for data never contemplated by SysML. Test plans have considerable text, and several figures, but the central information is in tables: identifying objects, with properties, related to other objects (Figure 8).

The next challenge was linking developmental test (DT) and operational test (OT). The first step was digitalizing OT plans. DT and OT test plans both trace up to requirements (e.g. Capabilities Development Document), which provided a linkage. This logically led to further documents and processes being digitalized, including the Mission Based Test Design (MBTD), Initial Evaluation Framework (IEF), and Test & Evaluation Master Plan (TEMP). This integrates contractor test (CT), DT, and OT at mission level. A change to one propagates automatically through all. The object-oriented database tool offers several methods of rapidly publishing global updates that do not require special software or skills, such as document reports and html.

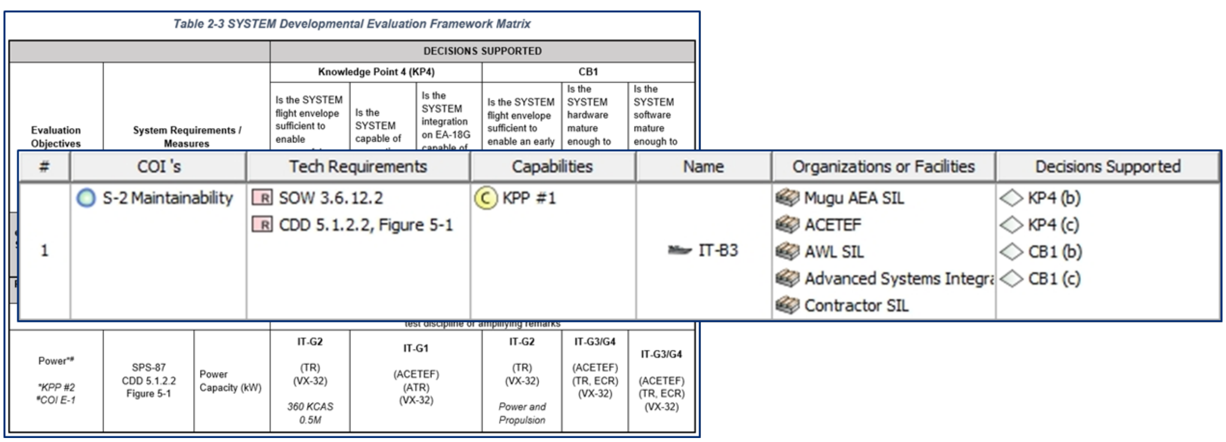

Figure 8. Digitalization of Documents

4.2.4. Conclusions

Not only was the program office satisfied with this method, their operational test force counterparts (DOT&E) became very interested in using a shared database, derived from their own manuals, to identify early OT opportunities, and assess the implications of DT results. The original method subsequently evolved into the exemplar for Capabilities Based T&E (CBT&E) in the service. Digitalization transforms documents into a database (without changing processes), optimizes resources, flows data, and reuses data. It further allows the modeling of processes to facilitate more efficient and error-proof planning and execution of programs. Direct benefits have been simplification of complex requirements, asset management, early identification of critical missing tasks, reconciling engineering and test plans, and relating every DT event to OT metrics. In sum, the benefits are coordination, efficiency and accountability.

4.3. Cross Functional Data Model

4.3.1. Background

A major program office needed a DoDAF system model for a mission planning system.

4.3.2. Purpose

To aid the government plan the second program increment, JHU/APL designed a decision support system (DSS).

4.3.3. Method

The DSS federated a T&E Model with a System Model, both connected to a Requirements Model, and invented a companion Cost Model and Risk Model to integrate with them. This DSS would also have program views to visualize integrated analytical products for alternative comparison and remain a queryable program database for subsequent excursions. The DSS was designed such that each of the five component models could be maintained independently within the DSS by the respective functional leads in a shared cloud environment, without breaking the established relationships. This allowed functional leads to retain ownership of their data repository while making it transparent to the other users and firmly related to the entire program. This connects data across the functions within a program office (Figure 9)

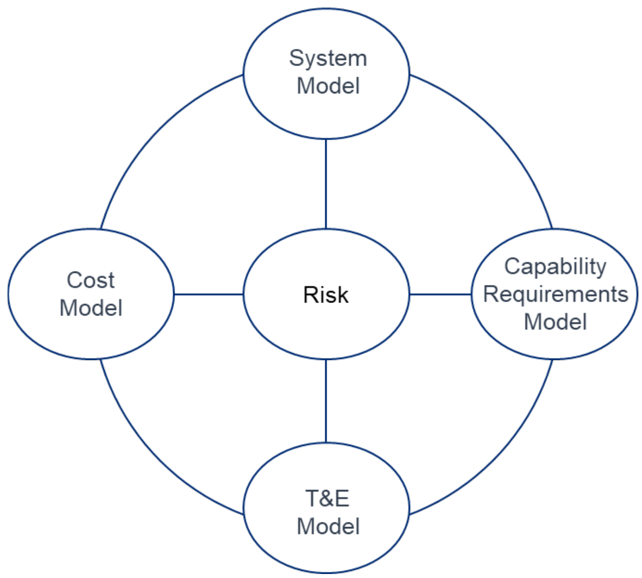

Figure 9. Cross Functional Data

4.3.4. Conclusions

This functioning DSS was a new conceptual framework, and the exemplar was well received. Since JHU/APL delivered it, the government hired three other research centers to replicate and extend it.

4.4. Connecting Decisions to Data to Process

4.4.1. Background

A service research lab program requested JHU/APL to draft a digitalized systems engineering plan (SEP), that document versions of the digitalized SEP (DSEP) be producible, and the SEP be widely available. Secondarily, the research lab wanted the SEP connected to the Office of Secretary of Defense (OSD) policy that required its content. In hindsight, the previous cross functional model provided for the majority of the data that a SEP covered, presenting an opportunity to connect the SEP directly to the data it managed.

4.4.2. Purpose

The purpose of this task was to digitalize a SEP, and connect that model to the data models it controlled as well as the process governing the SEP. This was housed in the related data repository (DSS).

4.4.3. Method

The DSS format contained virtually all the information resident in a Systems Engineering Plan (SEP): program technical requirements, engineering resources, technical activities and products. This directly connected the data (DSS) to the managing process (DSEP) and the approval authority decision, as described in a SEP example (Figure 10).

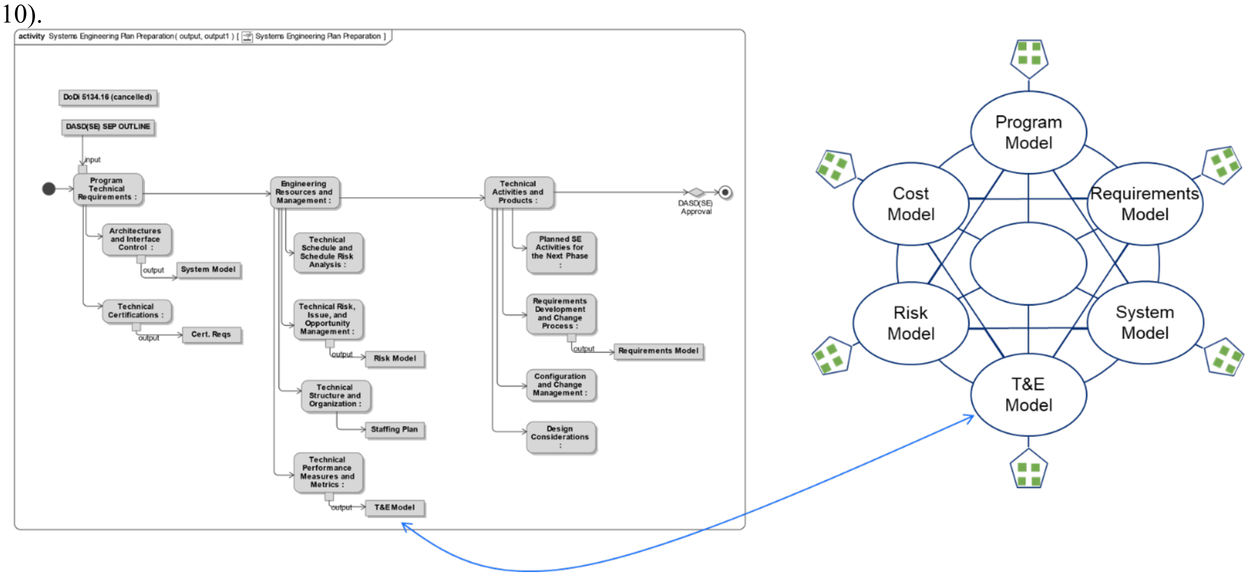

Figure 10. Connecting Decisions to Data to Process

4.4.4. Conclusions

A change in regulations immediately drives a change in process, which in turn causes change in the data. This is similar to commercial GRC. This connects data back to process and forward to decision.

5. Results

The principles learned from the cumulative case studies appear complementary:

1. Workable business processes models
2. Digitalization of documents into models
3. Cross functional data models
4. Connect decision to data to process

In combination, they can digitally reflect the totality of a real acquisition program. The data can change in real-time if so designed (e.g. T&E updates cascade to Integrated Master Schedule (IMS)). The cross-functional data repository connects critical program office products (e.g. Engineering to Risk). Data (and its changes) persist over the life of the program. These are the main attributes of a digital twin. Building these principles into a useable product requires three distinct steps.

The program needs a strategy spanning all program functions (engineering, test, logistics, cost, risk, etc.), defining what and how to digitalize processes that create data required for decisions. Using that framework, develop a program data model to support those decisions. Using that data model, populate a decision support system for execution over the lifecycle of the program, tied to the acquisition strategy and goals.

5.1. Digital Engineering Strategy

A conceptual framework for digital engineering was determined by systematic review of recent research, the objective being to select what and how to digitalize DoD acquisition processes, data, and decisions (Waugh, 2022). This study had five major findings: digitalization projects begin with strategic choices; digitalization is done within an ecosystem that constrains the technical options; digitalization requires a method of execution that assesses opportunity and limits risk; digitalization results in new processes using new data models that enable better decisions; feedback on that new business model will come internally from users and externally from customers.

External forces fall into ecosystem constraints and technology opportunities. The ecosystem includes people, resources, organization and the supply chain, which the entity may or may not control (Cong et al, 2021, Correani et al, 2020, Dethine et al, 2020, Garay-Rondero et al, 2020, Gastaldi et al, 2018, and Linde et al, 2021). Technical forces include the computing environment platforms, technologies, and data (Correani et al, 2020, Ghadge et al, 2020, Ivančić et al, 2019). Technologies do not equally benefit all desired outcomes, but several are key to Industry 4.0 application (Tortorella et al, 2021). The strategy will define what external forces are strengths, weaknesses, opportunities or threats (i.e. risk) (Linde et al, 2021).

Strategic choices determine the desired degree of change (Blackburn, 2017), the impact target (Tortorella et al, 2021) degree of circular economy (Kristoffersen et al, 2020), the design principles (Nosalska et al, 2019), and delimit the eligible processes (Donnelly, 2019). Continuous communications with the affected users (Rieken et al, 2020), customers (Ghage et al, 2020), and suppliers (Garay-Rondero et al, 2020) is necessary, seeking failure early and rewarding good outcomes. The strategy must consider necessary organizational changes. It will identify means to monitor feedback to propose future changes to the business model.

5.2. Data Model

The eligible processes are modeled as-is, and then to-be (Antonucci, et al, 2021). Compliance constraints (e.g. DoDI 5000.85) are modeled to discover information mandated at given decision points (e.g. milestones). Those decisions are decomposed into activity models that allocate actions to roles, showing data required and produced at each step. This Data Model documents likely decision points, the data required for those decisions, and the processes required to produce the data.

The data requirements are recoded as normalized terms (i.e. same name for same thing in DoDI, Service, SYSCOM instructions), themed into small groups of data (e.g. quality, security, and functional requirements), then synthesized into large groups (e.g. Requirements). The data items are characterized as objects, properties of objects, or relationships to other objects.

5.3. Decision Support System (DSS)

Populating the data model creates the DSS, the single repository for connected cross-functional program data, mapped to internal and external processes that manage or require it. It will visualize the data in simple decision aids, readily accessible to the program enterprise. The functional data will be segmented to allow internal fluidity while retaining external relevance: functional leads may redesign or repopulate their model (and not others) without breaking links to other models.

The DSS is the data platform to ingest, transform, and harmonize data to serve prioritized program manager needs, democratize the data environment using data services and business intelligence toolsets, with scalable and sustainable data /analytics products to accelerate time to value (Figure 11).

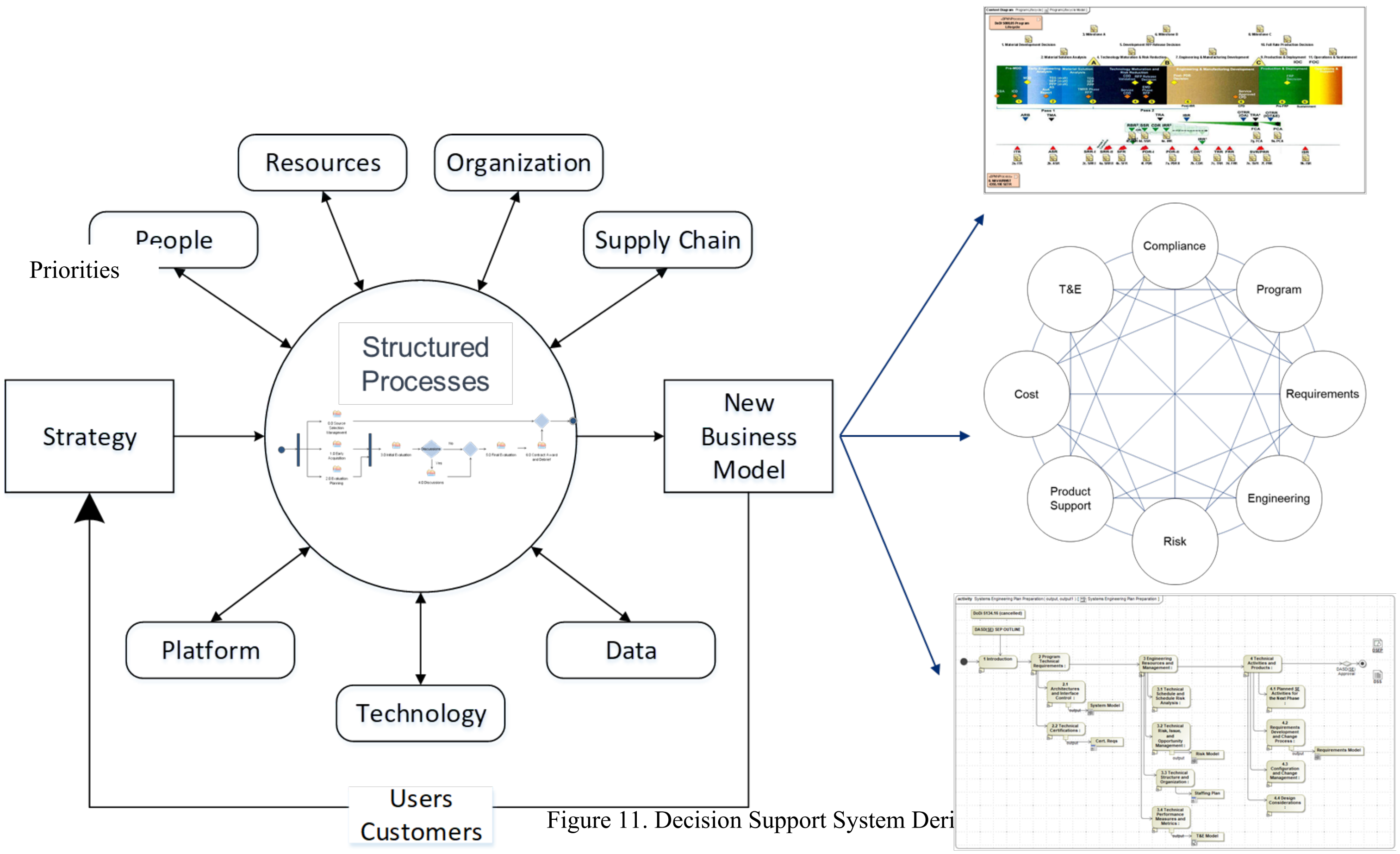

Figure 11. Decision Support System Deri

6. Conclusion

The proper goal of digitalization is to make better decisions using quality data from lean processes. It is easy to see digitalization merely as a problem of new applications, or the introduction of Artificial Intelligence (AI) into processes, or new data models depending upon personal perspective or experience. However, none of those solutions alone will have sustained or meaningful impact. New models may be better, but may not result in better decisions if disconnected from a unified data model. A web services firm may be able to house petabytes of data for decades, but if it is not designed for people to use in conjunction with their digital supply chain, its customer value is limited. Using AI as support infrastructure to communicate with customers is common, but without integration with the business process, it may not deliver value.

Entities have known they should digitalize, but did not know what or how to implement it. 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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