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U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

My Dog Ate My Engineering:

Empowering Excuse Free Digital Transformation

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Abstract

The National Nuclear Security Administration (NNSA) is striving to adapt and thrive in today's digital engineering ecosystem by integrating digital engineering technology into all enterprise areas. Digital transformation (DT) enables increased business efficiency and effectiveness, upleveling of agility and resilience, and accelerates innovation. However, decision-makers are often faced with unclear objectives, few technical specifications, and overall uncertainty about the cost of what it means to "go digital." Our team employed a mixed-methods approach of cost estimating practices to give decision-makers a clear picture of how to incorporate redundancy, cloud processing, storage, and AI/ML into their architecture. We will demonstrate how we leveraged public data and Cost as an Independent Variable (CAIV) techniques to define DT within the NNSA as well as how other agencies can learn from our experience. With this unique approach, leadership can see an immediate tradeoff between value in the DT space and the cost of investments.

Keywords: *Digital Transformation, Cost as an Independent Variable, Cost/Benefit Analysis, Cloud, AI/ML, Parametrics, IT, Methods, Data Collection*

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1. Introduction

1.1. What is Digital Transformation?

According to Google Trends, interest in Digital Transformation (DT) has steadily increased in the United States since 2014, gaining traction in both private and public sectors (Figure 1) (1). Still, many are unable to explain the details of what DT represents and what it means to their specific program or acquisition. Cost analysts then find themselves asking the question, what is Digital Transformation?

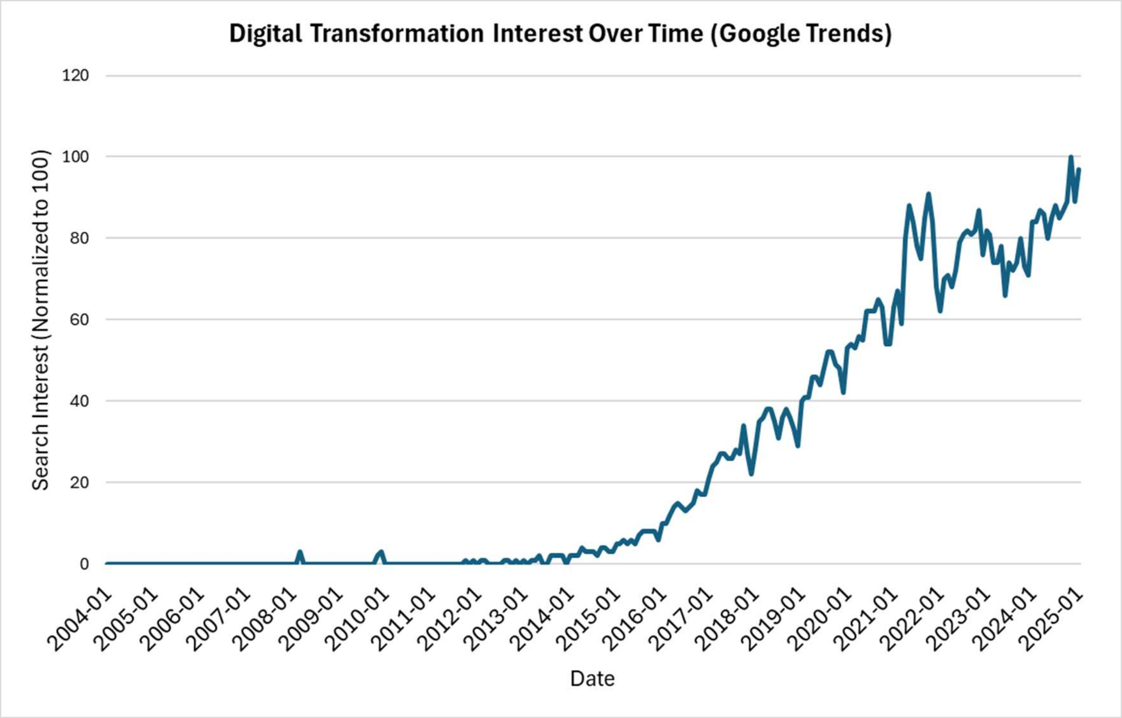

Figure 1. Interest in Digital Transformation Over Time According to Google Trends

In this paper, DT is defined as the incorporation of digital solutions and technologies to change and improve business operations. This can include increasing efficiency, providing more products or services, or communicating more effectively with customers to increase customer satisfaction. Applications of DT have large impacts on cost and buying power, in some scenarios cutting costs by over 25% according to one International Cost Estimating and Analysis Association (ICEAA) study (2) . However, implementing DT can vary drastically between organizations. This paper will explore the different applications of DT within the federal government and address some implementation challenges. While leadership understands that DT can have a positive impact on its business operations if approached correctly, there is often an unclear understanding of scope, objectives, and costs associated.

1.2. Digital Transformation and the Government

In an era where the government is prioritizing efficiency (3), one way to become so is by embracing DT within existing programs and processes. Digital transformation can enable the government to spend taxpayer dollars more efficiently while improving the information and services it provides. Utilizing digital solutions can also help the government reduce manual processes, saving time and money for additional efforts. Examples of federal agencies and the NNSA implementing DT, and realizing its benefits, will be discussed in the following sections.

DT can appear and be utilized differently depending on the federal agency and missions it supports. A recent example looks at the Department of Veterans Affairs (VA), which serves over 9 million veterans in accessing healthcare and other benefits. During the COVID-19 pandemic, the VA quadruped their bandwidth to make telehealth visits more accessible to their customers (4). In turn, the VA increased its trust rating from 55% in 2016 to near 80% in 2024 (5). This transformation included the infrastructure to support increased bandwidth, and the specialized labor needed to develop accessible websites and applications. However, while the VA has seen success with DT, there have also been roadblocks such as inconsistent budgets, team miscommunication, and misunderstood requirements (6).

In the defense space, DT tackles a different set of capabilities but with many of the same goals as other federal entities. Particularly, digital engineering and Model Based Systems Engineering (MBSE) have played a key role across the private and public defense industry by allowing more alternatives to be evaluated faster and, ideally, for systems to become operational quicker (7), such as in the case of the T-7A.

The Air Force's Red Hawk T-7A project, which has heavily utilized digital engineering, was able to expedite certain aspects of its process substantially. Boeing, one of the designers of the Red Hawk, stated that it has "experienced a 75% improvement in first-time engineering quality; an 80% reduction in assembly hours; and a 50% reduction in software development and verification time" as compared to "traditional" programs (7). However, the program still ended up experiencing a two-year delay. While these numbers demonstrate the potential of DT to reduce costs and schedule durations of new defense systems, the delays to the T-7A shows that it alone will not save cost or time, and most likely needs further alignment to realize the purported benefits. This demonstrates how an understanding of DT along with proper project management remains essential to any project's success (8).

1.3. National Nuclear Security Administration and DT

The National Nuclear Security Administration (NNSA) was established in 2000 as a semi-autonomous agency within the U.S. Department of Energy (DOE). The NNSA enhances national security through four major missions: 1) Maintaining the Stockpile; 2) Nonproliferation; 3) Counterterrorism and Counterproliferation; and 4) Powering the Nuclear Navy.

The NNSA is also implementing DT in several ways similar and different to other defense agencies, via means such as MBSE, data virtualization, and smart manufacturing. One way in which the NNSA is using DT to make more informed decisions is by utilizing these digital solutions to better monitor manufacturing facilities and decreasing machine downtime.

1.3.1. Impact on Mission and on-going DT work

The NNSA is utilizing DT to accelerate product realization and integrate digital tools as it does more work than it has since the time of the Manhattan Project (9). One notable initiative, the Product Realization Integrated Digital Enterprise (PRIDE) program, was established in 2007 to better respond to changing requirements and share weapons requirements data between NNSA sites (10). Recently, the enterprise's Pantex Plant, was able to achieve a 15% cost savings within the span of three months by leveraging PRIDE capabilities, according to a 2023 report (11).

Modernizing manufacturing practices are another way in which DT is making on impact on the NNSA mission. The Y-12 National Security Complex is using real time machine health monitoring to collect thousands of data points to analyze machine health. This data then helps Y-12 better plan maintenance of machinery and thus leading to less machinery downtime. When a machine does break, this data can also be used to better diagnose the root cause of the failure and develop procedures to mitigate it in the future (12).

At the Kansas City National Security Campus (KCNSC), smart factory technology - the usage of artificial intelligence and automation to increase the efficiency of the manufacturing process (13) - is being used to obtain real-time data that assists in identifying production problems quicker and thus improve manufacturing predictability (14). This same technology is being leveraged to improve the production of Gas Transfer Systems (GTS), demonstrating the ability to transfer DT capabilities across the NNSA enterprise.

As more NNSA sites can share data seamlessly, MBSE and data virtualization have the potential to decrease human error compared to a physical drawings-based system and decrease the time it takes to get from weapons design to manufacturing. By studying the underlying requirements and demonstrating the resultant impact that successful DT can have, programs can better inform decision makers of what it takes to get analogous efforts done.

1.3.2. General Challenges of DT in the NNSA

Accompanying the investment in DT, there are also on-going challenges that the NNSA are trying to solve. One major challenge for the NNSA is the limited bandwidth between sites that can slow the implementation of changes to design requirements. The NNSA has 8 laboratories, plants, and sites (LPS) across the country. Laboratories that design nuclear weapons generally have more bandwidth, modeling, and simulation capabilities than the sites where weapon components are produced. However, sites responsible for production are often the ones who need to implement the design changes as they occur. By increasing bandwidth across the enterprise, especially at production sites, the NNSA will realize changes in design requirements more rapidly (15). Understanding the requirements for this increased bandwidth, how these requirements can be fulfilled, and how much it will cost all present challenges to programs within the NNSA.

Another challenge is the NNSA's LPS model itself. Each LPS and NNSA headquarters have different policies and procedures that do not always align. This can make implementation of DT policy across the enterprise difficult. Further work on aligning digital policy will be essential in making DT successful (15).

Lastly, the overall physical infrastructure constraints that exist across the NNSA also affects DT's ability to be fully funded and implemented. Given the age of the enterprise's infrastructure, priority is often given to modernizing, maintaining, and replacing it (16). However, the NNSA has several of these large capital acquisition projects that are over budget and will likely remain the nuclear security enterprise's top priority given their importance to the enterprise's mission. Successful DT will require significant resources both within the NNSA budget and from its leadership and personnel. Making DT a priority will thus require a clear understanding of what investment is necessary and how it will support the mission need (15).

One step towards communicating the importance of what a fixed DT investment may accomplish is through the utilization of Cost as an Independent Variable (CAIV), which has been found to have immense value to programs according to one ICEAA study (17). Discussed in more detail later, CAIV enables quantitative technical analysis under a constrained budget environment, by using the budget as the focal point of analysis. Given the aforementioned funding constraints, stressing what *could* be accomplished could be one viable solution to garnering buy-in, or insightful for alternatives. CAIV has been found to. Given the relative scarcity of usage in the NNSA, this paper offers a unique look at how CAIV can be utilized in that space.

1.3.3. Role of Programming, Analysis & Evaluation (NA-MB-90)

The Office of Programming, Analysis and Evaluation (NA-MB-90) develops models and tools to support capital acquisition and planning, programming, budgeting and evaluation (PPBE) processes. NA-MB-90's toolkit includes cost estimating, schedule estimating, benchmarking, and portfolio analysis. Within NA-MB-90's cost estimating capability and experience in analogous work, there has been an increased demand for

DT estimating, including how to estimate cloud storage, Artificial Intelligence and Machine Learning (AI/ML) computing, software licensing, and other well-known DT capabilities by using CAIV and other forms of analyses. This paper will outline some of the methods used by NA-MB-90 to support stakeholders.

1.4. NNSA Digital Transformation Use Case

The NNSA has run several pilot programs to evaluate implementations of DT. Their intention was to integrate cloud computing, data analytics, and automation to streamline operations, reduce costs, and improve decision-making. Additionally, by leveraging Artificial Intelligence and Machine Learning, the NNSA could enhance weapons analytics and benefit from better predictive maintenance. The MB-90 was asked to evaluate one of these pilot programs to estimate a *should cost*, determine effectiveness of the solution, estimate the costs of a larger-scale implementation, and quantify the value of DT to the organization. Going forward, this project will be referred to as the NNSA Digital Environment Pilot, or NDEP.

The following sections will discuss the approach and methods taken for this effort, and the results and impacts on the NNSA’s digital engineering landscape. Although just one case study, many of the methods utilized could be applied to a DT estimating effort across any government agency.

2. Approach and Methodology

2.1. Approach

The general principles of DT have a few key problems that it is looking to solve. From a technical standpoint, the most basic level of transformation is a desire to move towards a cheaper and more centralized solution from an otherwise expensive and disparate digital and physical environment. Transitioning processes to the cloud was identified as being the most conducive to an effort such as this due to its cost, modularity, and scalability. To accompany a transition to a digital space, it is important to have a robust infrastructure with redundancy built in. These solutions require the labor and the surrounding overhead to support it, as well as ongoing monitoring and maintenance. How these solutions can best be implemented will be assessed in subsequent sections.

Ultimately, it was the study team's objective to illustrate to the customer the scope of a cloud-centric transformation, and how current budget constraints may inform the requirements of this type of project.

2.1.1. Multi-System Analytical Tool

The cost estimating process related to DT is relatively vague. Due to its ambiguous description, the cost estimating process tends to gravitate towards a 'where to best begin' approach rather than following a more systematic programmatic plan or implementation solution. However, before formulating an approach, a way to aggregate, store, and compile data, methodologies, visuals, and indices should be identified. An approach is only as good as the infrastructure surrounding it, thus establishing a centralized and robust framework for doing so is critical. A similar framework is followed in the space cost estimating industry via SPACEFRAME, which was covered in a 2023 ICEAA paper (18). Once performed, the underlying methodology to solve for the cost of DT can commence.

2.1.2. Cloud Parametrics and Services

Parametrics, or more specifically Cost Estimating Relationships (CERs), that were identified as having immediate applicability to NDEP were those based around the cloud. Based on discussions with program leads, there was a desire to transition more processes to a digital environment from current on-premises media, increasing scalability and modularity. As such, the desired objectives of this transition varied from the relatively basic, such as increased cloud storage and instantaneous computing capabilities, to the more advanced and experimental, like AI/ML utilization. Some of these capabilities were already in use, and therefore the team were better able to fine-tune solutions.

However, with few exceptions at the time of the study, cloud CERs were not widely available or used, so the study team had to create them. Thankfully, in today's increasingly digital environment, there is no lack of resources or providers for cloud services; many even have their own pricing tools and databases that can be leveraged for building parametrics. However, using the pricing tool itself is not always the most viable solution – they often require significant technical input, untraceable cost drivers, and often only represent a singular compute or storage instance; An instance in this case just means a specific resource provided by a cloud service. Programs will often have multiple instance requirements, and using the tool for multiple is impractical, whereas a parametric requires minimal inputs and has easy replicability.

Cloud services enable users to access powerful infrastructure for storage and computing without owning any physical hardware. This is typically referred to as just “the cloud” in most spaces. In the context of this paper, the cloud is used for two categories of DT: storage and computing. For storage, the cloud allows users to securely store, manage, transfer, and access data from anywhere, with scalable options to accommodate growing or diminishing storage needs.

For computing, cloud providers offer virtualized servers called ‘instances’ that can be quickly deployed to run applications, process workloads, or host websites. These can also provide computing power and frameworks to train, deploy, and manage AI/ML models efficiently. Common cloud providers include Amazon Web Services (AWS) and Microsoft Azure. Both providers have public information and data regarding their costs for cloud storage and computing online.

Amazon’s AWS and Microsoft’s Azure were the two providers used, as they fit various criteria: (1) They contain multiple capabilities, (2) have readily available pricing data, and (3) are compliant with U.S. regulatory requirements.

$$\begin{aligned} &Cost\ of\ Storage \\ &\qquad = Storage\ Type\ Dummy\ Variable\ (1/0) * Storage\ Rate\ Cost\ (\$/TB) \\ &\qquad * Amount\ Stored\ (TB) \end{aligned}$$

As an example of a CER developed for the study, take the above example for Simple Storage Service (S3). S3 is an AWS cloud storage solution that allows for centralized digital file storage that can also interact with other cloud utilities. It often comes with tiered storage rates contingent on how often the file is likely to be accessed – higher rates for frequently accessed files, and lower rates for more archival files. For end users, the cost ultimately ends up being dependent on the amount being stored, with a slight decrease in price per unit for larger loads and storage type. This leads to needing only two independent variables in the CER – Amount of data stored and the type of storage, represented as a dummy variable. A similar process has been followed to develop CERs for other cloud services, such as in the case of Elastic Cloud Computing (EC2), which was done for an analogous ICEAA cloud study conducted in 2023 (19), Kubernetes, and various cloud-centric AI/ML services.

2.1.3. Cloud-CAIV

Cost as an Independent Variable (CAIV) is a method leveraged by cost analysts that emphasizes technical scope/delivery within cost constraints, rather than treating cost as a result of other variables (20). In simpler terms, an analyst can re-arrange an existing parametric or CER to solve for a quantitative technical variable by using CAIV within the parametric itself. In the context of this paper, a few use-cases of CAIV include utilizing a cloud service CER to express the number of computing instances, and a cloud storage CER to approximate storage size (in Terabytes (TB)) as a function of cost (discussed later in Section 2.2.1). For CAIV to be effective, an analyst must still identify all technical variables except for the one being solved for. An example of how a CAIV parametric may be derived is shown below:

$$1)\ Cost\ of\ Storage\ (y) =\ Storage\ Rate\ Cost\ (a) * Amount\ Stored\ (x)$$

$$2)\ \frac{Cost\ of\ Storage\ (y)}{Storage\ Rate\ (a)} = \frac{Storage\ Rate\ Cost\ (a) * Amount\ Stored\ (x)}{Storage\ Rate\ (a)}$$

$$3)\ Amount\ Stored\ (x) =\ Cost\ of\ Storage\ (y)/\ Storage\ Rate\ Cost\ (a)$$

In the simple example above for cloud storage, an analyst already knows how much money has been budgeted for the cost of storage (y), as well as the storage rate cost (a) derived from cloud pricing documentation. What is not known in this scenario is how *much* storage (x) can be afforded. By doing some simple arithmetic, storage can be solved for (step 2), with cost becoming an independent variable within the parametric, and storage amount becoming the new dependent variable (step 3). Note that for most cloud storage options, there are multiple tiers of storage pricing for various access scenarios, and therefore this example has been simplified to demonstrate the concept of CAIV. If a customer needs to access their data daily, they might choose a frequent access tier, whereas if needed only a few times per year, they might choose a more archival access tier (21). These storage rates for AWS are shown in Table 1 below.

Table 1. AWS S3 Storage Rates

Storage Tier	Storage Rate/TB/Year ($)
Frequent	264
Infrequent	156
Yearly	48
Archival	12

This is one of the more basic ways to apply CAIV analysis, but there are many more examples that exist within cloud estimating and elsewhere. More information on the application thereof will be discussed in section 2.2.1.

2.1.4. Non-cloud Relationships and methodologies

For DT enablers that are indirectly cloud-related, the team had to explore different means of providing impactful results. While DT itself is the overarching objective, it still requires supporting activities required to fully stand up, maintain, and enable the new capability, such as infrastructure, redundancy of systems, labor, and procurement. Given the project's digital and cloud-centric nature, it can be easy to overlook these costs. As such, when presented in a Work Breakdown Structure (WBS) or other aggregated format, they are less explicitly broken out and so often need parsing out. While data to construct cloud parametrics is relatively accessible and abundant, finding data to estimate some of these underlying costs can be substantially more difficult.

However, before attempting to estimate the cost of these adjacent costs, the first need is to find out what specifically is to be estimated. As part of requirements gathering, the team was able to ascertain three discrete items that weren't cloud computing related: 1) network redundancy, 2) bulk procurement of software, and 3) labor.

1) BUILDER is an NNSA-owned database that captures these same costs, inclusive of materials, equipment, and labor, but utilizing agency-specific data (22). By exploring this data, several component costs can be gleaned, including for items that may have direct pertinence to the use case project: Of particular

interest being fiber optic cabling. Although there aren't specifics as to the type of optic cabling needed, assumptions can be established from information gathered from program leads. By creating histograms of the data, the team were able to derive a distribution to extrapolate the average cost for fiber optic cabling. It should be noted that while many items could contribute to fulfilling a network redundancy requirement, fiber optics was a known area of interest based on discussions with program leads

2) Another item of interest was the bulk procurement of software, which is not necessarily dependent on any kind of cloud capability – this would include items such as Microsoft Suite, Computer-Aided Design (CAD), or other digital engineering software. Current methods of procurement are often at the site-level, meaning individual sites are procuring their own capability needs instead of through some form of centralized entity. This has obvious cost implications from an agency perspective, as many vendors offer increasingly larger discounts for bulk purchasing software. To illustrate the concepts of bulk procurement, public software pricing data was used.

3) Similar to network redundancy, labor was a ubiquitous term without a definable enterprise requirement, with only projected budget costs to provide insight into potential cost. To aid in approximating the number of Full Time Equivalents (FTEs) and how many FTEs a budget may afford, the team looked to an analogous cloud project. Within the documentation for this analogous project were projected FTEs, their position, and the phasing of FTEs over the project lifecycle. By utilizing an adjacent database of historic labor rates for the lab site, a proportional number of FTEs could be derived for this project.

2.2. Case Study Use Case

A case study will be used to tie the previously outlined concepts together and demonstrate how these methods can provide value to stakeholders with little technical information available. The team leveraged a multi-system analytical tool to assist in the usage and analysis of developed methods, aggregation of results, and creation of the subsequent visualizations. It was instrumental in allowing the team to consolidate what would have otherwise been a disarrayed set of separate databases and other information.

For context, an office within the NNSA requested NA-MB-90's review of their current and forecasted DT budget. This budget was provided in the form of a 6-year budget sheet broken out by high level elements only. These were then transposed by the team into a more formal Work Breakdown Structure (WBS) to better organize and categorize costs. Our simplified exemplar WBS, showing one fiscal year only, is presented in Table 2 below. Please note that the table below is an exemplar of the budget sheet and is not inclusive of all data provided.

Table 2. DT Work Breakdown Structure.

Level	WBS	Infrastructure	FY Budget[1]
1	1	Collaboration Space - Project	$ 27,000,000
2	1.1	Leadership Staffing	$ 3,000,000
2	1.2	Vendor Instantiation - Compute	$ 4,000,000
3	1.2.1	Instantiation – Basic	$ 2,000,000
3	1.2.2	Instantiation – Advanced	$ 2,000,000
2	1.3	Hardware	$ 20,000,000
3	1.3.1	Storage	$ 2,000,000
3	1.3.2	Network upgrades/Redundance	$ 3,000,000
3	1.3.3	Network Staffing	$ 6,000,000
3	1.3.4	Lifecycle and management reserve	$ 9,000,000

It was then up to the team to determine how each cost pertained to the technical requirements of the project. Where possible, the team attempted to represent the analysis of each level 3 item in the subsequent sections with the exception of 'Lifecycle and management reserve,' as this item is often a factor on top of baseline costs to account for unknown risks. A broad strokes usage for each WBS element can be observed below.

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[1] All dollar amounts used in this paper have been obfuscated from budget actuals

2.2.1. CAIV for Compute and Storage

CAIV development and general applications were described in Section2.1.3. For NDEP, CAIV analysis was critical in defining what cloud procurement could look like when there was little to no technical details available. A budget, like in Table 2 above, was provided for items such as storage, basic computing operations, and advanced computing operations for mission workload. The team used CERs developed from public data (Section 2.1.2) for tiered storage and different levels of computing instances for CAIV in combination with the provided budget values.

For storage, the team aimed to demonstrate how tiered storage solutions could effectively address a variety of requirements by offering cost-efficient and scalable options tied to their data access needs. The NDEP customers informed us that their data storage requirements span multiple S3 storage tiers (Section 2.1.3), with much of their data potentially falling into the archival tier. Using the cloud storage CER, the team was able to solve for the number of Terabytes (TB) stored that the customer could afford given their budget, calculated per storage tier. An example of this analysis is shown below in Figure 2. In the figure, the percentages represent the percent of total budget allocated to that storage type.

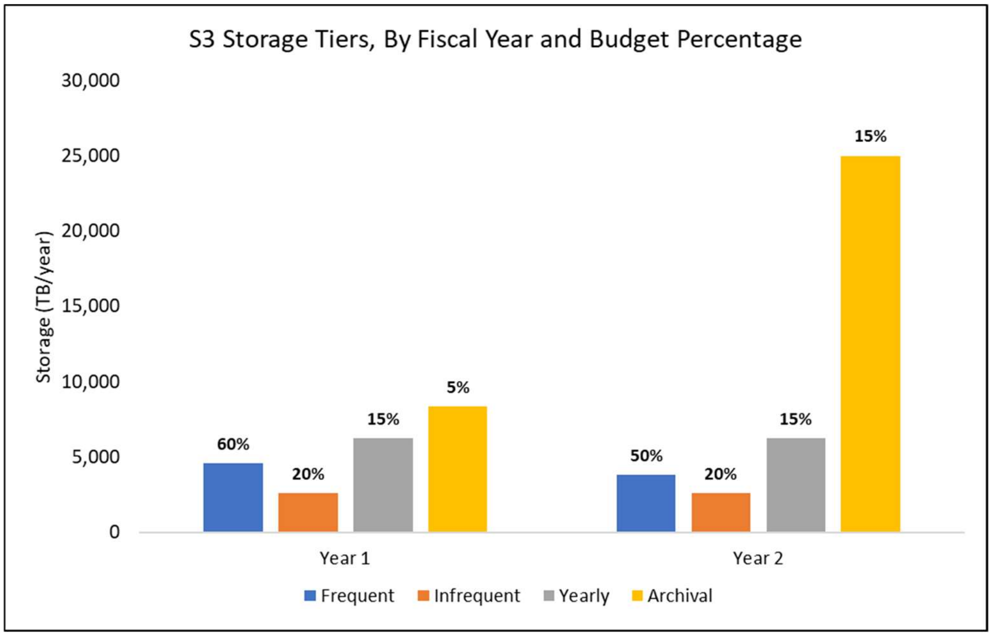

Figure 2. Tiered storage amounts by data access type, utilizing an annual storage budget of $2M

To estimate the number of computing instances that could be afforded, the team needed to look at two separate options based on the customer's budget breakouts: basic computing and advanced computing. To reduce the decision trade space, in the team made assumptions based on information from AWS and Azure to determine what computing parameters fit the customer's needs. Figure 3 below shows an example of the result of this analysis.

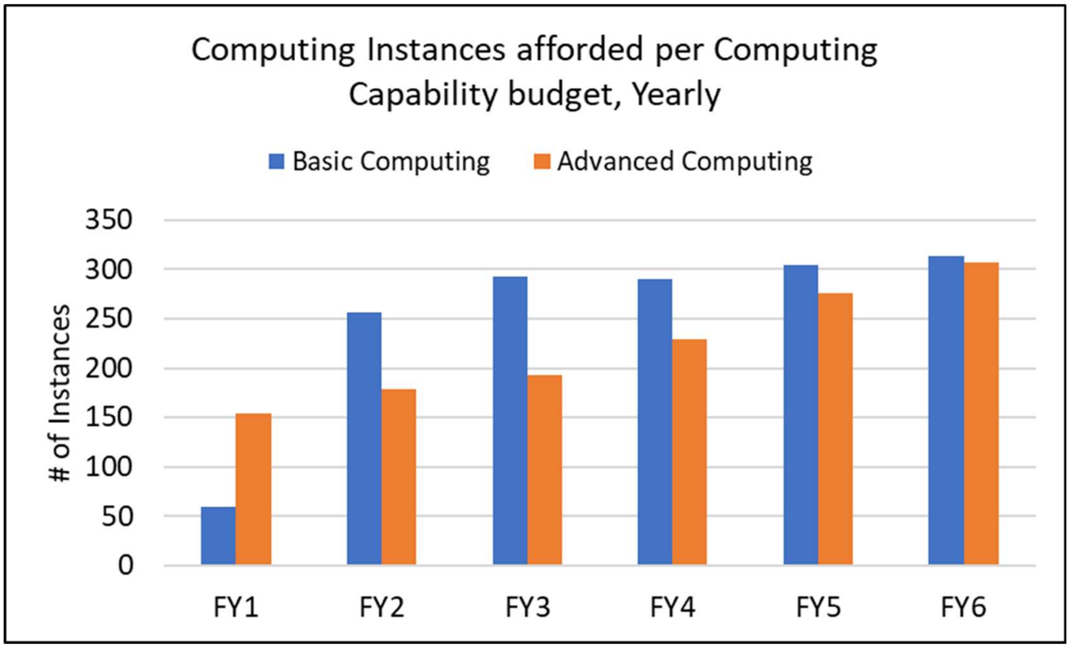

Figure 3. Computing Instances by Fiscal Year

Figure 3 shows just one option for procuring basic and advanced computing instances using the full budget for each within every fiscal year provided. Ultimately, this CAIV analysis did not recommend a specific decision but instead could provide a range of options, empowering the customer to make informed choices based on their unique goals, priorities, and budget.

2.2.2. Labor

Explicit labor requirements for the DT effort were not well understood by the program or defined for estimators. To overcome this and approximate the amount of labor that may be required, the team reviewed an analogous cloud project. The benefit to using this analogous project as a reference point was its labor breakout, FTE requirement, and how it categorized the various roles involved per year. For example, the number of cloud engineers were distinct from the number of helpdesk support, and so on. By having the breakout of these roles and their respective number of FTEs, labor costs for each effort could be calculated. To do so, an internal labor database containing the annual burdened cost for different worker types was utilized. By taking the total cost of labor from the analogous project, a proportional number of FTEs could be calculated for the DT Project for a given budget.

Take Table 3 below as an example, where a sample number of FTEs that could be afforded for DT was calculated. By taking the proportion of the amount of money budgeted to labor between the case study and the analogous project, and allocating that money to the various labor roles, an approximate number of how many FTEs could be afforded was estimated.

Table 3. Case Study Labor Roles and Rates[2]

Analogous Project FTEs	Role	Annual Wage Rate (Burdened) ($K)	Total Wages ($K)	DT Budget ($K)	Proportional FTEs Afforded for DT
2	Cloud Engineer	500	1,000	1905	3.8
2	Administrative	300	600	1143	3.8
1	Project Manager	500	500	952	1.9
3	IT	350	1,050	2000	5.7
Totals					
8			3,150	6,000	15.2

2.2.3. Network Redundancy

Given a lack of requirements for what would be encompassed by network redundancy, the team decided to provide insight into what one element may cost – Underground Fiber Optic Cabling. Ideally, doing so would inform how much buying power is currently available, and whether this aspect is under- or overvalued in relation to other requirements. To illustrate this, two scenarios were presented: What is the buying power of $3M (reported budget in Table 2), and what would an arbitrary distance, like one mile, cost? Figure 4 portrays a histogram of reported costs within the BUILDER

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[2] Analogous project numbers are made up for demonstration purposes

database for underground fiber optic cabling at a per unit scale. A high left skew can be observed.

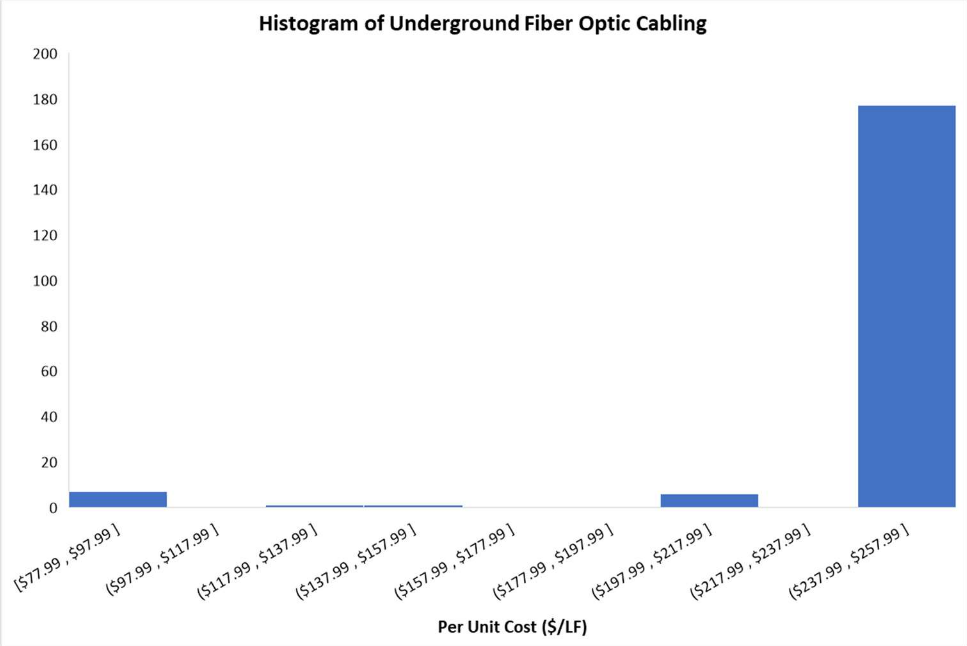

Figure 4. Histogram of Historic Cabling Costs[3]

This skewness is primarily due to the large proportion of the datapoints that (>90%) only exist at the same site and belong to the same property. Therefore, the median per unit cost was used as the basis for comparison. As a result, Table 4 compares the price of 1 mile of fiber optic cabling and the buying power of $3M to illustrate different buying scenarios.

Table 4. Buying Power of Cabling Investment in Linear Feet (LnFt).

	Cost ($M)	Length (LnFt)
Buying Power of $3M	3	12,200
Cost of 1 Mile	1.3	5,280

2.2.4. Enterprise Software Purchasing

To illustrate the concept of enterprise software purchasing, the team utilized publicly available pricing data from a common industry vendor – Jira, which is a cloud project

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[3] Actual costs obfuscated

management tool. To create an adequate cost improvement curve illustrating the power of centralized software purchasing, a sample number of licenses and its accompanying average cost per unit were taken at varying intervals. By graphing the respective average cost per unit and the corresponding quantity of units, the team identified a standard cumulative average cost improvement curve, seen in Figure 5.

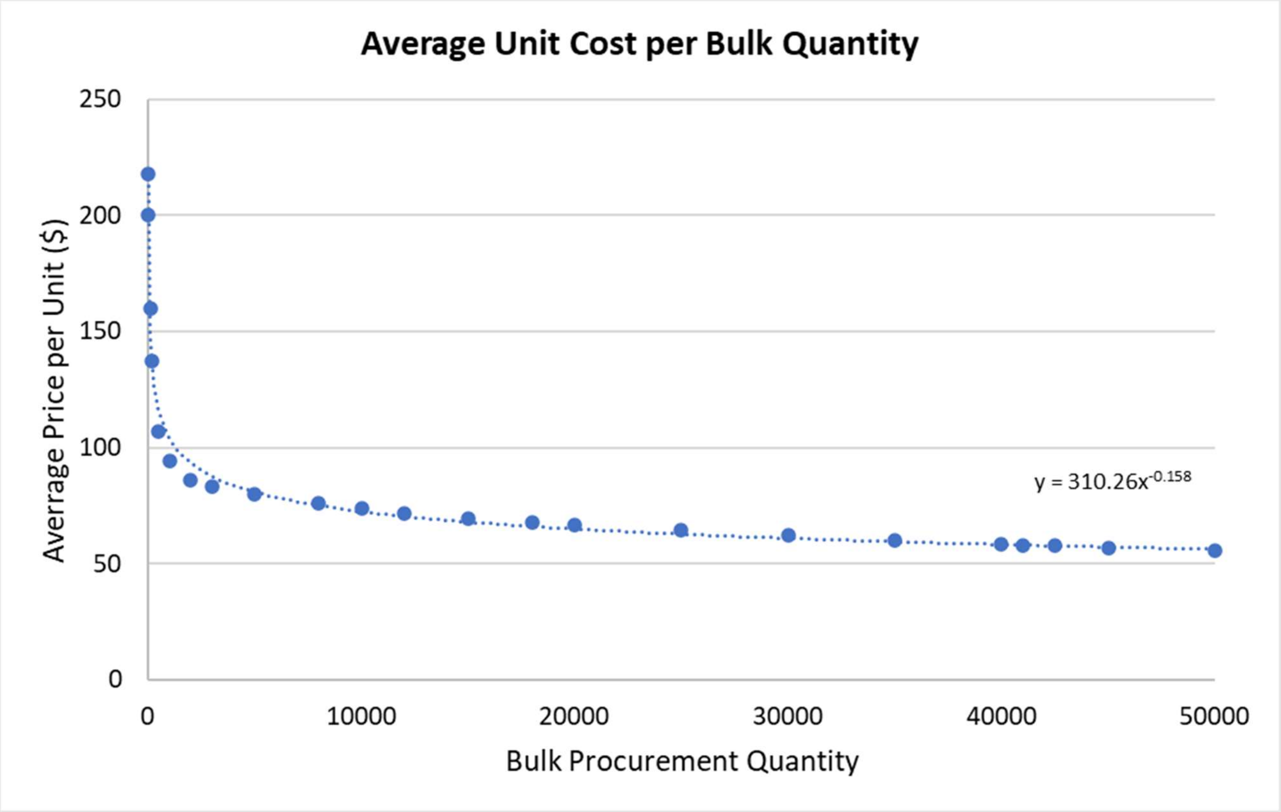

Figure 5. Average Unit Cost Quantity Purchasing

As a scenario, the team analyzed the potential cost of procuring 10,000 distinct licenses across three lab sites, versus bulk procuring 30,000 and distributing them among the same. The result of this analysis can be seen below in Table 5. As will be seen, this not only has direct cost benefits, but a perhaps overlooked aspect is the subsequent savings in the associated indirect costs, such as management and distribution of bulk procured items. As most sites have their own purchasing infrastructure, this can eliminate wasteful duplication. While indirect costs impacts were not quantitatively assessed, the team does acknowledge them.

Using the derived equation, the cost of procuring 10,000 units equates to $72/Unit. Comparing this with the cost of 30,000, which is $61/Unit, is a difference of $11/Unit. Extrapolating the two price points over a sample of 30,000 units results in a cost savings of over a quarter million dollars (15% savings) when buying in bundles. Table 5 illustrates a comprehensive view of this scenario with various purchasing schemes across multiple sites, for the same number of total licenses.

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Table 5. Cost Improvement from Higher Quantity Buys.

Number of Units	**Cost per Unit**	**Total Cost**
10,000 x 3	$ 72	$ 2,160,000
30,000	$ 61	$ 1,830,000
Amount Saved		**$ 330,000**

Figure 6 presents a spectrum of procurement scenarios ranging from one bundle of units, up to ten. Each colored block represents a single bundle of units, the size of which is predicated on the number total number of bundles. The total number of units stayed static at 30,000. The total procurement cost is lowest at a single bundle of units, further highlighting the potential cost savings using bulk procurements.

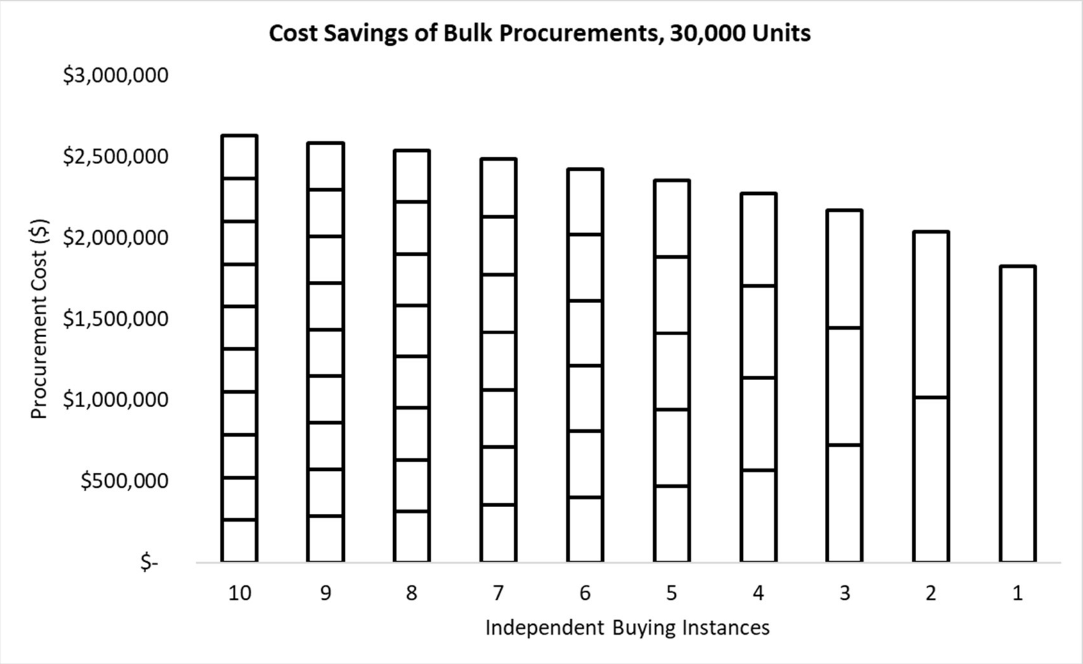

Figure 6. Cost Savings of Bulk Procurements

3. Results and Assessments

3.1. Case Study Results

Using the customer's annual budget data and minimal technical information as it regarded a transformation, the study team provided a broad decision space encompassing cloud storage, cloud computing, fiber optic cabling, bulk software procurement, and their buying power over time. This allowed the customer to explore data-driven, tailored solutions to maximize technical delivery of DT within a constrained budget.

By utilizing a multi-system tool, the team was able to consolidate disparate methods and costs and visualize what specific DT adoption approaches were feasible from both a granular and holistic viewpoint, as mentioned in Section 2.2. Figure 7 below summarizes the team’s findings. The solution in Figure 7 is one of infinite options trading capability between the various areas. Aside from applying cost realism through standardized inflation, the team offered the customers multiple technical solutions for cloud storage and computing using foundational techniques like parametric estimating and CAIV. Although the actions and results are in the hands of the decision-makers, the team was able to provide valuable insights into the realm of cost and technical possibilities for a DT that were otherwise unclear.

To adequately capture each elements contribution to the total cost, the team divided the expected budget items into an ad hoc WBS (discussed in Section 2.2) to better examine the purchasing power of each investment.

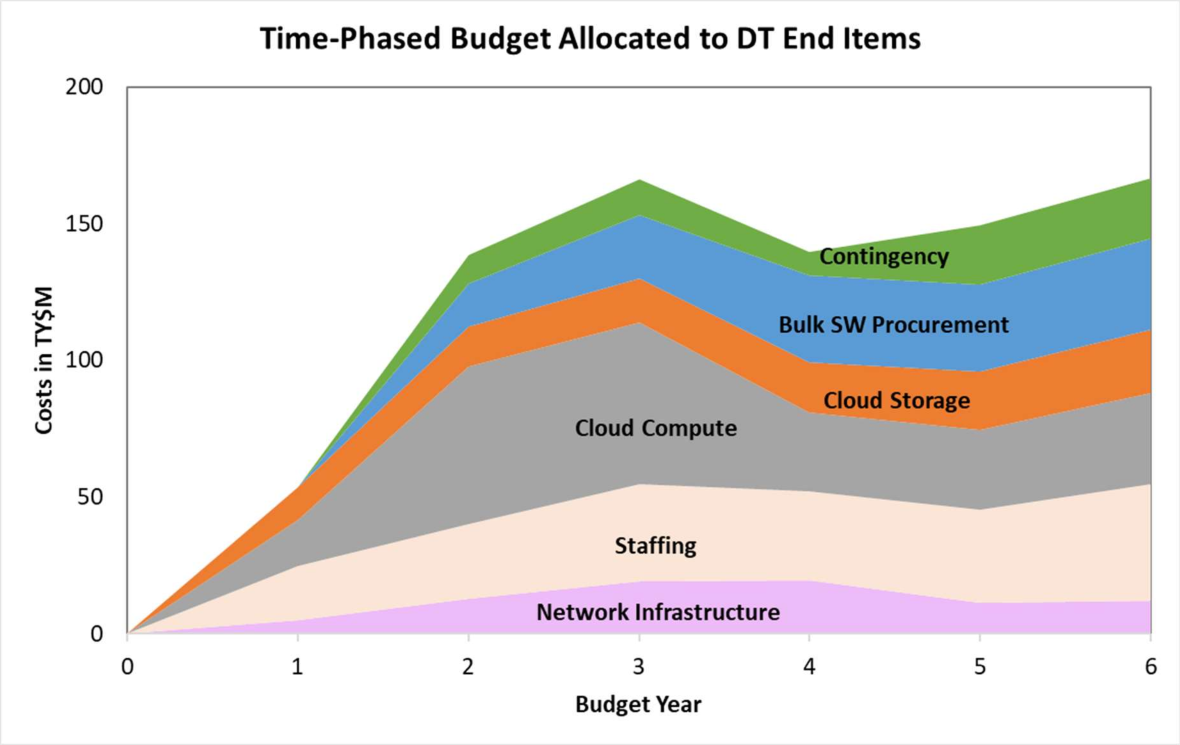

Figure 7. Budget Visualization of Digital Transformation[4]

The insights provided to the customer helped them in correctly scoping their infrastructure purchases. Doing so allowed the team to demonstrate various overlooked or non-assessed items. For example, the effects that inflation or unrepresentative labor

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[4] Budget actuals have been obfuscated

rates may have on diminishing buying power over time, or how their investments might be allocated towards different combinations of cloud and infrastructure purchases. This in turn identifying cloud service alternatives that are not currently utilized but may fit enterprise needs better if done so, such as the inclusion of AWS Snowball (hybrid cloud and physical storage) and Kubernetes (Containerized applications) services for more reliable computing, and intelligent tiering for dynamic data storage. The analysis paved the way for more informed discussions about priorities and goals and how to best usher the NNSA into an all-digital architecture of the future.

3.2. Limitations

Considering the constant evolution and ubiquitous nature, any study of DT has its limitations; particularly as it relates to a federal space that can have rigid policy compliance standards, guidance, and other bureaucratic hurdles to clear before implementation. However, there were some non-administrative limitations to the study as well.

Perhaps the most overarching limitation was the lack of concrete technical requirements, specifically as it relates to DT. While the goal of the effort was identified, the steps to get there were unclear. For most of the study, a more generalized idea of what was needed was the primary way of informing what sort of analysis was conducted. These needs were primarily ascertained by research or by utilizing information from analogous projects. For example, in instances where cloud was expressed as an item of interest, the team used commonly utilized cloud capabilities such as EC2, S3, and AI/ML. However, explicit requirements that fell under the umbrella of each of those were absent. Whether those capabilities pertained to the effort at all was unclear. Ultimately, the absence of this information allowed for the creation and usage of CAIV parametrics to inform technical buying power with given monetary constraints, which has provided valuable insight.

The lack of requirements had a larger impact on elements that weren’t inclusive of cloud capabilities, such as infrastructure, network redundancy, labor, and procurement needs. While, by description alone, these elements convey some general sense of what is required, they don’t necessarily qualitatively or quantitatively inform what may be needed.

Another limitation was the lack of a formal WBS. Unlike other governmental departments (23), there is no standardized WBS for IT or DT within the DOE. The lack of any such outline makes it difficult for an individual that is unfamiliar with the concept of a WBS to know how or where to most effectively classify costs. As such, the bucketing of costs requiring organization was abundant. A bottom-up approach to cost allocation would have yielded better results in definitively knowing what money was going where, and how much.

3.3. Areas for Future Analysis

One emerging area of interest for DT is chargeback – that is, the ability for an agency to consolidate purchasing and remit those costs back to departments based on usage. Some areas of consideration are cost allocation models and cost recovery to meet budget goals. For an enterprise to recoup investments with anticipated cost efficiencies and savings, they need to consolidate purchasing. Unfortunately, that consolidation removes the feedback mechanism to individual departments that usage is not being managed efficiently; thus, a robust policy is necessary to ensure efficient use.

Separately, while there are WBSs available for many areas of IT hardware and software development, a standard WBS for DT does not currently exist. A WBS for this area, while sharing many analogous costs with an IT system, would still be a novel concept. It would still contain items such as hardware, software, and adjacent services, but would also contain relatively unique items like dedicated AI/ML and cloud services. A more thorough exploration of standardized DT items would be a compelling and worthwhile area of future analysis.

4. Conclusion

Digital transformation is no longer a strategic option but a necessity for organizations seeking to operate in a digital world. By leveraging technologies such as cloud computing, artificial intelligence, and data analytics, organizations can enhance efficiency, streamline processes, reduce costs and optimize resource allocation.

However, achieving these outcomes requires more than adopting new technologies; it demands a cultural shift, strong leadership, and a vision that aligns technological investments with organizational goals. The cornerstone of this transformation is accurate cost estimating.

Looking ahead, the success of DT efforts will depend on the ability to navigate challenges such as resistance to change and legacy system integration. Organizations must remain adaptable, prioritize continuous learning, and foster collaboration across teams and departments. Additionally, leveraging data-driven insights will be critical in ensuring sustainable impact. As DT continues to evolve, organizations that embrace innovation and proactively adapt to change will be better positioned to meet the demands of a fast-paced, technology-driven future.

5. Appendix

5.1. History, Use Cases, and additional information about Digital Transformation

Developing digital services can make government services more accessible and increase the satisfaction of citizens with their government. By collecting and analyzing both new and historic data, decision makers from across the government can make more informed and evidence-based decisions that reduce government waste and enables them to respond to crises in a quicker and more efficient way (24). While DT has had a place in government since the early 2000s, there is still a significant way to go towards utilizing digital solutions in the most efficient way. As evidenced by a September 2023 OMB report, “only two percent of government forms are digitized, 45 percent of websites have not been designed to work on mobile devices, and 60 percent of websites are not fully usable by those who use assistive technologies.” (25).

The earliest efforts began in the 1990s, when the US government adopted the process of digitization: The creation of digital information from their physical counterparts. Though this created many new efficiencies and easier informational access for much of the population, many governmental areas still followed a “quasi-paper-based blueprint,” with physical records playing an important role in government business (26). To help reduce this, further legislation such as the Government Paperwork Elimination Act (GPEA) of 1998 was passed, which played a significant part in enabling more citizens to interact digitally with the government (27). During the 2000s, the National Archives and Records Administration (NARA) established the Electronic Records Archives (ERA) program, which began accepting electronic records (28). This was a major step towards institutionalizing how the United States government would archive electronic records. In 2012, the White House issued several Executive Orders and a Presidential Memorandum aimed at building “a 21st century digital Government that delivers better digital services to the American people.” (29). This led many government agencies, from the Department of State to the Social Security Administration, to develop Digital Government Strategies outlining how they plan to provide better digital services and information to the American people.

The Idaho National Laboratory (INL) defines digital engineering as “a holistic approach to the design of a complex system; Design using models/data instead of documents, integration of data across models, and the culture change across project teams to realize significant risk reduction on construction cost and schedule.” (30) Sandia National Laboratory (SNL) defines MBSE as the “application of digital tools to allocate and manage requirements, and design integration, analysis, qualification/certification and validation/verification through the entire product lifecycle.” (31)

The NNSA is also working to include more digital solutions within weapons systems. As a start, a process has been developed that qualifies digital products based on the way physical components are accepted and a product meets all its technical and quality requirements, also called ‘Diamond Stamping’. The first of these solutions, called Nightwatch, was developed by Lawerence Livermore National Laboratory (LLNL) and sits inside a weapon to log temperature fluctuations that provides more data on how they respond in different environments. LLNL continues to develop additional digital products for weapons that are slated to be ready to be diamond stamped in 2025 and 2026 (32).

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7. Acronyms

AI/ML	Artificial Intelligence / Machine Learning
AWS	Amazon Web Services
CAD	Computer-Aided Design
CAIV	Cost As an Independent Variable
CER	Cost Estimating Relationship
DOE	Department of Energy
DT	Digital Transformation
EC2	Elastic Cloud Compute
ERA	Electronic Records Archives
FTE	Full Time Equivalent
GPEA	Government Paperwork Elimination Act
GTS	Gas Transfer System
INL	Idaho National Laboratory
IT	Information Technology
KCNSC	Kansas City National Security Campus
LLNL	Lawrence Livermore National Laboratory
LnFt	Linear Foot
MBSE	Model-Based Systems Engineering
NA-MB-90	NNSA Office of Programming, Analysis and Evaluation
NARA	National Archives and Records Administration
NDEP	NNSA Digital Environment Pilot
NNSA	National Nuclear Security Administration
OMB	Office of Management and Budget
PRIDE	Product Realization Integrated Digital Enterprise
S3	Simple Storage Service
SNL	Sandia National Laboratory
TB	Terabytes
US	United States
VA	(Department of) Veterans Affairs
WBS	Work Breakdown Structure