Economics of Digital Twins in Aerospace and Defense

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Abstract— **The future of aerospace and defense systems engineering is in a global digital transformation from document to model-based frameworks leveraging lower cost high-fidelity multidisciplinary modeling, analysis and simulation (MA&S) tools. This in turn allows engineers to specify, analyze, design and verify systems. An emerging element within this framework is the concept of "Digital Twins" which is digital or virtual replications of systems of interest, products and processes that are used to increase speed to market, evaluate performance and reduce costs. Understanding how to evaluate digital twin return on investments (ROIs) is not straightforward when generating the cost to develop and utilize them. This paper looks inside the development of digital twin architectures, integration effort, cost drivers and capabilities as a component of MA&S and resulting life cycle cost estimates. Other factors that impact digital twin development costs include model fidelity such as the number and level of design features, analytical tools and integration difficulty, scalability across applications, company size, and programming languages. Results of these fundamental concepts are categorized and grouped to provide practitioners tools and methods to apply digital twin concepts within their recommended solutions. Cost drivers and maintaining positive ROIs and supporting the DoD Better Buying Power initiative are also investigated. Future work will assess methods for evaluating authoritative source of truth (ASOT) and implementing artificial intelligence and machine learning methods to support ASOT validation.**

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1. INTRODUCTION

Overview

The future of aerospace and defense systems engineering is in a global digital transformation from document to model-based frameworks leveraging lower cost high-fidelity multidisciplinary modeling, analysis and simulation (MA&S) tools. The advancement in digital engineering (DE) has significantly grown and has become instituted within the aerospace and defense community and is maximizing the use of model-based system engineering (MBSE). To support this digital transformation, the Department of Defense (DoD) in its 2018 Digital Engineering Strategy states "To help ensure continued U.S. technological superiority, the Department is transforming its engineering practices to digital engineering, incorporating technological innovations into an integrated, model-based approach."[1] The expected benefits include enhanced communication, increased confidence in capabilities that will perform as expected and increased efficiency in engineering and acquisition practices, at lower total cost of ownership (TCO). The DoD digital engineering framework includes digital twins as a key component of the of the digital engineering ecosystem. A digital twin (DT) is a

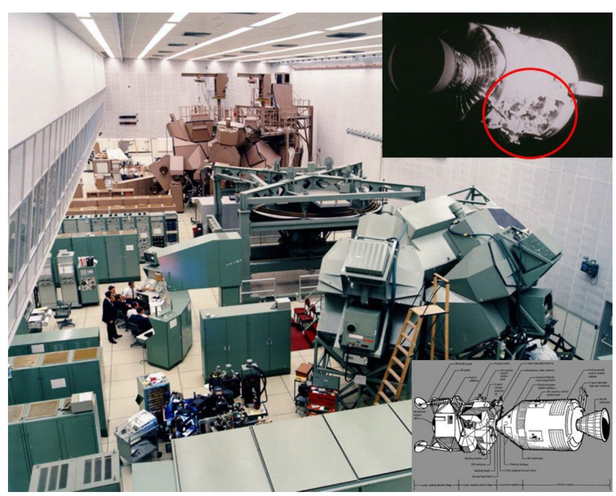

Figure 1. Apollo Simulators at Mission Control in Houston. The Lunar Module Simulator is in the foreground, the Command Module Simulator is at the rear. Image credit: NASA

virtual representation of a product, system or process that uses modeling, sensors, and data collected from a physical system to mirror it virtually. Its purpose is to mimic the actual physical behavior to provide actionable information and forecasting. The recently released DoD Instruction (DoDI) 5000.97 for digital engineering provides strategies to implement DTs. [2]

"Twining" History

Developing physical twins is not new. One of the famous twins that was quickly modeled is one during the Apollo 13 mission to the moon more than fifty years ago. [3] On the outbound leg the three astronauts were suddenly disturbed by a "bang-whump-shudder" shaking the spacecraft. Something was seriously wrong and with every minute, the spacecraft was another 400 miles away from earth. Mission Control acted quickly and worked around the clock to diagnosis and develop a solution. Using the 15 simulators used to train the astronauts and mission controllers, they quickly assessed multiple failure scenarios. Figure 1 shows the simulator room with the command module and lunar module. The upper right inset shows the damage to the command module and the lower right shows the survivability configuration of the damaged command module and lunar module on the return trip. Gene Kranz, the NASA Chief Flight Director for Apollo 13 stated "…these simulators were perhaps the first real example of 'digital twins'". NASA and the space industry has been using software replicas of its spacecraft for decades. Today, NASA continues the DT path for the Artemis program using high-fidelity digital models of physical systems and components. [4]

Digital Twin Trends

The global DT market size in 2022 was estimated at $10.25B according to Precedence Research. [5] It is projected to be around $269.1B by 2032 with a forecast compound annual growth rate (CAGR) of 38.7%. In 2022 the aerospace and defense market were 17.9% or $1.8B of the market basket and forecast in 2032 at about $48.2B. [5] In another study by McKinsey and Company indicates a market size of $48B by 2026, a 58% CAGR. [6,7] In both cases DT use will be increasing in the near term. Figure 2 illustrates the total market growth forecast along with the aerospace and defense component on the secondary axis.

Global

Precedence Research indicates the largest market is the Asia Pacific region and the fastest growing is in North America. Market drivers include increase in the number of technologies that are applied to DTs, improved efficiency of collecting information and the number of applications being developed that can be used to link DTs. Major challenges include increased cost driven by greater connectivity (internet, Internet of Things (IoT), data storage, etc.), and lack of skilled personnel.

Aerospace and Defense

Digital Twins are revolutionizing the aerospace and defense industry, providing unprecedented efficiency, accuracy, and insight into aerospace and space assets. They have the ability to, in real-time, track assets, facilitate better control over company operations and maximize overall efficiency. Moreover, Digital Twin technology can provide invaluable insights into maintenance cycles, preventative maintenance and reliability, allowing companies to deliver better customer experiences. With this capability, DTs offer advantages in the ability to significantly reduce costs, increase safety and allow for performance optimization in aerospace operations. [8]

In a recent report from the DoD Director of Operational Test and Evaluation (DOT&E) states, "Approximately 14 percent of programs under DOT&E are applying continuous integration/continuous delivery (CI/CD) … approximately 7 percent have built digital twins…". [9] Currently most DT implementation is performed during contractor level testing. However, their use is expected to grow and expand into operational environments.

The future of DT technology in aerospace and defense is expanding. As it matures and becomes more capable real-time predictive insights will enable decisionmakers the ability to foresee needed actions that can maximize opportunities.

Approach

This paper evaluates the digital engineering framework, where investment is needed to develop quality DTs and

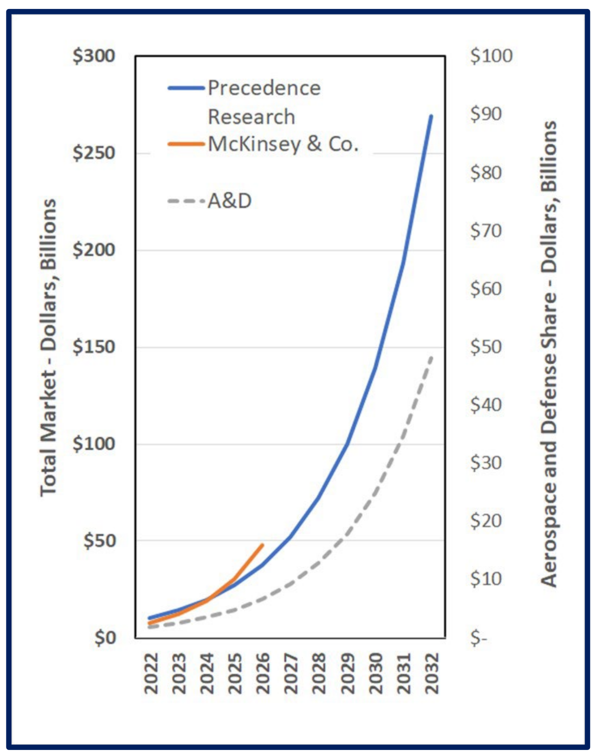

Figure 2. DT Global Market Size Forecast 2022 - 2032

highlights areas where the return on investment can be maximized. As will be shown, one of the important areas within the digital engineering framework is having validated data components to serve as a source of truth.

Evaluating the ROI is not straight forward. Calculating a net present value (NPV) can serve as a guide, then an assessment using the DoD's "Better Buying Power" (BBP) methodology is also used to express the benefit in terms of capability and product quantity. [10]

Future work will investigate novel methods to assess and develop authoritative source of truth (ASOT). Some of these methods will include artificial intelligence, machine learning, deep learning and augmented reality as these technologies continue to mature and are more widely accepted.

2. Digital Engineering

Definition

The U.S. Defense Acquisition University (DAU) defines Digital Engineering as "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" [retirement]. [11]

System Level Thinking

Systems thinking is a foundational aspect of system engineering lifecycle processes and supports the digital engineering transition. Similarly, model-based system engineering (MBSE) is a skeletal structure for digital transformation. Then, by extension, MBSE supports the creation of DTs by combining development, engineering and manufacturing processes to products. [12]

There are numerous definitions of systems thinking. Here are several relevant to MBSE and DT development:

- Systems thinking is a holistic approach to analysis that focuses on the way that a system's constituent parts interrelate and how systems work over time and within the context of larger systems.
- Systems thinking is an approach to problem-solving that views 'problems' as part of a wider, dynamic system. It is the process of understanding how things influence one another as part of a whole.
- Systems thinking is a systematic framework that analyzes systems as part of much larger, integrated systems rather than as self-sufficient entities. It can help make issues more apparent and easier to identify, balance the system, and manage the system's complexity. [13]

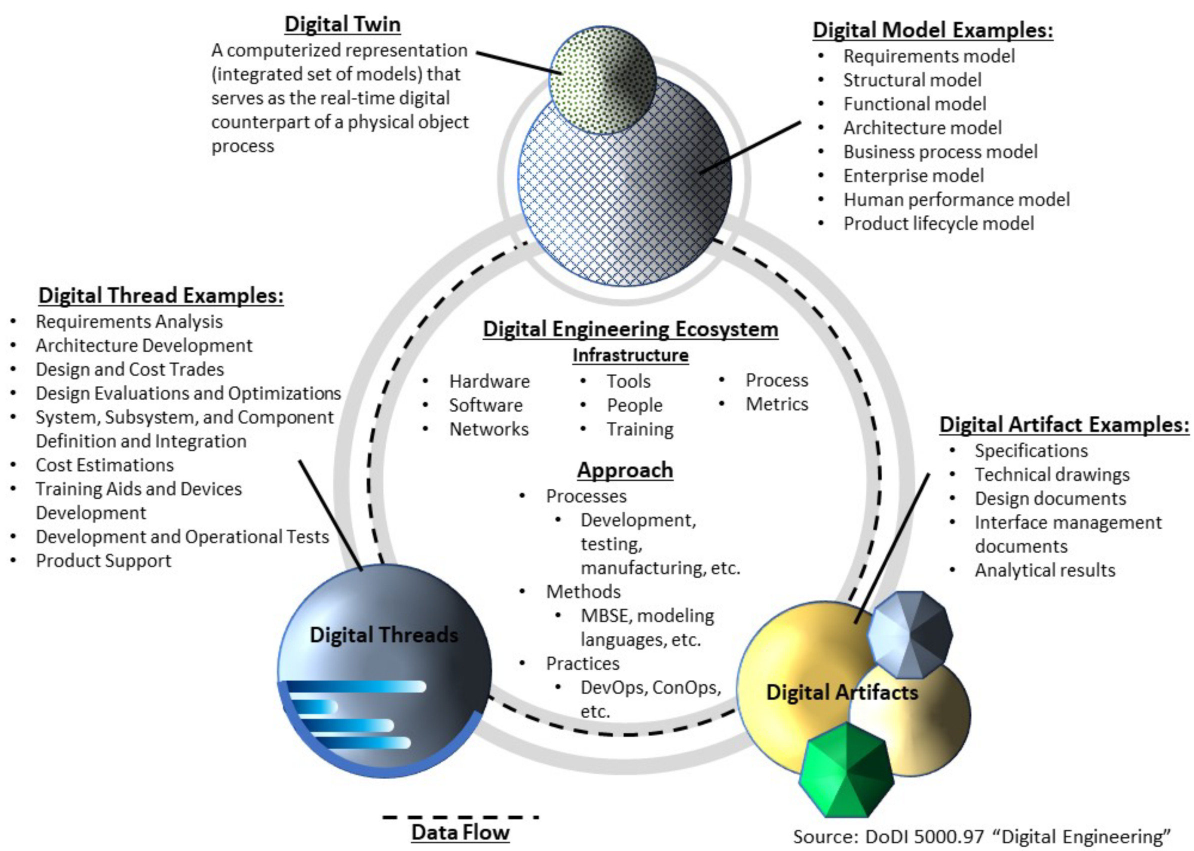

Figure 3. Digital Engineering Framework with data flow

Modeling, Analysis and Simulation

The terms modeling, analysis and simulation are often used interchangeably. However, they have distinct purposes. *Modeling* is the conception, creation and refinement of models. *Analysis* is the process of systematic, reproducible examination to gain insight. *Simulation* is the process of using a model to predict and study the behavior or performance of a system of interest (SoI).

Extending the digital engineering thread, there are two major types of models, physical and digital. Digital models are primarily used within the system engineering community throughout the lifecycle which makes them applicable for use when developing a digital twin.

Physical models can support internal as well as external stakeholders. These physical systems help communicate difficult concepts or may be a low-fidelity representation of a more complex system. For example, an aircraft wind tunnel model helps in analyzing flow phenomena that can be used to calibrate a digital model for additional simulations and reuse.

According the International Council on System Engineering (INCOSE), MBSE is one of the core elements of digital engineering. In MBSE and digital engineering, a digital system model is a digital representation of a system; integrating authoritative technical data and associated artifacts that define all aspects of the system into the model. These methods are applied throughout the lifecycle and serve as the ASOT for the system's design. The conceptual digital engineering framework is illustrated in Figure 3. It shows the four major elements, infrastructure (ecosystem), modeling, threads and artifacts.

When performing simulations, a digital model is almost always used and generally supports analysis, though not all analysis is performed through simulation. In many applications it is more cost and schedule effective to perform analysis and simulation with a digital, rather than with prototypes or physical models.

MA&S has been demonstrated to be useful across the lifecycle process. From business or mission analysis, to retirement with each stage serving a specific purpose. The digital models are being evaluated for different purposes in concert with physical/services as needed. In some life cycle life cycle stages such as architecture definition and design. These models are used to synthesize and define alternative concepts. For stages, like operations, analysis, simulations utilize the digital model to simulate environments (particularly where actual environments are unattainable), to understand and predict specific aspects and behavior of the SOI.

DT is a Subset of MBSE

The engineering firm Fenstermaker, in a September 2022 post states, "When utilized in a MBSE framework, digital twin technology can be used to test the behavior of virtual prototypes in 'what-if' simulations under the control of the systems engineer. Data is transferred from the physical object to its digital twin, and both interconnected entities are fed with additional data from MBSE tools and data acquisition tools." Figure 4 illustrates the link between physical and digital modeling.

In another instance from Deloitte Insights they state "As manufacturing processes become increasingly digital, the digital twin is now within reach. By providing companies with a complete digital footprint of products, the digital twin enables companies to detect physical issues sooner, predict outcomes more accurately, and build better products." [14]

Utilizing MBSE as the springboard for Digital Twin development provides an efficient way to maximize efficiency and reuse of existing modeling.

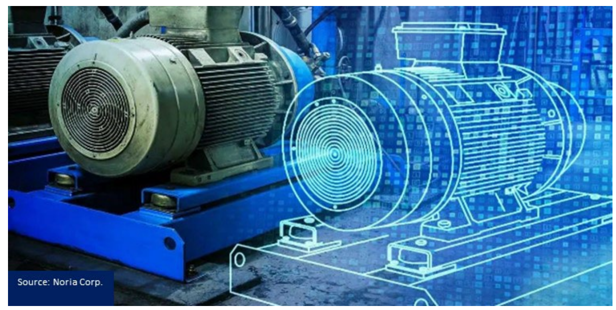

Figure 4. Illustration of physical and digital model used to forecast reliability.

3. DIGITAL TWIN INVESTMENT

Infrastructure

Developing DTs requires a robust digital infrastructure (ecosystem). Key components include digital engineering environment, validated data, tools, processes and skilled personnel. INCOSE states "[digital engineering] requires a supporting infrastructure and environment and a capable workforce and culture …working in accordance with process, following methods and using tools the organization supplies them". Moreover, they say "digital engineering leverages MBSE and the digital system model to enable digital threads and digital twins."

An effective DT environment requires upfront investment. The DT should be viewed as a product that requires a physical and virtual component working together. An important component of DT development is data and information that is validated (an ASOT), easily integrated within a tool set and accessible to multiple functional areas. [15]

The typical infrastructure framework can be grouped into six elements 1) environment, 2) tools, 3) processes, 4) people, 5) training and 6) metrics. This can be the starting point to obtaining an effective DT development infrastructure.

Environment

A DT environment as part of the digital engineering ecosystem should contain hardware, software, networks, processes, data, stakeholders, applications and services used to facilitate model development, make digital threads and generate artifacts.

Table 1. Common digital modeling types to support Digital Twin development

Common Digital Model Types	
1	Requirements models
2	Structural models
3	Functional models
4	Business process models
5	Architecture models
6	Enterprise models
7	Physics-based models
8	Human performance models
9	Threat models
10	Product life cycle models

Digital models are needed to develop specific behaviors to forecast action, understand system interdependencies and provide data flow to communicate information among stakeholders and support simulations using relevant cases to reveal and validate system behavior. Typical model types include those shown in Table 1. These can be separate individual models (generally of high-fidelity) to investigate detailed behavior in a signal functional area or combined as a suite of models to assess multiple system behaviors. In many cases these models can be extended and enhanced to support DT development, then performing MA&S to obtain actionable information.

As previously stated, a DT is a virtual representation of a product, system, or process that uses digital models, sensor information, data collected from physical systems and relevant input data to develop “mirror like” use cases. These can then be used throughout the lifecycle.

When investing in the digital ecosystem, attention to the interfaces and ease of data usage should be considered; this is especially true when developing models for complex systems and systems of systems (SoS) where understanding complex system interfaces can be critical.

The digital ecosystem must contain authoritative sources of information and data (refer to the INCOSE guidance). All data within the databases used for modeling should be validated based on some ASOT. This will validate the integrity of the DT and its outputs to help identify unique behavior when performing simulations within the DT environment for forecasting.

Digital threads are an element to bridge the internal digital environment with the external interactions and act as a communication portal. A digital thread is also used to connect and coordinate multiple digital models across the system lifecycle and support the development of a high-fidelity DT. The digital thread should be configured to have a feedback loop using the data flows to increase relevance in the models. A listing of digital thread examples is shown in Figure 3.

The third element of the digital ecosystem includes digital artifacts. DoDI 5000.97[2] recommends artifacts be created using standards, rules, tools and the infrastructure to create work products that facilitate product development and an executable programmatic structure. Common examples are listed in Table 2.

Tools

Digital engineering tools are core to the environment. They can consist of commercial off the shelf (COTS) like computer aided design and manufacturing (CAD/CAM), analytical tools such as finite element modeling and other integrated tools for structural, fluids and thermal environments, satellite took kit, etc.

In other situations, specialty models are developed for specific purposes to address complex problems or mission scenarios. For example, to address specific types of ships and the maintenance operational concept (OpsCon) specialty models may be developed specific to resupply of common materials and weapons. In the case of an aircraft fleet provisioning, fuel and common maintenance components can be optimized within the resupply methodology.

Important aspects of the tool suite is connectivity between tools, ease of use, data transmissibility, security (both physical and cyber), software compatibility (even between versions of the same tool sets) and environmental

Table 2. Common digital artifacts to facilitate Digital Twin forecasting

Common Digital Artifacts	
1	Design specifications
2	Technical drawings
3	Design documents
4	Interface management documents
5	Analytical results
6	Bills of material
7	Reliability/Availabiltiy forecasts
8	Software source code
9	Work breakdown structure
10	Production/machining instructions
11	Test planning and cases
12	Schedules
13	Budgeting
14	Product support strategy
15	Data flow diagrams

collaboration. All of this is the part of digital engineering infrastructures.

Processes

Within the digital engineering ecosystem is a need for a repeatable and flexible approach. Developing processes and procedures will help. Using the Integrated Product and Process Development (IPPD) approach can be a starting point. IPPD is a systematic approach to product development that achieves a timely collaboration of relevant stakeholders throughout the product life cycle to better satisfy customer needs. [16]

There are a number of organizations within the aerospace and defense community that have process models to facilitate this. Carnegie Mellon's Capability Maturity Model Integration (CMMI) for System and Software engineering is a good reference, National Defense Industrial Association (NDIA) and the American Institute for Aeronautics and Astronautics (AIAA) are other good sources.

For example, the CMMI is a process and behavioral model that helps organizations streamline process improvement and encourage productive, efficient behaviors that decrease risks in systems and software, product, and service development. Having process models in place prior to developing DTs facilitates repeatability and consistent quality.

People

The digital engineering ecosystem is run by people. This multi-functional set of disciplines require a myriad of skill sets across the life cycle. A talent management specialist can help define the skills needed when developing a digital engineering infrastructure. Typical areas include engineering (systems, software, physical, security, etc.) scientists, information technology, project management and business operations, etc.

Training

A sound digital engineering ecosystem requires renewal over the lifecycle. A robust training program is invaluable to support the infrastructure. It should work in concert with established processes and procedures across the other support areas within the environment. Training programs can be enhanced with subject matter experts (SMEs), and certifications from recognized organizations and mentoring.

Metrics/Reuse

To maintain high quality, process improvement and gap analysis, identification of a planned set of metrics will help. Using the quality approach developed by Deming of "Plan-Do-Study-Act" (PDSA) provides an approach for gaining valuable learning and knowledge for continual improvement of product, process or services. [17]

Having a mature digital engineering ecosystem provides the ability to develop robust and timely DT models that support physical systems. Figure 5 summarizes the components within the Ishikawa (Fishbone) diagram to provide quality DT products.

4. DIGITAL TWINS IN AEROSPACE AND DEFENSE

DT implementation is becoming common in the aerospace and defense industry and as confidence grows in DT technology, more companies are planning to invest. There have been demonstrated savings in jet engine development and maintenance, and component performance on aircraft. For example, General Electric (GE) has developed a DT for their GE60 engine family and supported development of a aircraft's landing gear helping identify potential failure

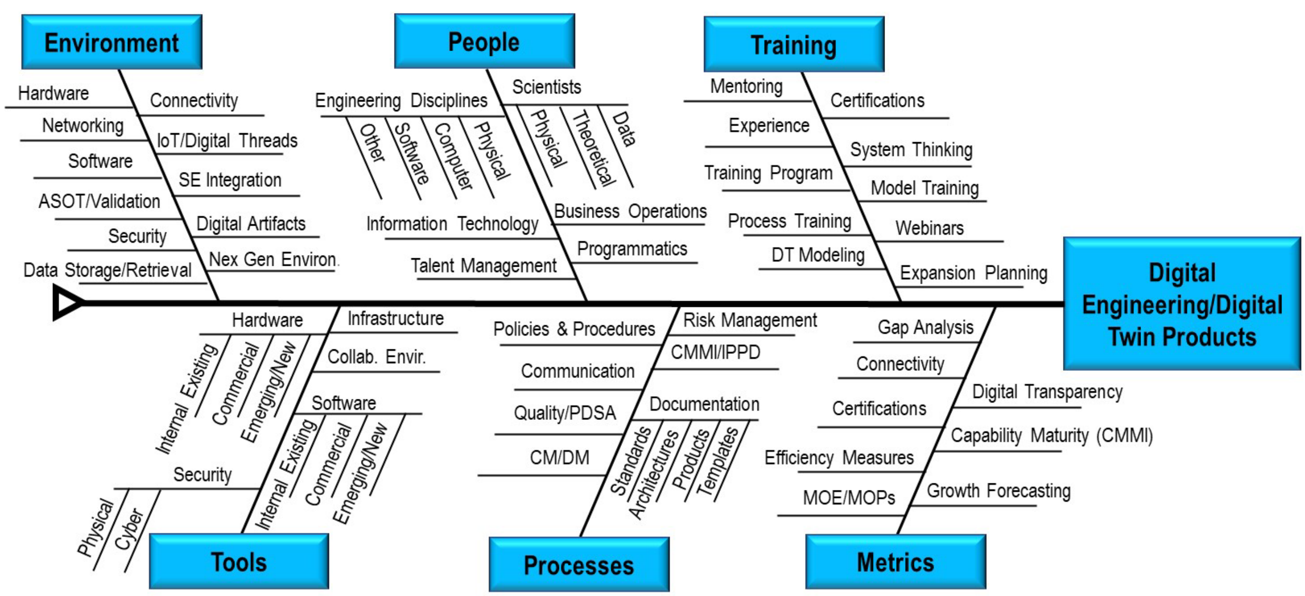

Figure 5. Elements of a mature digital infrastructure ecosystem to support DT development and use

points. Another aerospace company has claimed a 40% improvement rate of "first time" quality using DTs. [18]

In the defense industry, DTs enable the armed services to model and play out operational scenarios and enemy responses in a realistic but "consequence-free" wargame structure. The result is that troops are better prepared in high-stakes battle environments. For example, the U/S. Air Force Research Laboratory (AFRL) developed a DT of a collaborative "swarming" weapon system called "Gray Wolf" that can determine, in real time, improvements in its physical counterparts. [19]

According to Cap Gemini Research, there are three main DTs suited to the aerospace and defense environment:

- *Product/Asset Twins – those utilized in design and development to enhance products and shorten time to market.*
- *Process Twins – a manufacturing related process or measurable and monitorable process to optimize the integration of resources, processes and products to increase system output and enable scalability.*
- *Network Twins – These allow organizations to increase performance and resiliency through network simulations of supply chains, logistics and transportation for example.*

Applications within Industry 4.0

We are in the fourth industrial revolution. It is the center of digital transformation and shaping how researchers, technologists and business operations are transforming and adapting to the environment. It is the era of connectivity (of everything) using high fidelity sensors that get fed back to users through the data ocean and Internet of Things (IoT). In one case study shown by Cap Gemini, the development of a new pilot's seat from concept to certification generally took 24-32 months at a cost of $3.5M. Using digital modeling tools, it took less than six months and less than $1M. That is a savings of almost 75% of the funding and one fourth the time. [20]

5. BENEFITS AND ROI

There are numerous benefits making the transition to a digital engineering environment. Enhancements can be obtained when adding DTs. However, there is a cost to implement a digital engineering framework and DT models. At a macro scale, we investigate the benefits and ROI obtained.

In a survey of 300 "C-Suite" executives, across industries state there are significant advantages to implementing Digital Twins. They include potential increase in revenue of 10%, a reduced time to market by as much as 50% and improved product quality. Figure 6 is a sampling from the executive survey results of DT potential improvements. [21,22]

It is important to note that the ROI used by the DoD is different than that used for companies. Typical financial metrics used are internal rate of return (IRR), profitability index (PI) and a more flexible NPV. In a recent report developed by Burger and Dillon-Merrill, they state: "The DoD has used various simplified forms of ROI…currently, there is no reliable framework for ROI calculations that consider the unique mission values for DoD acquisition". [23]

Although DoD acquisitions are difficult to measure as an ROI, using the Better Buying Power initiative instituted in 2010 which states: "is the implementation of best practices to strengthen the Defense Department's buying power, improve industry productivity, and provide an affordable, value-added military capability to the Warfighter." [24] This can be summarized from a product (or service) perspective as higher quality and more capability (or units) available for use.

Figure 6. Common benefits of implementing Digital Twins across business elements

This paper has described numerous advantages and benefits of making a transition from classic System engineering and migrating into the Digital Engineering transformation and the benefits of Digital Twins. To illustrate benefits of the digital engineering and DT migration a simple example showing the digital engineering infrastructure investment compared to a classic solution, and the potential lifecycle cost can be lower than that used with a classical solution. In terms of ROI using a commercial model with NPV, the focus will be on the additional capability gained at a similar NPV. Benefits that reinforce BBP include additional capabilities and more product available to the Warfighter.

Table 3. Investment and development comparison

WBS	Segment	Values Classic ($K)	Digital ($K)
0	**Classic Vs Digital Twins**	**$47,650**	**$28,050**
1	*Investment Elements*	*($7,100)*	*($15,550)*
1.1	Environment	($3,500)	($5,200)
1.2	Tools	($3,600)	($7,200)
1.3	Process Development	$0	($2,050)
1.4	Training	$0	($1,100)
2	*Product Development*	*$54,750*	*$43,600*
2.1	Design	$2,800	$6,900
2.2	Development	$9,950	$8,050
2.3	Production	$15,000	$11,650
2.4	Operations/Sustainment	$27,000	$17,000

Example

In a comparative analysis, a government acquisition for an improved drone has been requested. The total budget planned is in the range of $50 - $80M for a minimum of 400 units based on a classic acquisition approach. The classic development and production approach is use as the benchmark. The other approach is implementation of a digital engineering and DT model integrating new technology.

Determining a ROI in a government acquisition is difficult (Burger/Dillon-Merrill). Another metric will be used, that is the incremental capability (quantity) that can be acquired (with the same budget) as a result of using a DT approach. In this example, the supplier looked at initial investments for both the classic and the DT approach. The investment and product development elements were reviewed. It was determined that there were four areas where investment was needed. 1) The environment including infrastructure, 2) Tools, 3) Processes and 4) Training. For product development including prototypes and DTs, there are four areas A) design, B) development, C) Production, and D) Operations and sustainment. Table 3 illustrates the investments and costs for both approaches.

It was found after some analysis that the DT approach needed almost twice the investment as the classic approach. However, the product development was approximately twenty percent less than the classic approach.

Determining the NPV for each is straight forward using a industry discount cash flow method for a range of discount rates to assess sensitivity. For this example, at a zero percent discount rate, the classic method NPV results in $23.4M, and with the DT approach it is $37.3M. Now, matching the Classic NPV to the DT forecast we can determine the additional capability (number of units) that can be acquired. Since normally a higher NPV would be the choice approach, for Government acquisitions, this does not apply because the supplier is paid for the product development (versus the organization investing in the product) based on the available budget. For instance, if the supplier product cost is less than a government estimate, more products can be obtained, adding buying power.

Calculating the cash flows and NPV for each approach, it is found that the benefit in additional capabilities translates to additional units. This is done by matching the DT NPV to the classic approach. Table 4 shows the classic NPV, the native DT approach with the same quantity and the updated DT approach matching in this example, the benefit can now be measured as additional capability by a factor of over 25% depending on the discount rate used in the NPV model. The analysis is summarized in Figure 7.

Longer term benefits include DT scalability and reuse, lower total cost of ownership, higher fidelity comparative analysis and troubleshooting using a variety of case studies and failure mode scenarios that can improve quality, reliability and forecasting.

6. SUMMARY

Making the transition to a digital engineering environment and using DTs, can provide significant benefits to aerospace and defense organizations. Having a robust Digital infrastructure enables efficient use and reuse of the MBSE and DT methods with artifacts to provide more product capability. In the example, using a DT approach allowed the unit cost of the product to be reduced by over 25%. As a result, the additional capability (better buying power) in the form of additional units can be acquired depending on the discount rate. The results are shown in Figure 7.

Table 4. Cost of Capital vs NPV and incremental quantity demonstrating BBP

Discount Rate	Classic NPV	DT NPV	Qty	NPV Match	Benefit
0.0%	$23,400	$37,250	127	$37,250	1.32
1.5%	$20,785	$33,867	125	$33,867	1.31
3.0%	$18,379	$30,741	123	$30,741	1.31
4.5%	$16,165	$27,850	121	$27,850	1.30
6.0%	$14,126	$25,175	118	$25,175	1.30
7.5%	$12,247	$22,698	116	$22,698	1.29
9.0%	$10,515	$20,402	115	$20,402	1.29
10.5%	$8,917	$18,273	113	$18,273	1.28
12.0%	$7,443	$16,298	111	$16,298	1.28
13.5%	$6,082	$14,465	109	$14,465	1.27
15.0%	$4,825	$12,761	108	$12,761	1.27
16.5%	$3,664	$11,178	106	$11,178	1.27
18.0%	$2,591	$9,706	105	$9,706	1.26

7. FUTURE WORK

As digital engineering and DT use expands, there will be more tools and applications available to increase efficiency, productivity and more reliable products. To aid in the ability to make predictions, enhance DT fidelity and use artificial intelligence (AI), machine learning (ML) and augmented reality (AR), the industrial metaverse will be investigated and applied to collaborative environments, 3D models and System of Systems. Among other applications.

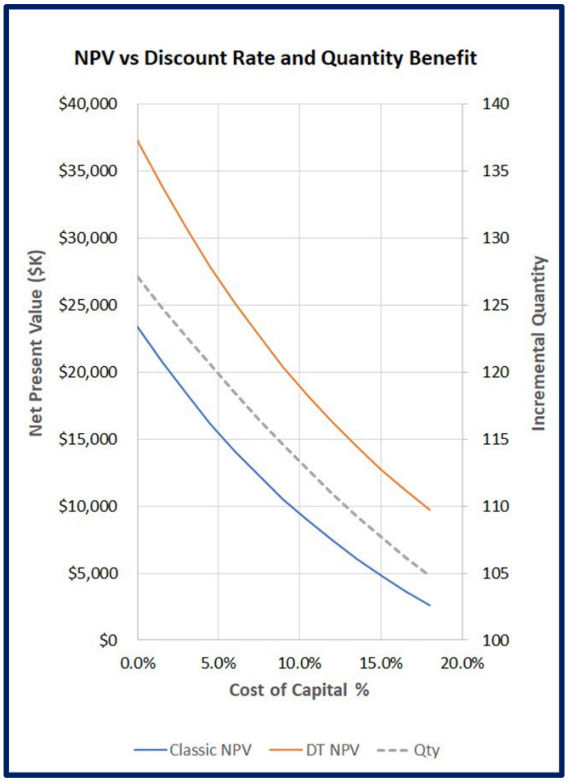

Figure 7. NPV vs Discount Rate and Incremental quantity showing buying power

APPENDIX

ACRONYMS

A&D	Aerospace and Defense
AI	Artificial Intelligence
AIAA	American Institute of Aeronautics and Astronautics
AR	Augmented Reality
ASOT	Authoritative Source of Truth
BBP	Better Buying Power
CAD/CAM	Commuter Aided Design and Manufacturing
CAGR	Compound Annual Growth Rate
CI/CD	Continuous Integration/Continuous Delivery
CM/DM	Configuration and Data Management
CMMI	Capability Maturity Model Integration
COTS	Commercial off the Shelf
DAU	Defense Acquisition University
DE	Digital Engineering
DoD	Department of Defense
DoDI	DoD
DOT&E	Director, Operational Test and Evaluation
DT	Digital Twin
GE	General Electric
INCOSE	International Council on System Engineering
IoT	Internet of Things
IPPD	Integrated Product and Process Development
LC	Life Cycle
MA&S	Modeling, Analysis & Simulation
MBSE	Model Based System Engineering
ML	Machine Learning
MOE	Measure of Effectiveness
MOP	Measure of Performance
NDIA	National Defense Industrial Association
OpsCon	Operational Concept
ROI	Return on Investment
SOI	System of Interest
SoS	Systems of Systems
TCO	Total Cost of Ownership
UTM	Unmanned Traffic Management

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BIOGRAPHY

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