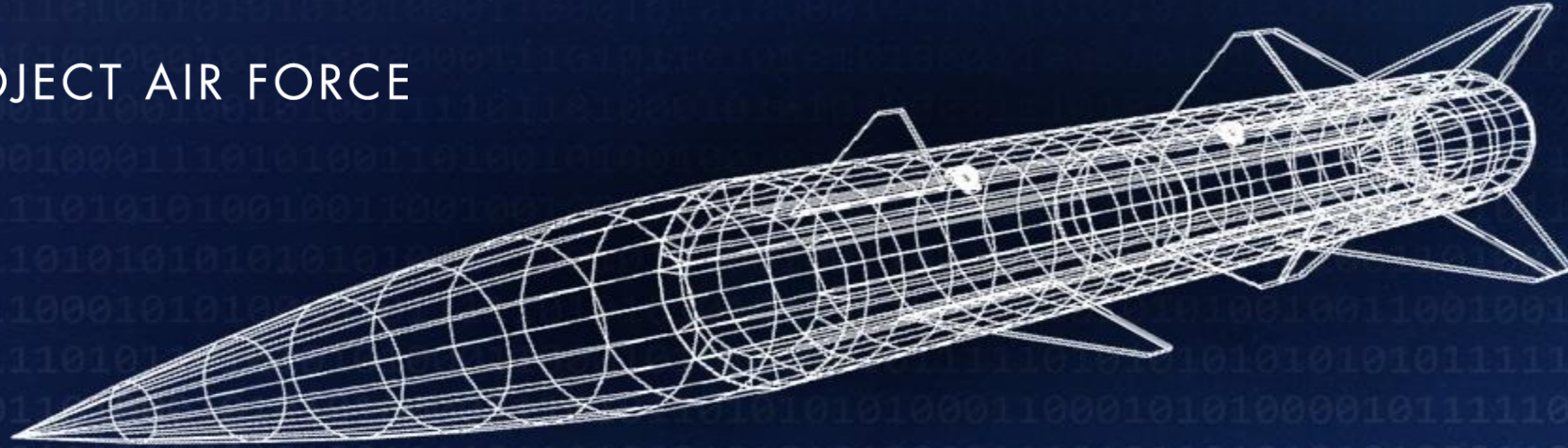




RAND

PROJECT AIR FORCE



# A Preliminary Assessment of Digital Engineering Implications on Weapon System Costs

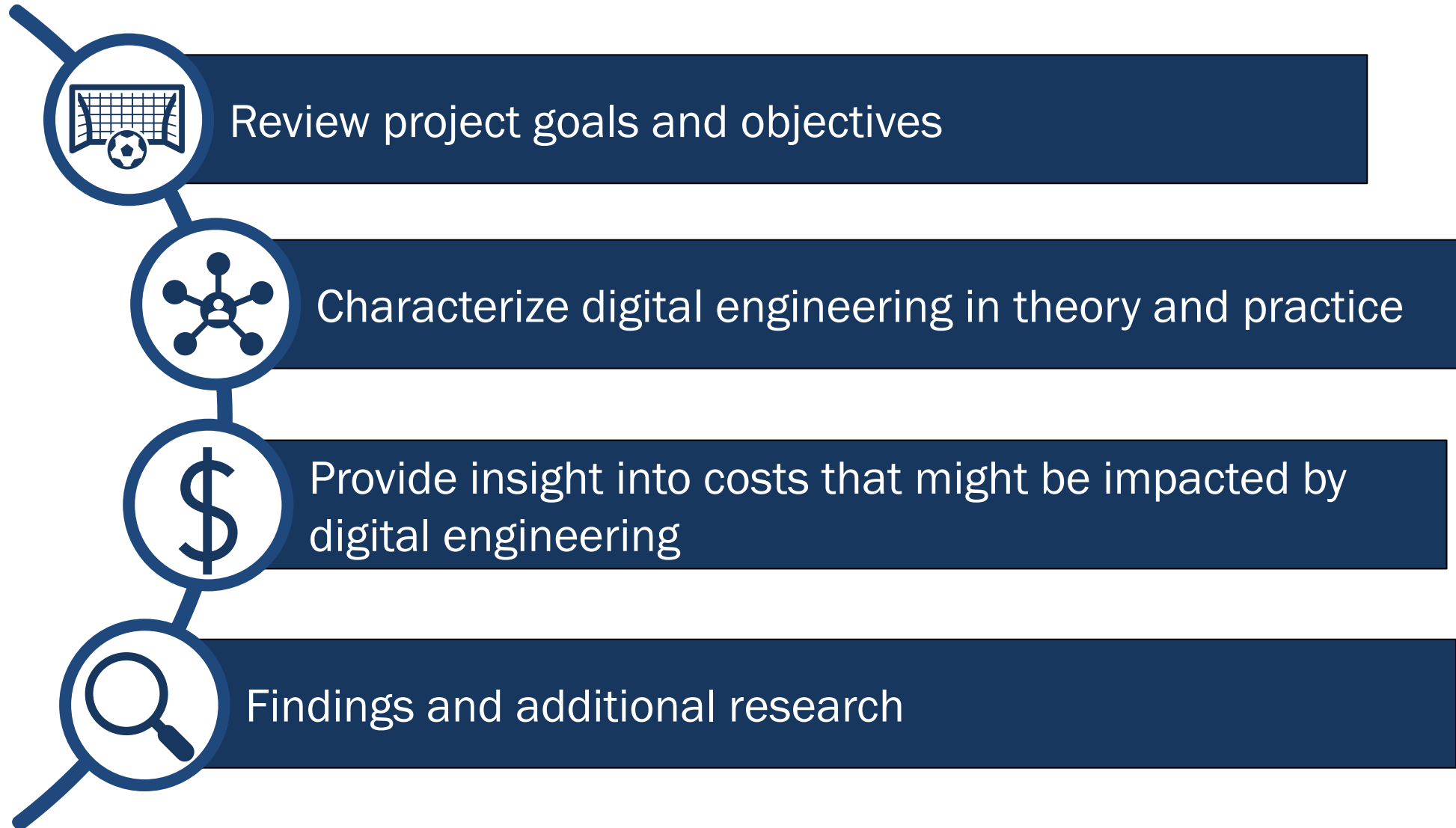
ICEAA OEM COG Brief

Brittany Clayton

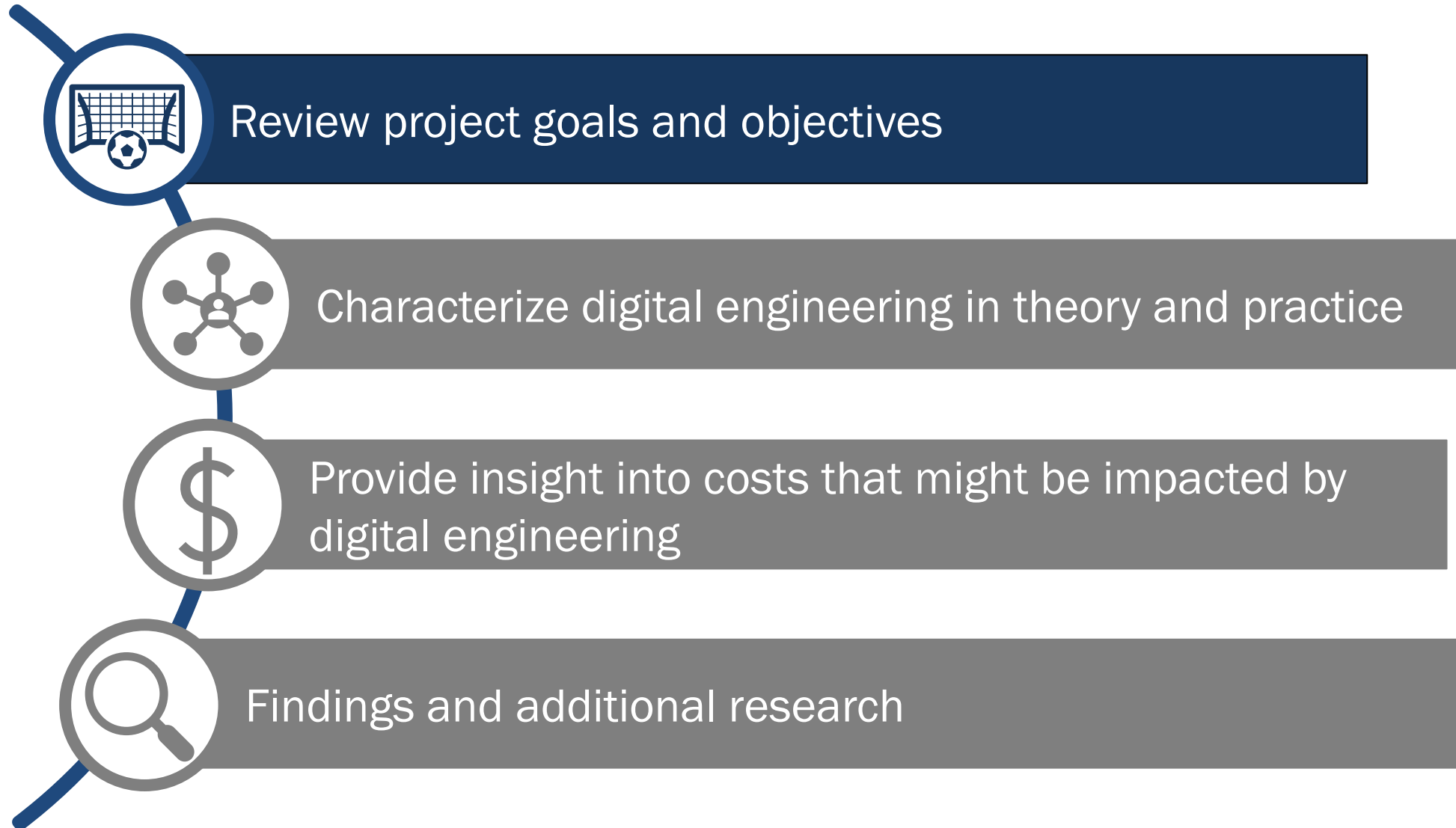
RAND Corporation

November 2023

# Today's discussion will cover several topics



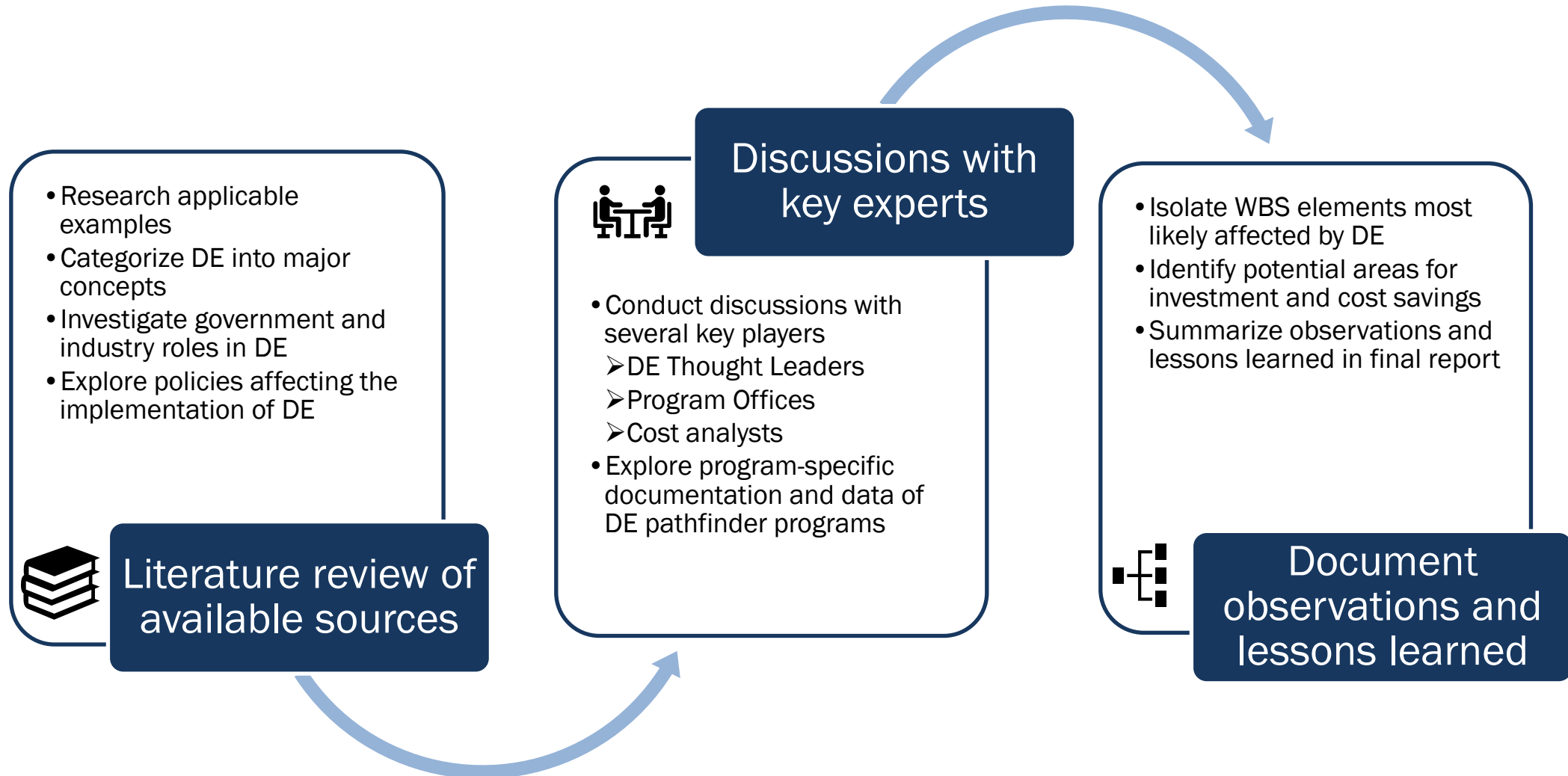
# Today's discussion will cover several topics



# This presentation is based on work performed by RAND Project Air Force (PAF)

- Work was sponsored by Air Force Cost Analysis Agency (AFCAA) and focused on digital engineering (DE) from the cost estimator's perspective
- Multi-disciplinary team included:
  - Principal Investigators: Dr. Thomas Light, Dr. Obaid Younossi
  - Ms. Brittany Clayton, Dr. Peter Whitehead, Dr. Jonathan Wong, Dr. Spencer Pfeifer, Dr. Bonnie Triezenberg
- Initial research conducted between June 2020 – June 2021
  - Rapidly evolving area of study
  - Follow-on study completed and currently being reviewed
- Research questions included:
  - What does DE mean to DAF (and DoD) weapon system programs?
  - How are defense programs implementing DE?
  - Which cost elements will be impacted over the system's lifecycle?

# Our research methodology included collecting and reviewing information and data from relevant literature and experts in the field



# Most cost estimators will need to account for some level of DE implementation as defense programs move toward a more digital environment

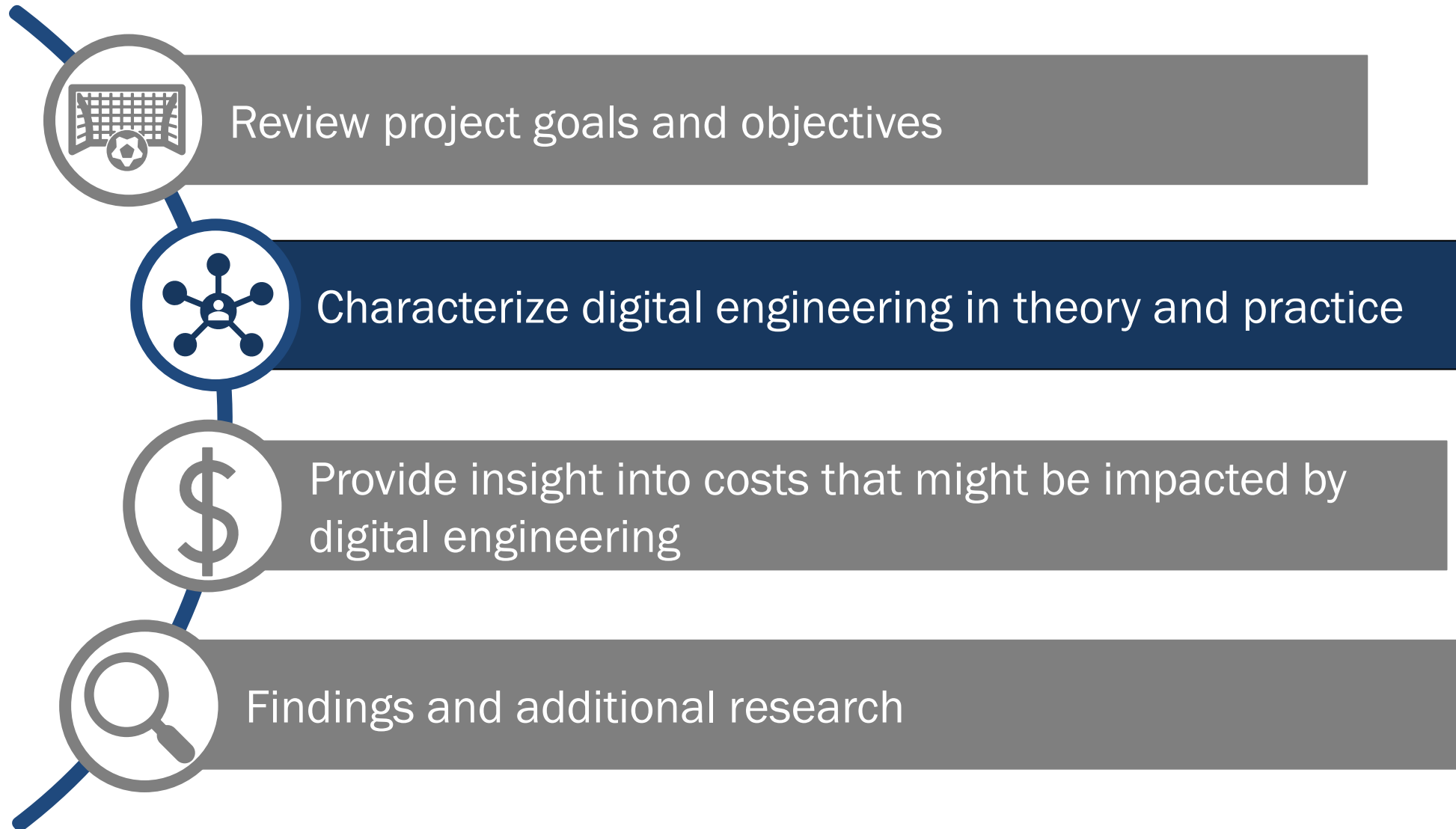
- Defense programs across military services are implementing DE to some extent
- DE implementation has the potential to impact cost analysis tasks
  - Consideration of DE strategies during analyses of alternatives (AoA)
  - Development of system's lifecycle cost estimate
  - Impact on cost benefit analyses for trade-off studies
  - Influence on confidence level during uncertainty analyses

*Audience Challenge:*

*How are you addressing DE in your cost estimate?*

*What additional research needs to be done to successfully incorporate DE cost impacts?*

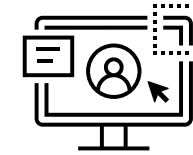
# Today's discussion will cover several topics



# DoD's Digital Engineering Strategy provides a useful starting point for our research

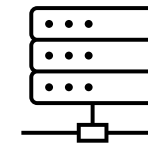
DoD defines digital engineering as “an integrated digital approach that uses authoritative sources of system data and models as a continuum across disciplines to support lifecycle activities from concept through disposal.” (DoD Digital Engineering Strategy (2018), p. 2)

Integrated digital approach



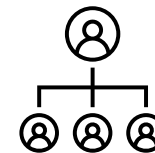
Digital products developed (where possible) that “talk” to each other

Authoritative sources of data and models



One “authoritative source of truth” for program information

Across disciplines



Leveraged by all program stakeholders

Support lifecycle activities



From program initiation through disposal of the system



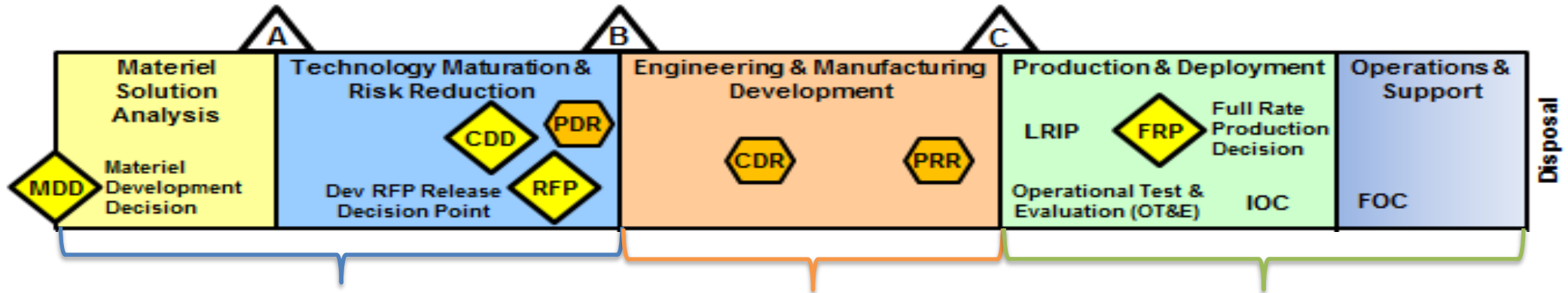
# DAF is pursuing DE implementation, among other similar initiatives

- Policies require DE implementation
- Development of new offices and roles dedicated to the advancement of DE
- Digital initiatives are part of broader efforts to increase speed at which capabilities are developed to meet warfighter needs
  - All aspects of weapon systems are becoming more software-intensive and connected
  - Acquisition is becoming more digitized

*AFI 63-101/20-101:*

“The PM utilizes Digital Engineering (to include model-based systems engineering), modular open system approaches, software-defined capabilities, and commercial standards and interfaces to the maximum extent practicable... For systems in sustainment, the program office should implement model-based systems engineering to the maximum extent practicable.”

# There exist many examples of DE activities that could be pursued through the weapon system lifecycle



- ❑ Establish model-based links between mission capability and system capability during AoA
- ❑ Use modeling to define requirements and acquisition strategy
- ❑ Develop model-centric RFP/source selection/acquisition processes
- ❑ Define data/model requirements that prime must share with government via SysML
- ❑ Develop data/model validation and verification steps
- ❑ Negotiate contract terms for digital deliverables (e.g., data, models, and IP)

- ❑ Establishes in-house DE capabilities and expertise
- ❑ Contractor digitally shares weapon system design models, data, and IP with government
- ❑ Government engages more intensely with contractor to reduce design, development, and verification costs and make tradeoffs
- ❑ Streamline technical review, data reporting, verification and validation, and test and evaluation processes
- ❑ Transition to model-based deliverables

- ❑ Maintain and update data, models, design and manufacturing information and make accessible to stakeholders
- ❑ Use models to inform cost and schedule trades and during the operational testing phase
- ❑ Reflect deployment plans in program models
- ❑ Leverage data/models in the pursuit of predictive maintenance
- ❑ Use models to identify and evaluate future enhancement and technology refresh opportunities

# DE differs across programs, in both definition and implementation

- In practice, we found that no single program was undertaking all of these activities
  - Experts had varying definitions for DE
  - Programs implementing DE in very different ways
- Some of this was dictated by the program's life cycle phase, enthusiasm by program leadership, expertise within the program office, and other considerations

## Program A (TMRR)

- High-fidelity digital models employed, in hopes to achieve several things
  - Support faster deployment times
  - Support smaller batches of iteratively-upgraded platforms
  - Trouble shoot design, assembly
  - Identify issues in maintenance before physical system exists

## Program B (EMD)

- Training simulators designed using digital approaches
  - Model-based engineering
  - 3D design tools

## Program C (EMD)

- SysML-based models used to inform program decisions such as acquisition requirements prior to source selection
- Government reference architecture developed to capture, store, link, and use relevant design data
- Digital twin created for every command-and-control element

# In literature published in 2020, SAF/AQ Leadership believed DE would yield benefits in many areas

	Purported System Benefits	Purported Portfolio Benefits
<b>Cost</b>	<ul style="list-style-type: none"> <li>• More accurate requirements help avoid cost overruns</li> <li>• Iterate designs digitally at minimal cost</li> <li>• Move down cost improvement curve faster</li> </ul>	<ul style="list-style-type: none"> <li>• Commodifies design and process to allow faster cycle and more competition</li> <li>• More development cycles, resulting in less operating and maintenance spending</li> </ul>
<b>Schedule</b>	<ul style="list-style-type: none"> <li>• Gets to a better design faster</li> <li>• More efficient development process</li> </ul>	<ul style="list-style-type: none"> <li>• Allows acquisition system to regain enough speed to support more frequent program starts</li> </ul>
<b>Performance</b>	<ul style="list-style-type: none"> <li>• Enables earlier, more accurate identification of requirements and design</li> <li>• Enables open architecture approach that leads to better enhancements over time</li> <li>• Allows for the creation of designs so complex that they cannot be developed without DE</li> </ul>	<ul style="list-style-type: none"> <li>• Guides portfolio development with greater accuracy in iteration on requirements, maintaining industrial base.</li> </ul>

***Benefits, however, are based on several key assumptions:***

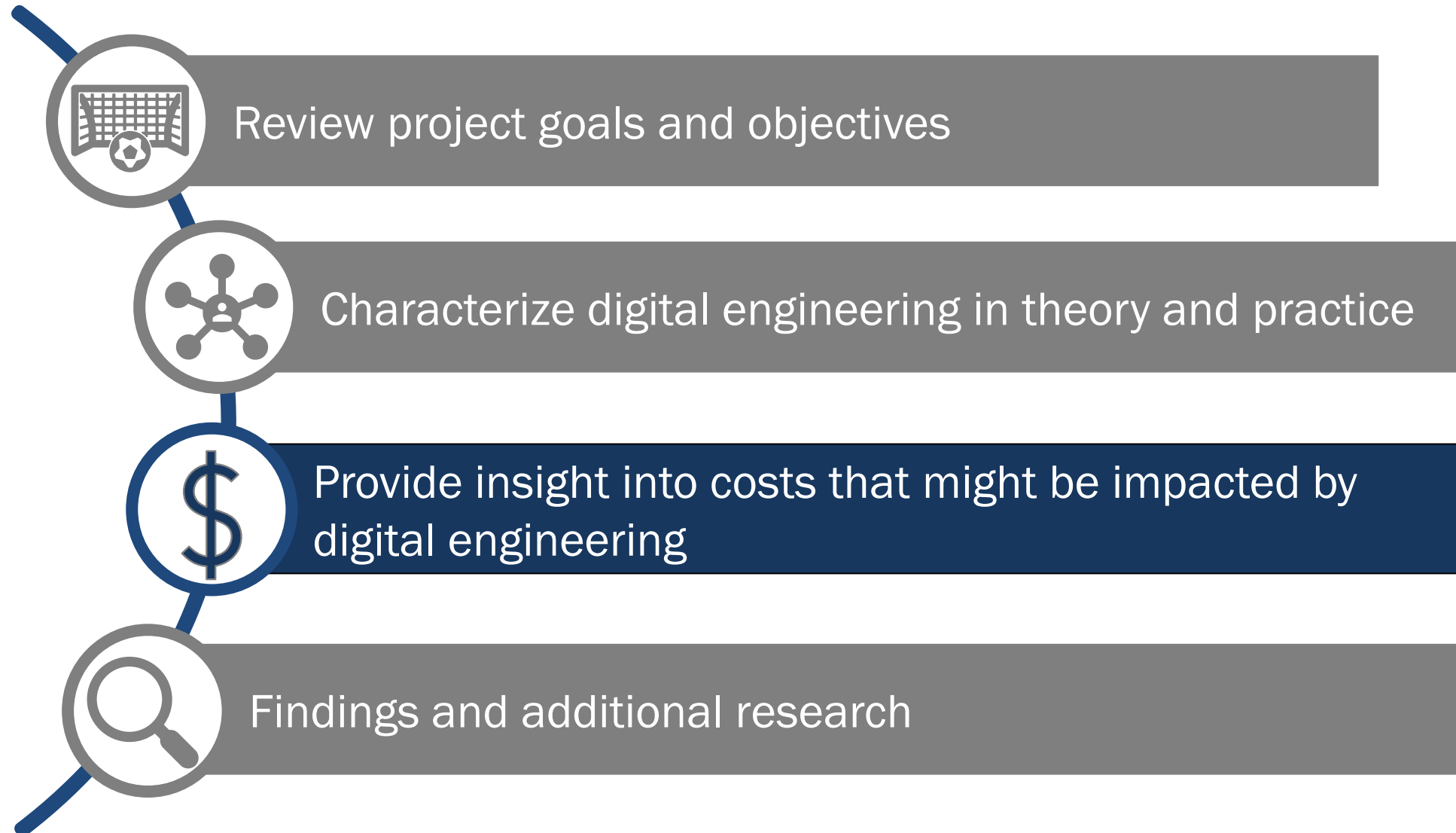
DoD/DAF Execution	Industry	Nature of DE
<ul style="list-style-type: none"> <li>• DE enables acquisition speed that overmatches the enemy</li> <li>• Government can implement at the scale necessary to reap benefits (especially portfolio)</li> <li>• O&amp;M savings at least partially offset RDT&amp;E and Procurement cost increases</li> </ul>	<ul style="list-style-type: none"> <li>• Manufacturing base can design and manufacture to required tolerances</li> <li>• Industry is willing to restructure to play in a more commodified marketplace</li> </ul>	<ul style="list-style-type: none"> <li>• Digital Twin: Models are accurate and robust enough to <i>replace/reduce</i> physical prototyping</li> <li>• Single “Authoritative Source of Truth;” right people have access to right information across disciplines</li> </ul>

# There is plenty of anecdotal evidence of DE and model-based system engineering (MBSE) benefits but almost no verifiable empirical evidence

- **Physical prototyping:** Digital models may reduce (but not eliminate) the need for costly physical prototypes
- **Test and evaluation:** Digital testing may reduce the iterations of physical testing needed, or refine the testing and evaluation plan more precisely, resulting in less spending on test and evaluation
- **Manufacturing:** DE efforts may allow greater optimization of requirements and manufacturing designs
- **Weapon system maintenance and modifications:** The development of digital twins and systematic collection of other weapon system data may aid in future maintenance and modification efforts
- **Weapon system capability:** Digital development enables more (spiral) development efforts, smaller total quantities, and greater diversity of fielded systems
- **IP Ownership to government:** Government will own technical baseline of more weapon systems; this will enable DoD/DAF to share and leverage models and data across acquisition, sustainment, and modernization efforts

A review of 847 papers found that all but 2 papers report perceived benefits of DE/MBSE without evidence and most noted benefits unrelated to cost  
(Henderson and Salado, 2021)

# Today's discussion will cover several topics



# Discussions with cost analysts confirm there are challenges with incorporating DE into the cost estimate

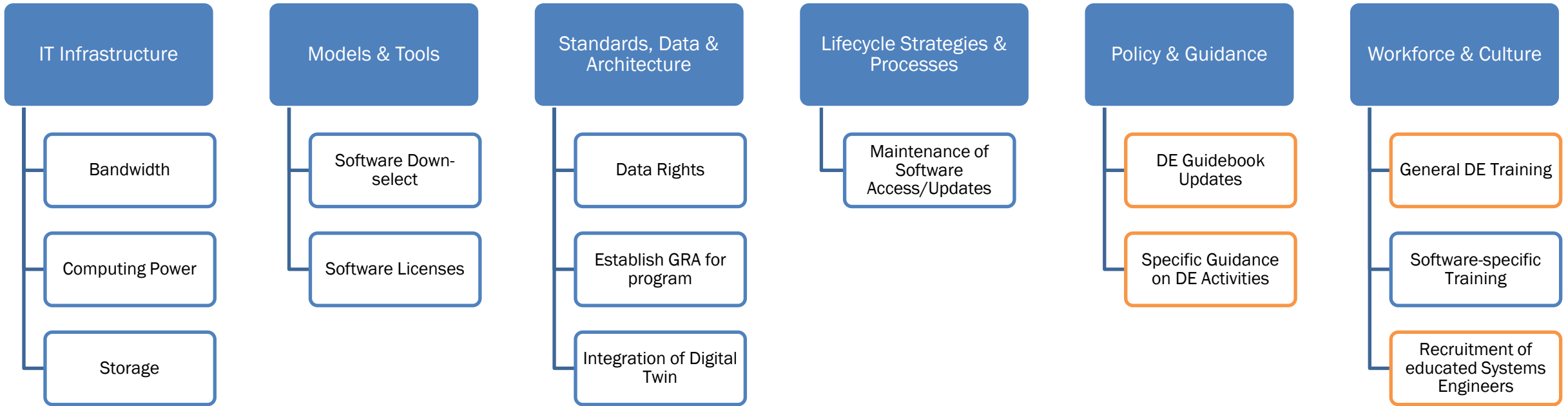
- Uncertainty around what DE means to DAF
  - Familiarity with digital engineering concept varies
  - Challenges with isolating DE from other initiatives (agile acquisition, open system architecture, etc.)
  - Differences in how DE is being implemented by programs
- Confusion around the roles and responsibilities of government vs. contractors
- Concerns that classification levels will create a challenge with integration and sharing of data/models
- Enterprise efforts to support DE (training opportunities, investments in computing power, etc.) are still being defined and not mature
- Limited evidence and no methodology to support adjusting program cost estimates to account for DE

# Discussions from varying perspectives hint at possible broader insights that have implications for cost analysis

Theme	Emerging Observations	Potential cost analysis implications
Definition	Defining DE may depend on what benefits are expected to be gained	Cost analysts may need to <b>work closely</b> w/ program management to understand DE benefits being sought, tailor cost analysis approach to match
Implementation	New paradigms needed to relate digital thread to cost analysis areas of interest	Cost analysis may wish to <b>deliberately take different approaches</b> to leveraging digital threads across different pathfinder programs to accelerate experience and learning
Benefits	Increased weapon system performance may be the most feasible DE benefit gained	Cost analysts may need to adopt a <b>cost avoidance mindset</b> at program level to better understand, contextualize DE investments and potential benefits while looking to measure cost savings at enterprise level
Measurement	Measuring investment costs will be possible; returns may be indirect, difficult to measure	Estimates for discrete investments (training courses, software licenses, etc.) will likely be straightforward. <b>Quantifying downstream or enterprise effects will be more difficult</b>
Stakeholder relationships	Renewed DoD systems engineering role will have program management impacts	Renewed DoD systems engineering role may have cost implications as DoD <b>regenerates expertise</b>



# The Air Force has identified six main areas of focus to accomplish DE



## Examples of investments from SME discussions:

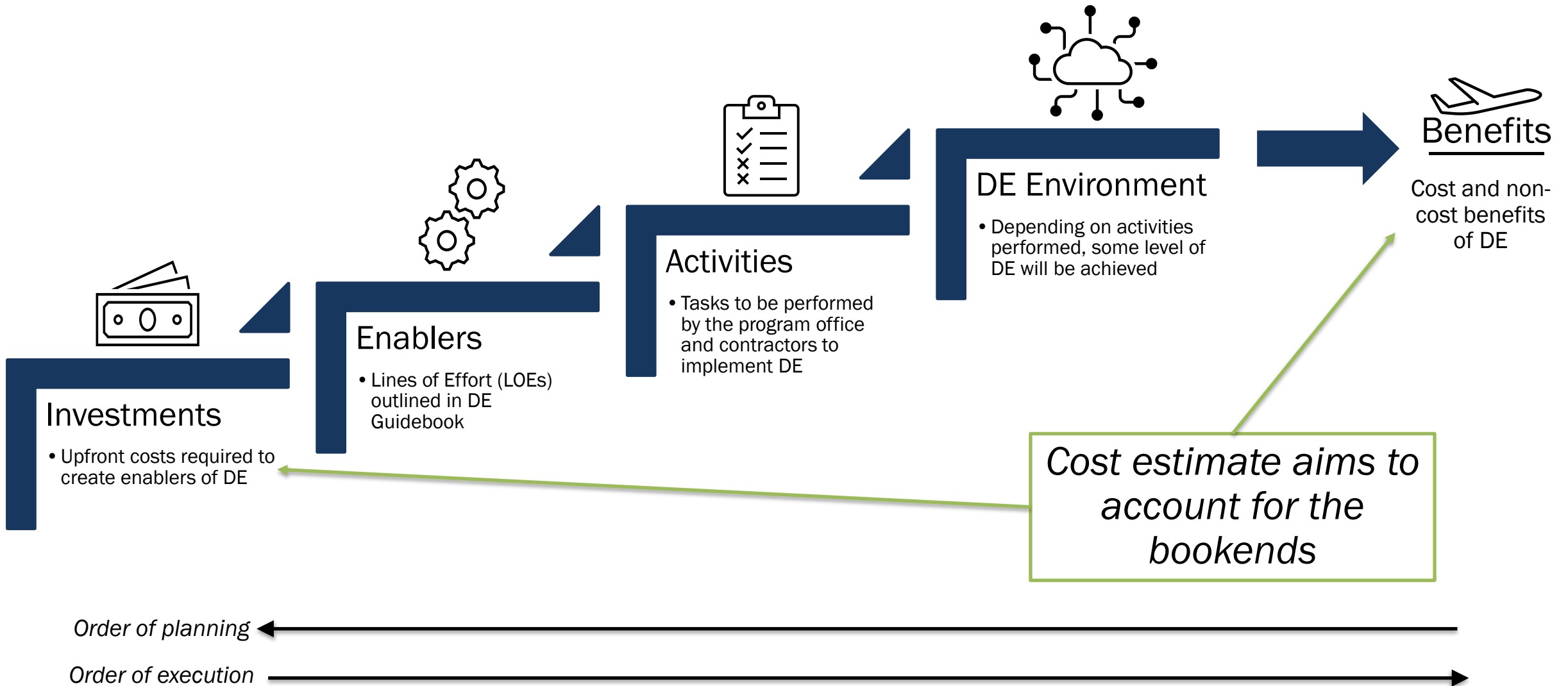
- 1 FTE dedicated to the transport layer including hardware, interconnectivity, connection to cloud, etc.
- 3 FTEs working on MBSE models and the GRA
- Program office training on TeamCenter software package expected to take 18 - 24 months
- Purchase of TeamCenter seat licenses for program office and external stakeholders
- Purchase of PlatformONE licenses, software updates, associated tools, etc.
- Hiring contractors / FFRDCs / UARCs to help with implementation

Responsible Organization:

Air Force Enterprise

Program Office

# Our team developed a framework for considering the costs and benefits of DE



# A generalized process can be repeated across multiple programs working to include DE into the cost estimate

## 1. FAMILIARIZE

Familiarize the cost team with the concepts and goals of digital engineering.

- Digital Engineering Guidebook
- The Digital Air Force white paper

### AF Digital Enterprise Guidebook Table of Contents

This guidebook seeks to provide the reader with information for a program or project to achieve the five AF Digital Enterprise goals. Below are the Chapters (page links) on Digital Enterprise topics to help you create and implement the Digital Enterprise solution that best fits your program.

#### 0. Digital Enterprise

#### I. Background

- Description
- What it is
- General

#### II. Digital Enterprise

- Digital Enterprise
- Digital Enterprise
- Early
- Development
- Program
- Sustained

#### III. Digital Enterprise

- Particular
- Items
- 4. Identify

#### IV. Digital Enterprise

- While it
- Benefits
- That are
- Retained

#### V. Digital Enterprise

- 12 Steps to a successful implementation of a Digital Air Force Program.

#### 1. Define the effort and acquisition strategy that the program will use Digital Enterprise and modeling approaches

- The Air Force program's vision for digital data operations over the life cycle should be captured in a Digital Enterprise

#### 2. Identify

- Our world is entering a new age of technological discovery and advancement. Big data analytics and the Internet of Things are transforming societies and economies, and expanding the power of information and knowledge. Every part of our communities, businesses, and nations will be touched by this phenomenon, including the military forces that protect them.

#### 3. Identify

- These advances are fueling a revolution in how we fight and evolving the character of war. Victory in combat will depend less on individual capabilities, and more on the integrated strengths of a connected network of weapons, sensors, and analytic tools. Today's Air Force must transform to employ the data, technology, and infrastructure we need to prevail. Today's Air Force must transform to employ the data, technology, and infrastructure we need to prevail. We have no choice—we must change to dominate this future.

#### 4. Identify

- To compete, deter, and win over our great power adversaries, we are forging a Digital Air Force that will:

1. Field a 21st century IT infrastructure responsive to the demands of modern combat
2. Leverage the power of data as the foundation of artificial intelligence and machine learning to enable faster decision-making and improved warfighter support
3. Adopt agile business practices that improve the effectiveness and efficiency of our management enterprise

#### 5. Estimate

- While it
- Benefits
- That are
- Retained

#### 6. Estimate

- While it
- Benefits
- That are
- Retained

#### 7. Estimate

- While it
- Benefits
- That are
- Retained

#### 8. Estimate

- While it
- Benefits
- That are
- Retained

#### 9. Estimate

- While it
- Benefits
- That are
- Retained

#### 10. Estimate

- While it
- Benefits
- That are
- Retained

## 2. COORDINATE

Coordinate with your program office to understand how they are implementing digital engineering.

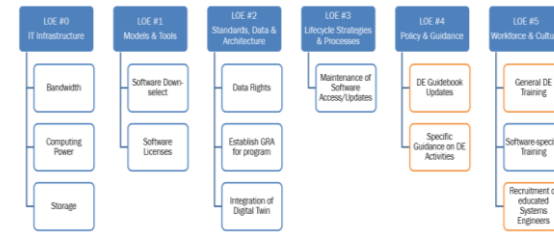
- Understand which activities the program office is undertaking through each phase of the acquisition lifecycle.
- Use the mapping of activities to enablers to identify focus / goals of digital engineering specific to your program.

Count	Activities	Typical Engineering System	MSSE methodology followed	MSSE	LOE #1	LOE #2	LOE #3	LOE #4	LOE #5
1	Develop system and architecture design, components design, integration, model representation (PDF, etc.)	Document-centric approach where models are used for representation and illustration. Paper interface control documents or independent documents (Word, PDF, etc.)	MSSE methodology followed	Model should capture architecture elements, associations, dependencies between elements, interaction between elements, and behavior of elements. System model becomes source for system information, interface control documents generated from the model.					
2	Allocate performance parameters to the elements of the architecture	Allocate performance parameters to the elements of the architecture	Allocate performance parameters to the elements of the architecture	Performance parameters and allocations maintained in document management systems.					
3	Allocate requirements to the elements of the architecture	Requirements traceability commonly performed on high-level requirements. Requirements maintained separately from architecture in requirement management tools such as DOORS and ReqView.	Allocate requirements to the elements of the architecture	Requirements can be maintained in system model or synchronized with requirements tool. Leverage model-based traceability features (e.g., SysML, SysML, SysML) (capability) to allocate requirements to high- or low-level model elements.					
4	Perform government and software process approval	Government performs traditional approval process, such as SCAMP.	Perform government and software process approval	Government approval focuses on the maturity of the contractor's MSSE process.					
5	Develop hardware and software architecture and detailed design	Document-centric approach where models are used for representation and illustration. Paper interface control documents or independent documents (Word, PDF, etc.)	Develop hardware and software architecture and detailed design	Model-based (object-oriented) model development should capture architecture elements, associations, dependencies between elements, interaction between elements, and behavior of elements. System model becomes single source for hardware and software information. Use flow control documents generated from the model.					
6	Allocate requirements to hardware and software design elements	Requirements traceability commonly performed at high level, such as from system to software subsystems or hardware units. System, hardware, and software requirements maintained independently. Not all programs do this currently.	Allocate requirements to hardware and software design elements	Requirements traceability can be improved directly in model through implied traceability or tool-specific traceability features.					
7	Connect and trace to mission assurance guidelines and tools	Validation and verification on the system architecture and requirements through manual inspections and reviews. Prototyping or modeling, analysis, and simulation performed on some low-level components. (How these are different. Both need to be performed.) (How these are different.)	Connect and trace to mission assurance guidelines and tools	Traceability of mission assurance (MIA) guidelines and tools to model elements—requirements, design, test, Assurance Support Digital.					
8	Validate and verify system model appropriate for this stage	Validation and verification on the system architecture and requirements through manual inspections and reviews. Prototyping or modeling, analysis, and simulation performed on some low-level components. (How these are different. Both need to be performed.) (How these are different.)	Validate and verify system model appropriate for this stage	Leverage consistency checkers in MSSE tools. Leverage model-based traceability features (e.g., SysML, SysML, SysML) derived to ensure all elements are derived from requirements. Simulate and validate behavior in models (e.g., sequence diagrams, state machines, etc.). Manipulate for and derive models with appropriate level of detail. Simulate and validate functional properties (e.g., semantics).					

## 3. IDENTIFY

Identify specific investments and benefits applicable to your estimate.

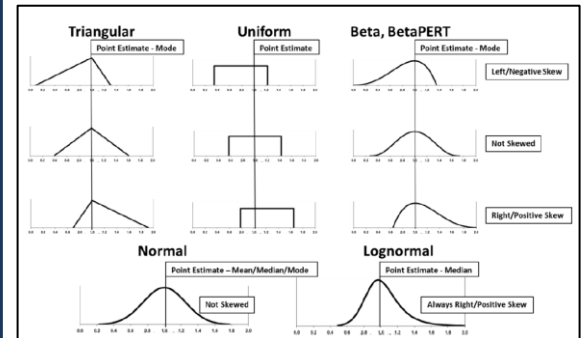
- Investments line up with enablers
- Map investment to your WBS



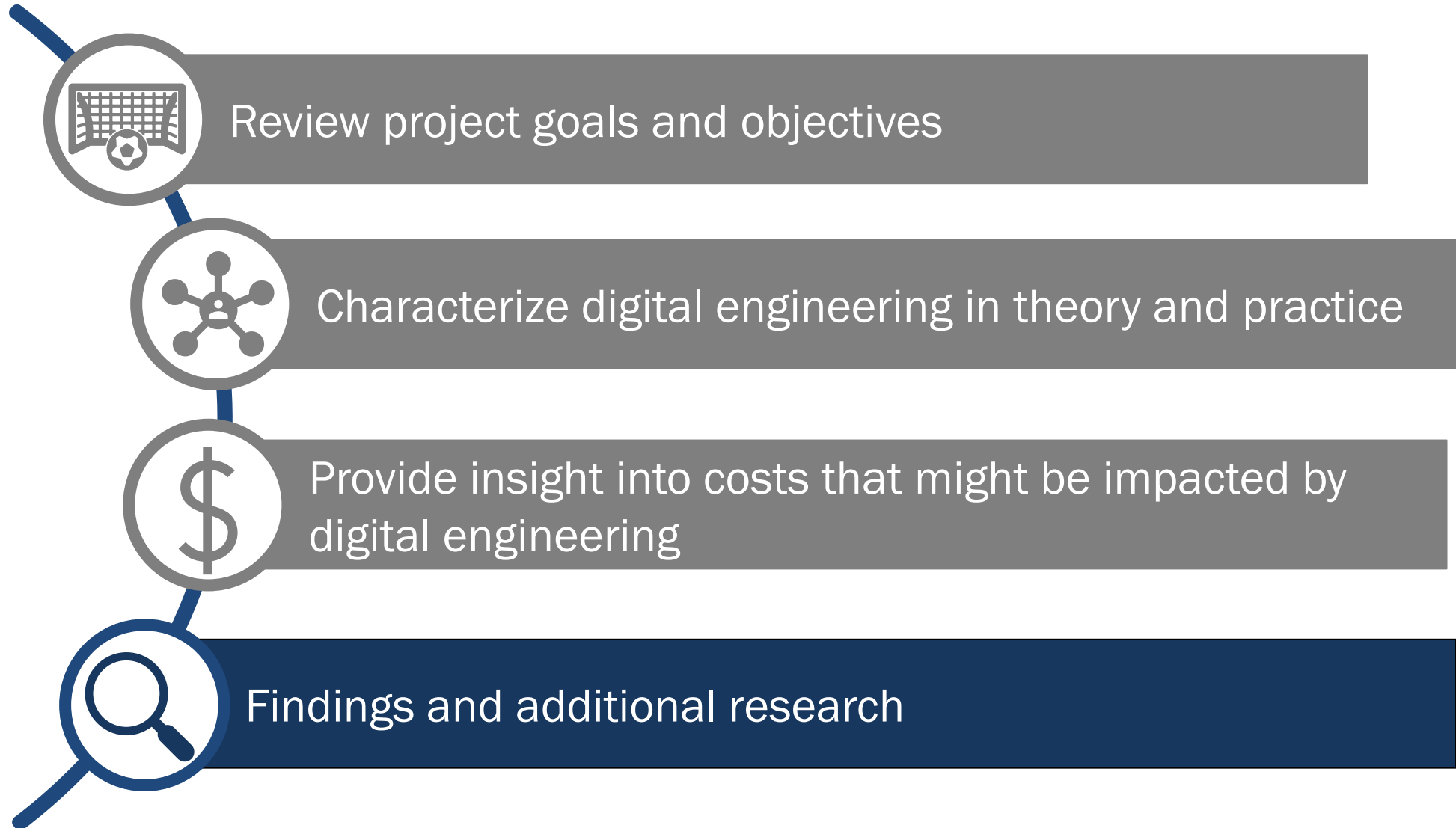
## 4. INCORPORATE

Incorporate investments and benefits into the estimate using a generally accepted approach.

- Adjust the point estimate
- Incorporate into uncertainty analysis
- Develop sensitivity analysis



# Today's discussion will cover several topics



# Initial project reports five major findings

- So far, programs have used tailored implementations of DE to address unique challenges to those programs.
- Before cost savings or other benefits from government DE efforts are realized, there will likely need to be significant investments made by the DoD and/or DAF.
- Investments to support DE will likely impact both contractor and government program office costs.
- DE could be employed for a variety of reasons beyond potential cost savings.
- Although there is plenty of anecdotal evidence, there are almost no verifiable data to inform cost analysis on the magnitude or likelihood of cost savings generated from DE efforts.

# Follow-on work supports findings from initial research and investigates new topic areas

- Continue literature review from initial project
- Conduct deep dives into four pathfinder programs
- Focus on DE implications on the supply chain
- Design and execute a survey to aerospace industry primes and subcontractors that investigated several areas, including:
  - DE activities being pursued
  - Challenges with implementing DE
  - Costs and benefits of DE
  - Metrics being collected

