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George Mason University

From Breakthroughs to the Battlefield

BEST PRACTICES FOR TAPPING INTO THE POWER OF PROTOTYPING

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From Breakthroughs to the Battlefield

Best Practices for Tapping into the Power of Prototyping

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Executive Summary

Prototype: an original model on which something is patterned.

— merriam-webster.com

Prototype: a model (e.g., physical, digital, conceptual, and analytical) built to evaluate and inform its feasibility or usefulness.

— DoD's Prototyping Guidebook

Discussions around prototyping frequently lay blame on the bureaucratic acquisition process for not transitioning the prototype to production; calls for acquisition reform then echo.

This report explores the power of prototyping and how this power can be amplified beginning with the initial breakthroughs continuing all the way to use on the battlefield. What if the benefits of prototyping were better appreciated? What if best practices for prototyping were consistently adopted? What if successful prototyping was defined and measured? Is it time to discuss prototyping reform?

Tapping into the power of prototyping begins with acknowledging the benefits of prototyping are not limited to simply learning fast, furthering knowledge, or even transitioning the prototype to a program of record. Prototyping offers many more benefits. Sometimes, these include improving an existing weapon system. Other times, the power of prototyping lies in enhancing the defense industrial base's manufacturing capacity and efficiency. Prototyping always serves to develop the next generation's workforce.

This report notes that the power of prototyping is realized when certain best practices are adopted. When done right, the best prototyping starts with a customer willing to commit the necessary resources and provide feedback. Best practices for prototyping also include an obsession with understanding the customer's real problem. This, in tandem with questioning legacy requirements in the prototyping effort, ensures tangible results for the customer. Other best practices include an unwavering commitment to digital acquisition, pursuing simple and open designs, using internationally recognized standards, and prototyping iteratively—all critical for a successful prototype. Without this type of comprehensive and collaborative effort between industry, academia, and the customer, prototyping would be limited to exploring technical and engineering dimensions of a problem, with limited ability to drive adoption.

But why do we prototype and what is a successful prototype? Is it the same for every effort? What organization does it best? These questions are often asked—but not answered—by DoD, Congress, and industry. Finding consensus is difficult due to the conflicting definitions of prototyping, and resolving the difference would be a first step towards defining success. Once success is defined, evaluating the outcomes of current efforts is achievable. This then allows for identifying, replicating, and resourcing the most successful organizational models—maximizing the power of prototyping.

To this end, this report offers several recommendations for tapping into the power of prototyping, from breakthroughs to the battlefield. These include:

- Resolving conflicting definitions between DoD, Congress, and industry.
- Measuring success, evaluating outcomes, and then modeling the most successful organizations.
- Leveraging all types of readiness levels to support assessment throughout the prototyping process to include technology, software, manufacturing, and sustainment readiness levels
- Aligning prototyping efforts with stakeholders and Services acquisition strategies.
- Capturing and sharing knowledge across the scientific disciplines to truly learn at the speed of relevance and create prototypes that work today.
- Adopting best practices in all prototyping efforts.

1
Introduction

This report is the result of a partnership between the National Defense Industrial Association's Emerging Technologies Institute and the Greg and Camille Baroni Center for Government Contracting at the Costello College of Business, George Mason University. This unique collaboration between academia and industry seeks to inform a better way of defense prototyping to maximize the impact of taxpayer dollars and put the best products in the hands of the customer. The collaborative research team conducted surveys, organized webinars, held workshops, and arranged one-on-one interviews uncovering the benefits and best practices for successful prototyping, document challenges, and offer a way forward.

SURVEY

Sectors Represented

Over 200 individuals from industry organizations, academia, and government entities responded to the survey distributed through multiple industry and academia electronic mailing lists. All sectors of the defense industrial base were well represented in the survey to include those supporting the individual Services as well as Munitions, Electronics, and Cybersecurity activities. (See Figure 1)

Organizational Types Represented

The survey captured input from a diverse set of organizations including small businesses and primes as well as traditional and nontraditional defense contractors. Academic institutions including federally funded research and development centers (FFRDCs) also participated. While the vast majority identified as part of the defense industrial base, 20 respondents identified as non-defense contractors. (see Figure 2)

WEBINARS, WORKSHOPS, AND ONE-ON-ONE INTERVIEWS

Two public webinars were held featuring discussions between consortia and think tanks as well as former senior DoD officials and congressional staff.[1, 2]

In addition, two workshops were held with a curated group of representatives from both traditional and nontraditional defense contractors varying in size, FFRDCs, academia, and consortia. These workshops focused on four topics to include approaches to prototyping, the contracting process, best practices for successful prototyping, and the expectations for and circumstances leading to follow-on prototyping activities.

Finally, the authors solicited feedback from peer reviewers to ensure the findings were reasonable and the recommendations actionable.

With all that said, the authors see this report as the start of the conversation, not the final word.

1. Greg and Camille Baroni Center for Government Contracting, George Mason University Costello College of Business, *From Breakthroughs to the Battlefield*, July 2023. https://business.gmu.edu/news/2023-07/demand-video-breakthroughs-battlefield-how-prototypes-are-enabling-innovation-future.

2. Greg and Camille Baroni Center for Government Contracting, of Business, The Value of Prototyping for the Defense Industrial Base, December 2023. https://business.gmu.edu/news/2024-01/demand-video-value-prototyping-defense-industrial-base.

Figure 1. Defense Industrial Base Sectors Represented in Survey
(respondents could select more than one choice)

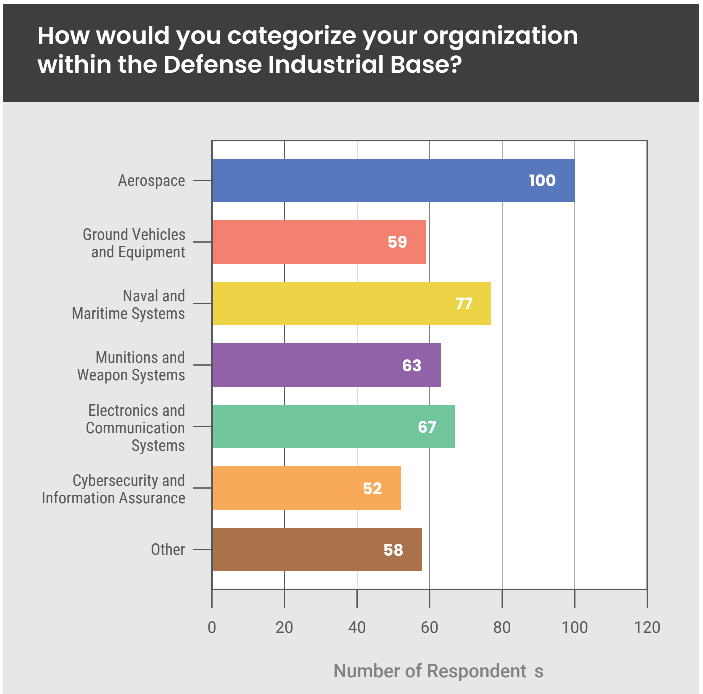
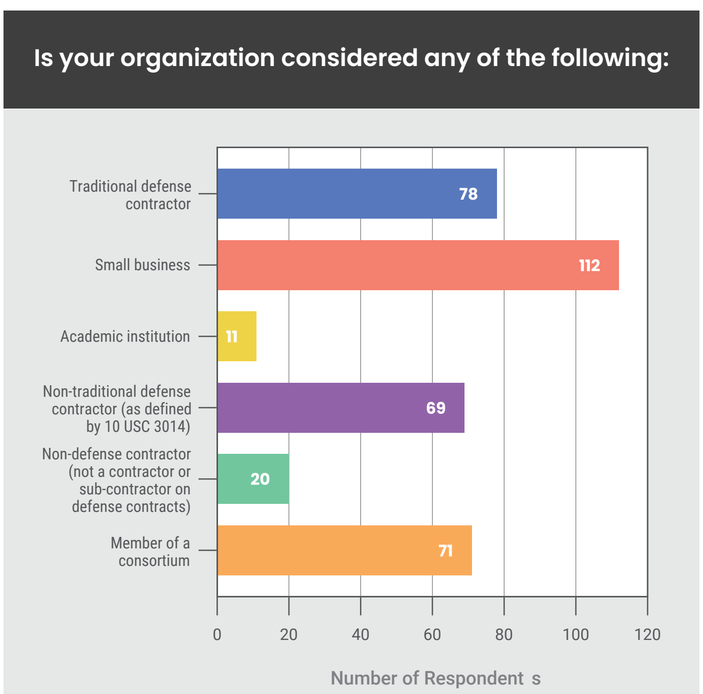


Figure 2. Organizational Types Represented in Survey



2

The Power of Prototyping

One of the key findings of this research is that industry and DOD have differing views of the purpose and power of prototyping. Prototyping often endeavors to learn more about technology, and at other times is intended to drive toward acquisition and procurement of a product. Some of the powers of prototyping are more obvious than others and they range in both actual and perceived impact. When surveyed, industry responded that the power of prototyping lies in transitioning prototypes to programs of records and improving existing weapon systems. In contrast, DoD guidance focuses on the benefits of speed in prototyping to include rapid learning and "failing fast."[1] In between the aspirations of industry and the goals of DoD are several other tangible benefits to include developing the next generation workforce and enhancing the defense industrial base. The power of prototyping can and should be viewed as multifaceted and is amplified when more than one facet is realized in the prototyping effort.

The Power of Prototyping

- Transition to a Program of Record
- Improve Existing Weapon Systems
- Develop the Next Generation's Workforce
- Enhance the Defense Industrial Base's Manufacturing Capacity and Efficiency
- Further Knowledge
- Learn at the Speed of Relevance

TRANSITION TO PROGRAM OF RECORD

From an industry perspective, transitioning a prototype to a program of record is the "holy grail." When industry was surveyed, nearly 40% ranked transitioning to a program of record as the most important metric for a successful prototype. (Figure 3) This position was also supported by the workshop participants in that ultimate success was when the prototype was transitioned to industry to produce a deliverable product. Interestingly, DoD's Prototyping Guidebook does not formally list transitioning a prototype to a program of record as a benefit of prototyping.[2] Although the power of prototyping is multilayered, for industry, the optimal culmination of prototyping activities is transitioning a product to a program of record.

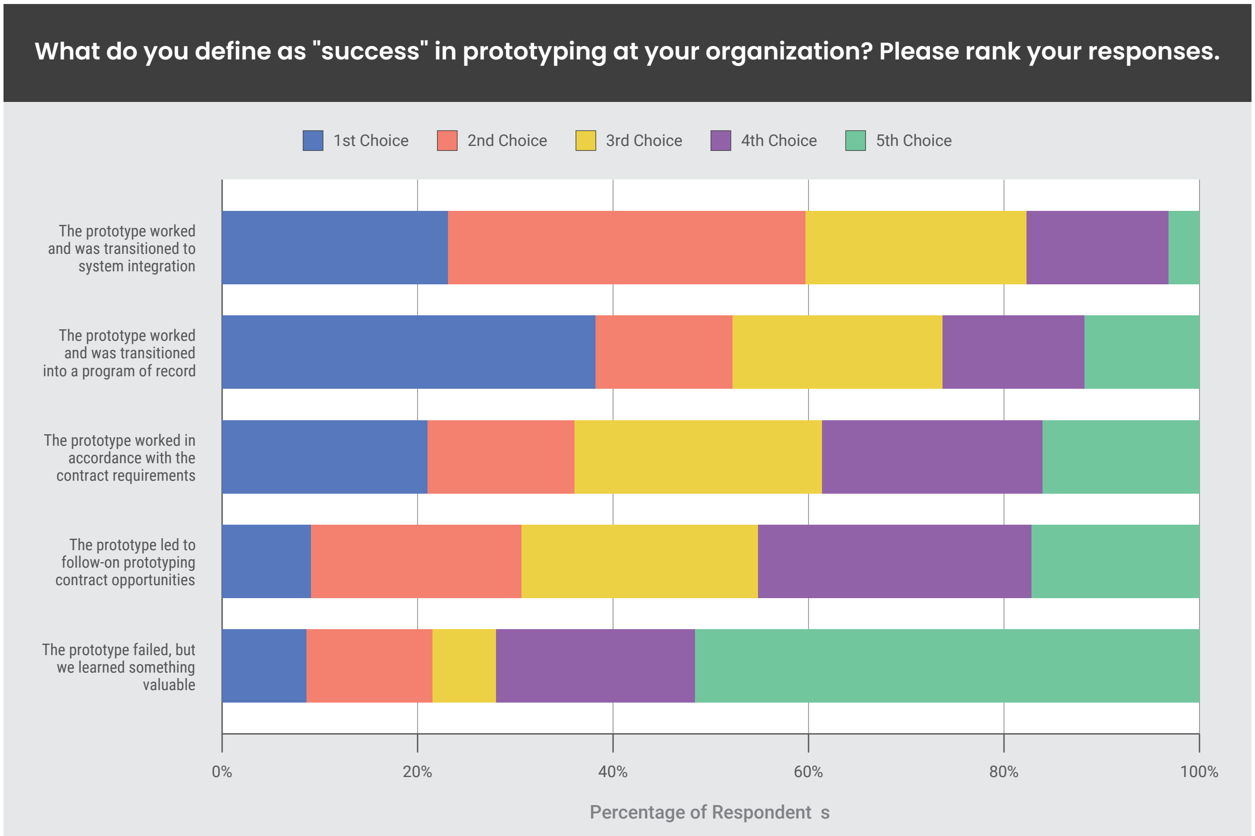
IMPROVE EXISTING WEAPON SYSTEMS

Prototyping efforts often result in improving an existing weapon system. While industry participants are often eager to push to transition a prototype to a program of record, the quickest way to adapt to a changing market or environment is to upgrade an existing system, not deliver a new one. Notably, over 60% of the industry sur-

1. Office of the Under Secretary of Defense for Research and Engineering, *Department of Defense Prototyping Guidebook*, October 2022. https://www.dau.edu/tools/dod-prototyping-guidebook.

2. Ibid.

Figure 3. Definition of a Successful Prototype by Survey Respondents



vey respondents ranked "system integration to improve an existing weapon system" as their first or second choice. This was higher than the number of respondents who chose "transitioning into a program of record" as either their first or second choice for defining a successful prototype. (See Figure 3)

DEVELOP THE NEXT GENERATION'S WORKFORCE

Another often-overlooked power of prototyping is workforce development. Participation in prototyping efforts accelerates the learning and experience of the next generation's workforce as well as provides motivation and sense of meaning. Take for instance, the opportunity for students early in their careers to participate in prototyping activities. These opportunities can inspire a lifelong commitment to a particular field of study or even public service.

The Department of Defense executes fewer large scale prototyping programs compared to the past. This then leads to situations where, for junior professionals, large scale, high priority, high-cost programs, like the next generation bomber (B-21), are the first opportunity to work on the development of a complex prototype.

Prototyping programs also provide workforce experience with systems integration, hardware

Case Study A—Prototyping to Inspire Next Generation of Leaders

The National Defense Authorization Act of Fiscal Year 2020 directed the Department of Defense to establish the Defense Civilian Training Corps (DCTC) to target critical skill gaps necessary to achieve the objectives of the national defense strategy and national security strategy and prepare scholars for DoD careers in fields like acquisition, digital technologies, engineering, and finance.

DoD established the ROTC-like program to prepare future DoD civilians at four universities: North Carolina A&T, Purdue University, The University of Arizona, and Virginia Tech University. The program includes targeted education and development during the school year as well as summer internships.

For the summer internships, scholars are organized into cohorts from different universities and matched with DoD program offices to collaborate on real world problems. Each 8-week internship is project-based and product-focused, in many cases involving the development of a prototype. At the end on the internships, the scholars turn the prototyped product back to the sponsor for continued development which could include involvement of the scholars during their academic year. The summer internship has proven to be the highlight of the DCTC scholar's experience.

Interview with John Willison, AIRC Fellow and DCTC Strategic Partnership Lead

Case Study B—Prototyping Manufacturing Processes for the COVID-19 Vaccine

Manufacturing enough vaccines for every person on the planet had never been done before and manufacturing 100 million doses of a vaccine had also never been attempted. But early in the response to the COVID-19 pandemic, this is exactly what was needed–not just developing an effective vaccine but also the ability to manufacture the vaccine at scale.

Operation Warp Speed, a partnership between DoD and the Department of Health and Human Services, scoped the colossal challenge as a prototype: a prototype to not only develop but manufacture 100 million doses of a vaccine with the ultimate goal of manufacturing enough vaccines for every person on the planet. This approach ensured the development of the vaccine was done with the understanding that the vaccine must be able to be manufactured quickly and within the existing industrial base. Practically, this meant that the materials needed to be sourced quickly, the methods would need to be familiar, the tooling would need to already exist or be built quickly, and the additional workforce could be easily trained.

The first contract was awarded in July 2020 and, the first COVID vaccines were administered in December 2020. While developing the vaccine was monumental, the ability to manufacture at scale was the real triumph of Operation Warp Speed.

and software interfaces as well as human factors engineering. These challenges are best examined through well-designed prototyping efforts. (See Case Study A)

ENHANCE THE DEFENSE INDUSTRIAL BASE'S MANUFACTURING CAPACITY AND EFFICIENCY

Prototyping is often visualized as creating and testing a "widget"—a physical item. However, prototyping can also involve creating and testing a process. Prototyping a manufacturing process is not often top of mind when considering the benefits of prototyping but for a widget to be relevant it needs to be manufactured. A production ready manufacturing process requires sourcing the materials at scale, developing repeatable methods, building the required tooling, and training the workforce. In some cases, prototyping these manufacturing processes is an independent and distinct prototyping effort from creating a widget. Prototyping a manufacturing process is a valuable, albeit underused, activity for expanding the capacity and efficiency of the defense industrial base. (See Case Study B)

FURTHER KNOWLEDGE

Undoubtably, prototyping is a way to further knowledge. Most great scientific advances are rooted in the ability of research to further knowledge, leading to novel real-world applications. Prototyping is part of the feedback loop to help "prove out" these advances. It can shape the customers' awareness of the engineering and cost "trade space," allowing them to be a more discerning and engaged transition partner. It can also serve to shape the customer's understanding of technical possibilities and limitations, improving the quality of requirements generated that drive acquisition programs, and creating knowledge that can shape personnel, training, and maintenance strategies.

LEARN AT THE SPEED OF RELEVANCE

While furthering knowledge is the primary goal of academic research, in many cases the ability to do this at the speed of relevance is even more important. This is especially critical when focused on delivering to a customer in need. Prototyping not only provides the feedback loop but accelerates the cycle time towards further development, production, and use.

3

Best Practices for Tapping into the Power of Prototyping

Recognizing and acknowledging the various benefits of prototyping serves to expand and extend the power of prototyping efforts. However, this is not enough. Fully tapping into this power includes adopting best practices. The following best practices, identified in the survey, webinars, workshops, and one-on-one interviews, lay the foundation for future successful prototyping efforts whether the goal is to transition to a program of record or to simply gain further knowledge.

Best Practices for Tapping into the Power of Prototyping

- Commitment and Collaboration of Resources
- Develop Thoughtful Requirements
- Understand the Real Problem
- Embrace Digital Acquisition
- Pursue Simple and Open Design
- Use International Standards
- Prototype Iteratively

COMMITMENT AND COLLABORATION OF RESOURCES

Commitment and collaboration of resources is key for tapping into the power of prototyping. Resource commitment includes funding but also includes the focus and attention of the government sponsor as well as the customer. A collaborative spirit should accompany this focus and attention, one where the government sponsor and customer works with industry and academia throughout the entire prototyping process.

DEVELOP THOUGHTFUL REQUIREMENTS

Developing thoughtful requirements balances an understanding of the needs of the customer and quality market research. Thoughtful requirements include enough specificity to signal to industry they should invest in the effort. Thoughtful requirements should always question legacy requirements and rationalize them with the current operational environment.

UNDERSTAND THE REAL PROBLEM

Whether a prototype is furthering knowledge or transitioning to a program of record, understanding the technical or operational problem trying to be solved is a best practice. Understanding the problem keeps the focus on the customer and how the prototype will solve their problem. With a focus on the customer, the probability the prototype is successful increases—however success is defined.

EMBRACE DIGITAL ACQUISITION

All prototypes should be "born digital." Digital acquisition is using digital tools to support the acquisition process; an approach where all

*"With MOSA, rather than building a "perfect" closed system, the U.S. can field "good enough" systems and build them up later with rapid and agile technology upgrades. Traditional, closed systems have to be upgraded as a whole, forcing DOD to wait for major upgrades. With MOSA, the Pentagon can incrementally and continually upgrade weapons systems at the pace of technological advancement."**

aspects, both technical and management, of the prototype are digital across the entire life cycle. Digital acquisition is much more than just digital engineering, technical data management, modeling and simulation but encompasses requirements and resourcing, continues through contracting to program management, and lives on in sustainment. Digital acquisition even supports audit compliance and is the thread that ties together all acquisition and prototyping reform.

PURSUE SIMPLE AND OPEN DESIGN

Simple and open designs are key to tapping into the power of prototyping, especially as a path to production. Simple designs are easier to manufacture as well as sustain; simple designs avoid using "unobtanium." Open designs, for example as conceived under Modular Open System Architecture (MOSA) approaches, use common interfaces and are a building block to supply chain resiliency avoiding risks like single and sole source suppliers as well as diminishing manufacturing sources and material shortages. Just like being born digital, simple and open designs should be first principles of prototyping.

USE INTERNATIONAL STANDARDS

If prototyping is viewed as a path to production, internationally recognized standards should be the gravel foundation. Over time, DoD has created their own standards for products and materials. In some cases, military specifications need to be more stringent than non-military standards. In most cases, internationally recognized standards are sufficient. DoD engineers must challenge their use of military standards and shift to using internationally recognized standards whenever possible. This will allow DoD to fully leverage open designs to incrementally upgrade systems. An added benefit is the number of companies participating in the defense industrial base will expand and diversify.

*Al Shaffer and John Whitley, *Modular Open System Architecture allows continuous weapon upgrades* (C4ISRNet, November 2023). https://www.c4isrnet.com/opinion/2023/11/28/modular-open-system-architecture-allows-continuous-weapon-upgrades/.

PROTOTYPE ITERATIVELY

Prototyping should be done iteratively, not only building on what already exists, but continuously experimenting. If the original is the result of the previously identified best practices, then the iterative prototype will simply build on that foundation. If not, the iterative prototype can transition to embracing prototyping best practices. Over time, legacy systems will be digitally reborn with open designs and use internationally recognized standards.

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4
Pain Points in Prototyping

10 USC 4022 – Authority of the Department of Defense to carry out certain prototype projects

(5) The term "prototype project" includes a project that addresses-

(A) a proof of concept, model, or process, including a business process;

(B) reverse engineering to address obsolescence;

(C) a pilot or novel application of commercial technologies for defense purposes;

(D) agile development activity;

(E) the creation, design, development, or demonstration of operational utility; or

(F) any combination of subparagraphs (A) through (E)

Even if all the best practices of prototyping are adopted, challenges exist with realizing the power of prototyping as well as optimizing the use of resources. Conflicting definitions of the purpose of prototyping leads to challenges to measure success, evaluate outcomes, and identify high performing organizational models. These pain points impact DoD, Congress, and industry alike.

CONFLICTING DEFINITIONS

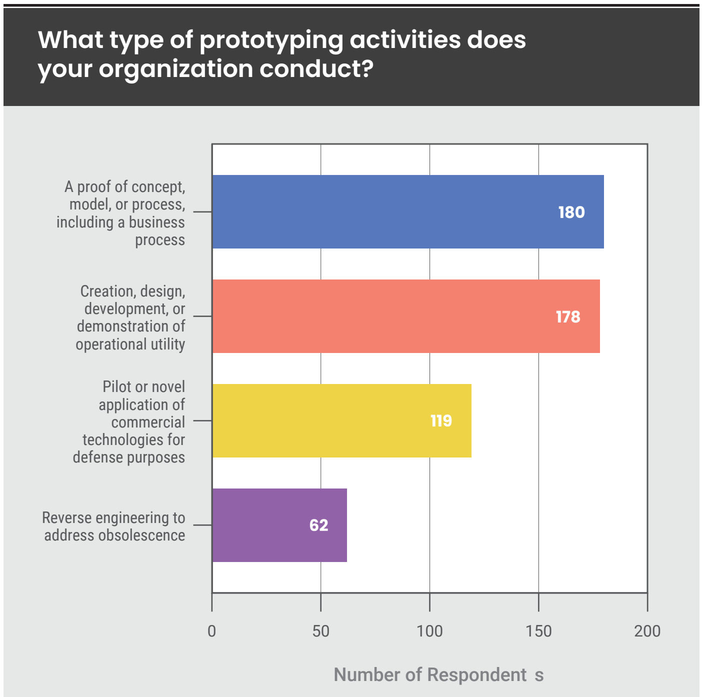
Words matter and definitions matter even more. Definitions create clarity of purpose and focus of effort, and shape incentives for all participants and the evaluation of outcomes. The disconnect between definitions of prototyping leads to misalignment of priorities and resources on behalf of DoD and Congress and misunderstanding of strategic outcomes for industry.

In the DoD Prototyping Guidebook, prototyping is defined as "a model (e.g., physical, digital, conceptual, and analytical) built to evaluate and inform its feasibility or usefulness." DoD's definition of the prototype ends when the feasibility or usefulness is determined. The definition does not include any intent to do anything with this determination.

Congressional use of the word prototyping falls more in line with the dictionary definition of creating a model to be patterned. While there is no official statutory definition of a prototype, statute does describe *prototyping activities* in multiple sections. Section 4022 of Title 10 U.S. Code outlines several definitions of prototype projects to include "the creation, design, development, or demonstration of operational utility." This is aligned with DoD's definition. However, the other projects listed in 10 USC 4022 are more focused on creating something to be patterned: developing a prototype to prove a concept, reverse engineering a part for production, or demonstrating an application of commercial technology.

In recent years, Congress has highlighted the

Figure 4. Prototyping Activities of Survey Respondents
(Options were selected based on the definition of prototyping activities in 10 USC 4022)



need to prototype for a purpose and placed additional requirements for prototyping efforts to promote the creation of minimally viable products[1] and fielded prototypes.[2] Most recently, Congress again defined prototyping when it established the Joint Energetics Transition Office. In the context of energetics, Congress clearly stated its expectations of transitioning prototypes as the purpose of the office.[3] Additional responsibilities of the Transition Office include activities to "mature, integrate, prototype, test, and demonstrate" as well as testing, evaluating, and acquiring novel energetic materials and technologies. All of these are focused-on prototyping for a purpose with a path to production.[4]

While industry doesn't have a formal definition of prototyping, an informal definition was gained for this report through information gathered from the survey, webinars, workshops, and interviews. Not surprisingly, industry's definition of prototyping is more in line with the dictionary definition as well as statutory views that prototypes are original models to be patterned. When surveyed on participation in the prototyping activities outlined in 10 USC 4022, industry supported "creation, design, development or demonstration of operational utility" as much as it participated in "proof of concepts, model or processes." Only half of the activities were for a "pilot or novel application of commercial technology" and just a quarter were for "reverse engineering to address obsolescence." (See Figure 4)

DISAGREEMENT ON WHAT CONSTITUTES SUCCESS

The conflict among the definitions of prototyping used by DoD, Congress, and industry leads to ambiguity in purpose and more importantly in what constitutes success. DoD's definition suggests rapid learning and failing fast to learn constitutes success. However, this is not how industry views a successful prototype. When industry was asked to define a successful prototype, over 50% of the industry survey respondents viewed

1. 10 USC Ch. 205 Front Matter, *Software Development Pilot Program Using Agile Best Practices*, enacted on December 12, 2017.

2. 10 USC Ch. 221 Front Matter, *Middle Tier of Acquisition for Rapid Prototyping and Rapid Fielding*, enacted on December 20, 2019.

3. FY24 NDAA, Section 241, *Establishment of Joint Energetics Transition Office*, codified in 10 USC 148.

4. 10 USC 148, *Joint Energetics Transition Office*, enacted on December 22, 2023.

a failed prototype, even if it provided further knowledge, as the *least* successful prototyping effort. (See Figure 3) Instead, industry defines success as transitioning to a program of record and integrating the prototype into an existing system. It is worth noting that the DoD definition of failing fast may lean more towards finding disruptive technologies than the industry definition, which seems to seek an outcome that can lead to continued revenue streams under development or procurement programs.

ABILITY TO EVALUATE OUTCOMES

Evaluating the outcomes of prototyping efforts is difficult without clear measures of success. Typical current prototyping programs do not have formal evaluation or reporting requirements. In comparison, DoD annually evaluates and reports the outcomes of its high priority testing activities in Operational Test and Evaluation Reports,[5] and major defense acquisition programs are evaluated through annual Selected Acquisition Reports by their cost, schedule, and performance outcomes.[6] However, there are limited examples of data collection and reporting on outcomes of prototyping efforts and those that are reported are scattered in annual reports and testimony, or independent assessments made by the Government Accountability Office (GAO) or other organizations. Prototyping activities should be evaluated and reported in a comprehensive manner—publicly to the extent possible. Without a comprehensive approach to evaluating the outcomes of prototyping efforts, determining follow-on investments based on prototyping efforts is challenging for DoD, Congress, and industry.

ASSESSMENT OF ORGANIZATIONAL MODELS

Many DoD organizations fund the development of prototypes. Certainly, some organizations are more successful than others. However, the lack of metrics on what constitutes success makes it difficult to assess these organizations or even identify organizational best practices. Assessing the most successful organizational models and practices in concert with evaluating prototype successes would enhance the ability of DoD, Congress, and industry to determine where to allocate future investments.

RESOURCE REQUIREMENTS

Successful prototyping requires a commitment of budget, personnel, and research, manufacturing, and testing infrastructure. More realistic prototyping, well connected to real world operational challenges and constraints, will generally also require more exquisite engineering and testing capabilities. Agile software programs, which prototype with frequent cycles and require the participation of technology developers, acquisition experts, and operational users are extremely personnel intensive. Additionally, timely prototyping can often be misaligned with DoD's regimented, bureaucratic, and slow budget request and appropriations processes. All of these resource issues can increase the difficulty of DoD and industry effectively executing prototyping programs.

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5. The Office of the Director, *Operational Test & Evaluation, DOT&E Annual Reports.* https://www.dote.osd.mil/annualreport/.

6. Department of Defense, *Selected Acquisition Reports.* https://www.esd.whs.mil/FOIA/Reading-Room/Reading-Room-List_2/Selected_Acquisition_Reports/.

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5

Prototyping Organizations and Funding Across the DoD

Many DoD organizations have activities focused on prototyping, from consortia to FFRDCs to innovation hubs. A closer look at the organizational models, how they operate, and how they are funded can provide a starting point for assessing the most effective, capturing lessons learned, and improving outcomes.

CONSORTIA

Leveraging the consortia model is a popular choice for DoD Research Development, Test, and Evaluation (RDT&E) organizations to conduct prototyping efforts. As detailed in *The Power of Many,*[1] government sponsors use the consortia model to access industry and academia for a particular technology area. Comprised of three entities: the government sponsor, the consortium, and the consortium management firm (CMF), most consortia models use other transactions (OT) authority as their contracting vehicle. Other Transactions can require significant participation of nontraditional defense contractors creating access for DoD to an expanded defense industrial base. In 2022, a survey of 12 of the 42 existing consortia revealed there were over 4,500 companies who did not traditionally work with the DoD participating in those consortia.[2]

Another benefit of the consortia model is the partnership with consortium management firms (CMF). CMFs provide administrative functions for both the government sponsor and industry, including nontraditional defense contractors. The CMF functions often include managing the solicitation process, program management, invoice receipt and payments. When used appropriately, CMFs can provide support and surge capacity to the government acquisition workforce. (See Table 1)

The consortia model promotes collaboration between industry and the government sponsor. When surveyed on the most important aspects of a successful prototyping contract, industry respondents overwhelmingly ranked communication with the government sponsor as the most important. (See Figure 5) Access to follow on contracting opportunities—something which consortia-based OTs provide—was the next most important. Rounding out the top three most important inputs for successful prototyping was time to award.

One challenge faced by the DoD is transparency of its use of other transaction authorities, especially when leveraged in a consortia model. If DoD collected and reported this information, the impact, effectiveness, and outcomes of the con-

1. *The Power of Many: Leveraging Consortia to Promote Innovation, Expand the Defense Industrial Base, and Accelerate Acquisition*, Baroni Center for Government Contracting, School of Business, George Mason University, July 2022. https://business.gmu.edu/news/2022-07/power-many-leveraging-consortia-promote-innovation-expand-defense-industrial-base-and.

2. 10 USC 4021, 4022, and 4023 outline the conditions to be met for using other transaction authorities.

Table 1. Examples of Consortium Management Firm Functions

For the Government	For the Consortium
• Solicitation Preparation/Webinars • Submission Portals • Whitepaper & Proposal—Receipt/Compliance Review • Award Processing/Cost Analysis Support • Project Administration/Close-out • Milestone/Deliverable Tracking • Invoice Receipt/Payment • Technical and Financial Reporting • Nontraditional Tracking/Reporting	• Consortium Leadership Support • Member Training and Mentoring • Collaboration Portal and Website • Collaboration Events/Membership Meeting • Member Application Processing • Member Database (DD-2345, “good standing” tracking) • Dues/Assessment Invoicing and Collection • Program Status & Financial Reporting • Conferences/Booth

Interviews with Advanced Technology International (ATI), a consortium management firm.

Figure 5. Most Important Characteristics of a Contract to Survey Respondents

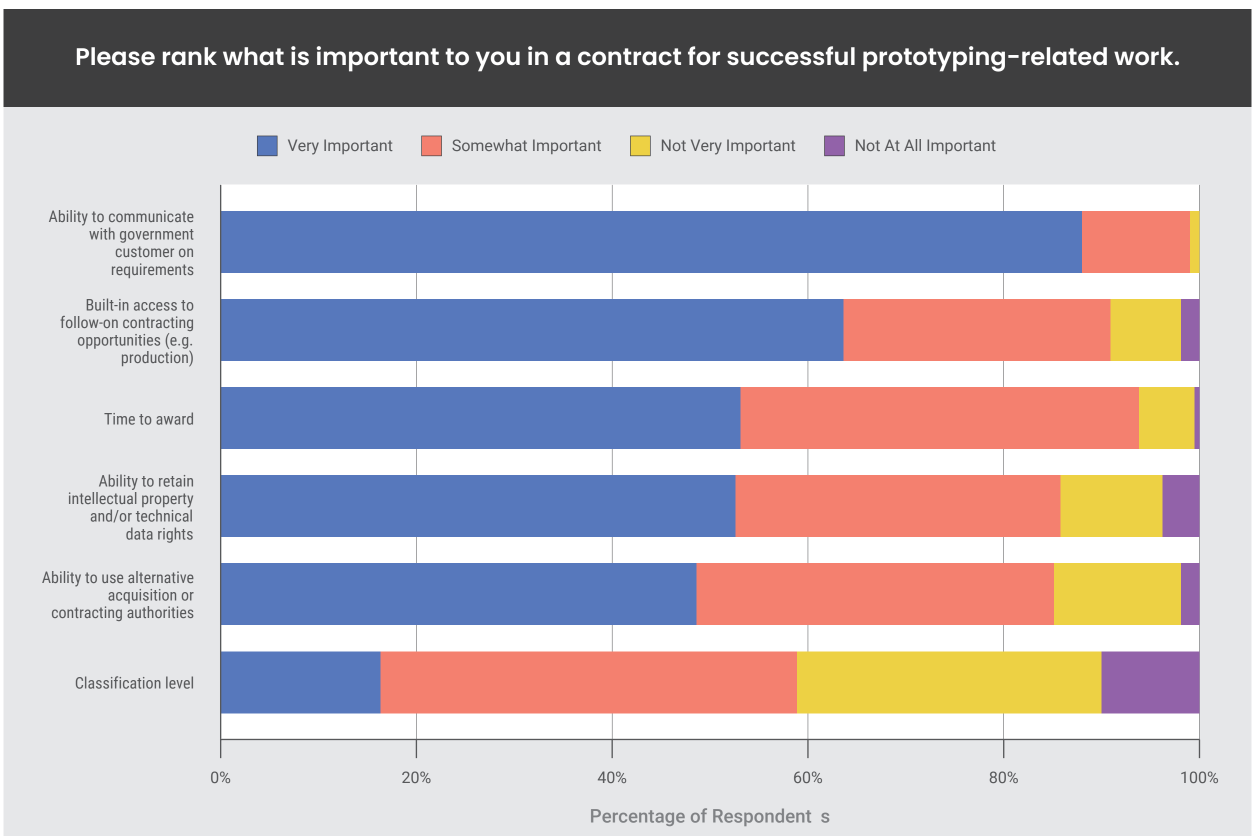
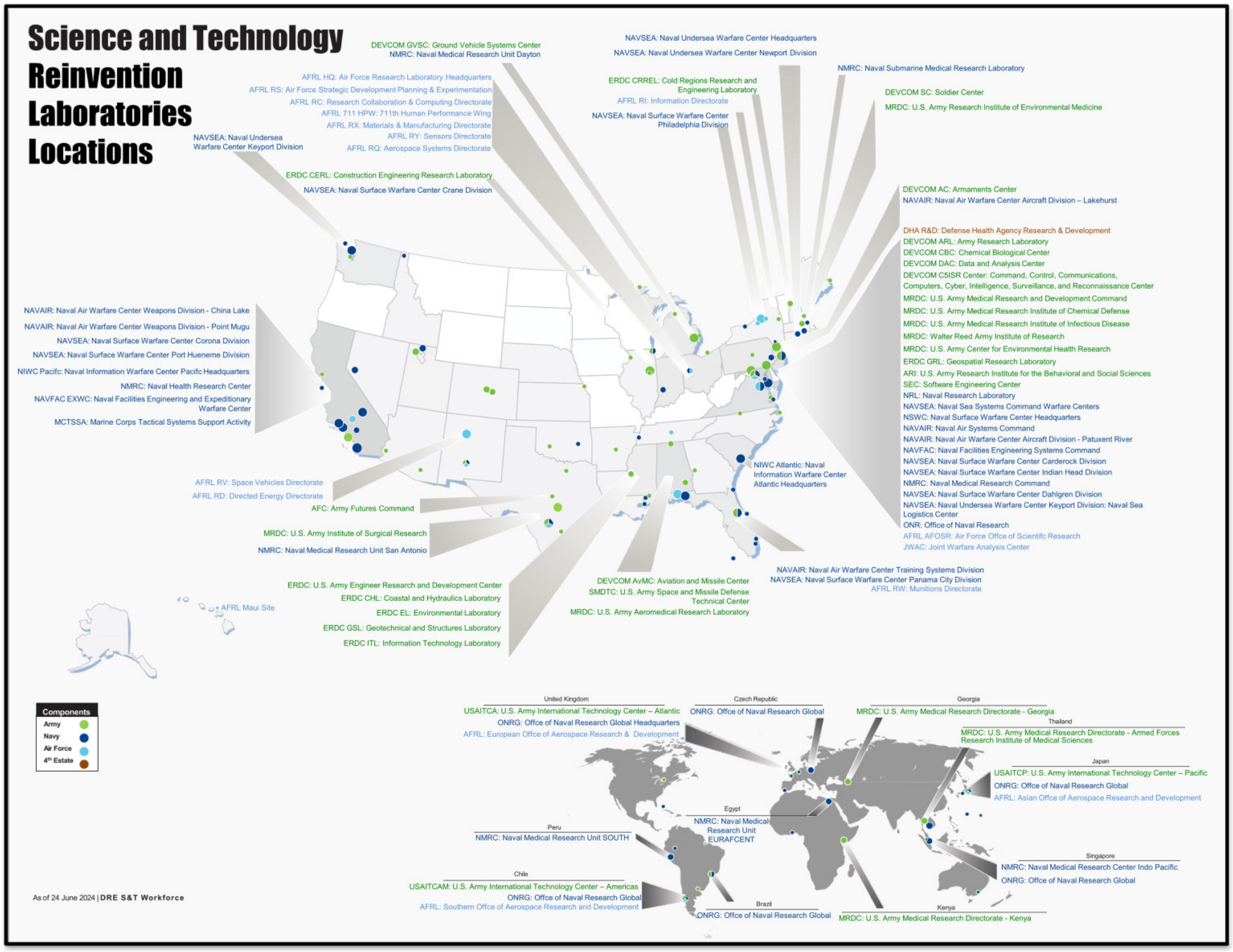


Figure 6. Defense Laboratory Enterprise (Academia, Labs, FFRDCs)



Department of Defense, Science and Technology Reinvention Laboratories Locations, https://rt.cto.mil/rtl-labs/

sortia model prototyping efforts could be better evaluated and used to improve the execution of activities.

Many consortia provide visibility of individual solicitations, awards, awardees, and amounts of awards on their individual websites. However, DoD does not report these awards in a consolidated, online, publicly available location even though Congress has directed DoD to report on the activities for many years. Most recently, Section 825 of the Fiscal Year 2022 National Defense Authorization Act (NDAA), (10 USC 4021 Notes), directed DoD to collect and report the use of other transaction authority as well as any individual task orders awarded under each consortium's overarching other transactions agreement in a consolidated online publicly available location. Statute specifically directed the General Services Administration (GSA) to create the necessary fields in the Federal Procurement Data System (FPDS) and for DoD to report the data in FPDS. While GSA has created the fields, they remain blank from the lack of input from the government personnel.

DEFENSE RESEARCH AND ENGINEERING ENTERPRISE

The Defense Research and Engineering (R&E) Enterprise (See Figure 6) includes both the funders and performers of research and development activities, such as Service laboratories, warfare centers, and engineering centers, large and small businesses, universities and research centers, FFRDCs, and University Affiliated Research Centers (UARC). The Defense R&E Enterprise conducts forward-looking research and development but also has missions to support technical needs of operational units and the acquisition community, transition new technologies and innovation into acquisition programs to address defense requirements, and transfer technologies into the private sector for commercialization or further development and systems integration. Laboratories are primarily organizationally aligned to the Services and operated by the Army, Navy, Air Force, and Defense Health Agency. Each organization participates in a range of prototyping activities, either performing the engineering and technical work internally, funding such activities in other government or private sector organizations, or working in partnership with external partners.

DEFENSE UNITS AND AGENCIES

Several defense agencies conduct prototyping activities, including the Defense Innovation Unit (DIU). DIU has a mission to leverage commercial technology for national security missions and awards funds for research and prototyping efforts.[3]

The Defense Advanced Research Projects Agency (DARPA) is another agency that supports defense innovation, and historically leverages high-risk, high-reward awards for external research. DARPA currently has about 250 active programs. DARPA's activities range from basic research to systems-level prototyping, including funding complex prototypes (such as unmanned systems, satellites, and battlefield networks). Historically, DARPA prototyping activities have led to modern military capabilities, such as stealth aircraft, precision munitions, and tactical networking systems.

Another government organization, the Strategic Capabilities Office (SCO), focuses on existing DoD systems and invests in repurposing them as complex prototypes for future conflict through "application to new missions, integration with other systems, incorporation of recent technology, or adoption of non-traditional operational concepts."[4]

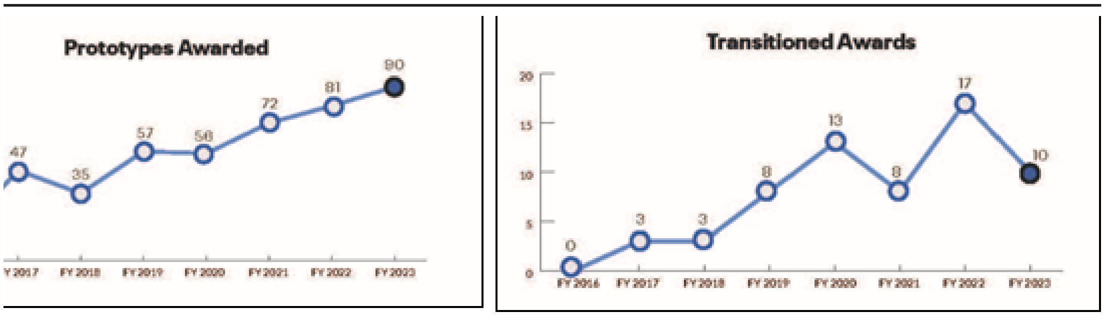
Considerable prototyping activity of relevance to DoD occurs in the private sector as well, sometimes funded by DoD's extramural research programs and sometimes through industry independent research and development (IR&D) or other private sources. This often occurs at engineering centers such as those found within major research universities, FFRDCs, UARCs, and in the corporate research labs of large defense and commercial firms.

Each of the government agencies, along with the Military Services science and technology programs, invests considerable resources in prototyping activities with the intent of transitioning systems or capabilities into acquisition programs and then to operational use. It is difficult to mea-

3. Department of Defense, *Defense Innovation Unit Commercial Solutions Opening*, March 2020. https://sam.gov/opp/e00f6563e0c84a04adc0a36215663e15/view.

4. Department of Defense Directive 5105.86, Director, Strategic Capabilities Office, November 2016. www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/510586_dodd_2016.pdf.

Figure 7. Defense Innovation Unit Prototypes Awarded and Transitioned



Department of Defense, The Defense Innovation Unit FY 2023 Annual Report, https://downloads.ctfassets.net/3nanhbfkr0pc/57VfnQbajgWdONRicxv6nG/44f831e7a0e857bb8494508f8571fd71/DIU_Annual_Report_FY2023.pdf

sure the effectiveness of these efforts due to a lack of data collection, common language and metrics, and the cost of such collection and analysis. A 2015 GAO report on DARPA transition of technologies, for example, found that ". . . inconsistencies in how the agency defines and assesses its transition outcomes preclude GAO from reliably reporting on transition performance across DARPA's portfolio of 150 programs that were successfully completed between fiscal years 2010 and 2014. These inconsistencies are due in part to shortfalls in agency processes for tracking technology transition."[5] Specifically, DARPA's process for tracking transition outcomes does not include technology transitions that occur after a program is completed. This is a gap in tracking that the science and technology community struggles with generally, as there is no contractual requirement for reporting during this time frame.

One effort to track prototyping activities can be found in DIU's annual report, which includes metrics on program activities, to include the number of solicitations, proposals, and awards as well as time to award. Additionally, DIU reports on the number of prototypes transitioned to production. In 2023, DIU made 90 prototyping awards for a total of $298M. Ultimately, 10 of those 90 transitioned to production, with DIU's definition of transition being ". . . when the prototype successfully completes and results in a production or service contract with a DoD or U.S. government entity."[6] (See Figure 7) To support more effective prototyping and transition of the products of prototyping activities more organizations should be reporting on their achievements and lessons learned as well as what constitutes success needs to be defined.

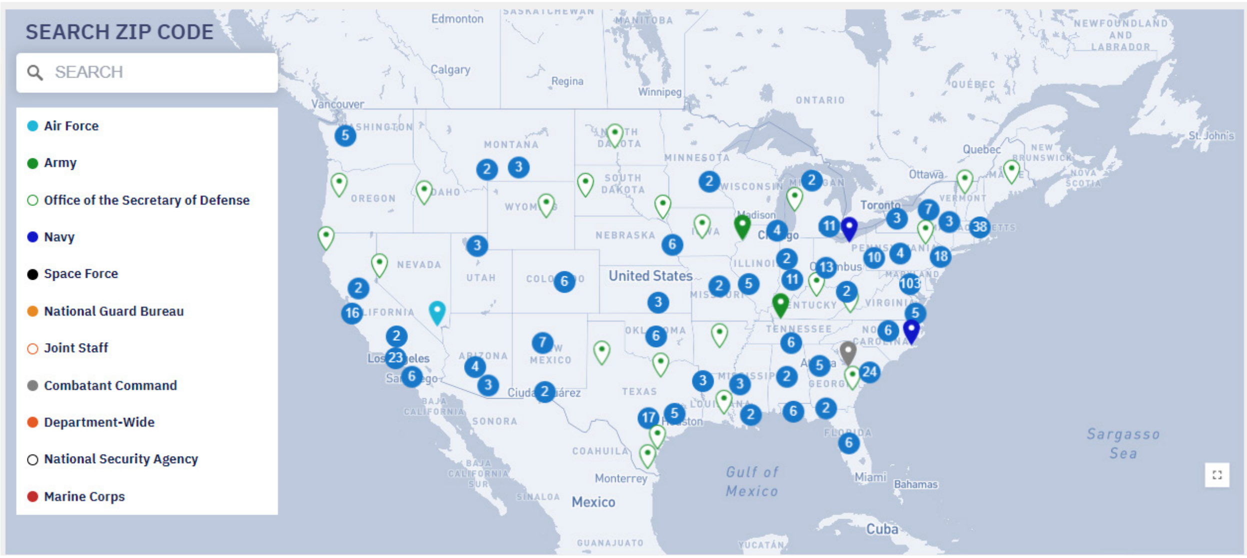
INNOVATION ORGANIZATIONS

According to DoD's Chief Technology Officer, there are 300 organizations that make up the "innovation pathways" across the DoD (see Figure 8). Visibility into the consolidated activi-

5. Government Accountability Office, *Defense Advanced Research Projects Agency, Key Factors Derive Transition of Technologies, but Better Training and Data Dissemination Can Increase Success*, November 2015. https://www.gao.gov/assets/gao-16-5.pdf.

6. Department of Defense, *The Defense Innovation Unit FY 2023 Annual Report.* https://downloads.ctfassets.net/3nanhbfkr0pc/57VfnQbajgWdONRicxv6nG/44f831e7a0e857bb8494508f8571fd71/DIU_Annual_Report_FY2023.pdf.

Figure 8. Department of Defense Innovation Organizations



Department of Defense, Office of the Under Secretary of Defense for Research and Engineering, Map of Innovation Organizations, https://www.ctoinnovation.mil/innovation-organizations.

ties of the innovation organizations is difficult and assessing the results of these activities is even more challenging. As a first step to evaluate outcomes of prototyping, Congress directed the Under Secretary of Defense for Research and Engineering to report on transitioning innovation efforts for critical technologies in Sec. 217 of the FY21 NDAA. Surprisingly, DoD's report to Congress is marked as controlled unclassified information (CUI) even though much of the activity at the innovation organizations is conducted at an unclassified level and in partnership with nontraditional defense contractors, commercial firms, and universities. Interestingly, the DOT&E Annual Reports[7] and Selected Acquisition Reports,[8] which are more focused on near-term capabilities and ongoing acquisition efforts, are unclassified and publicly available online.

FUNDING—BUDGET ACTIVITY CODES

To fund the organizations listed above, RDT&E appropriations requests are required by DoD's Financial Management Regulation to include a budget activity (BA) code that generally corresponds to the RDT&E technology readiness level (See Figure 9). This coding is unique to RDT&E budget requests and is more granular than procurement programs which are only identified by the procurement program name. Prototyping is typically associated with programs funded under BA codes 2 through 4 and total funding for these budget activities has doubled since 2001. However, the lack of transparency from DoD in the out-

7. Department of Defense, The Office of the Director, Operational Test and Evaluation, DOT&E Annual Reports. https://www.dote.osd.mil/annualreport/.

8. Selected Acquisition Reports. https://www.esd.whs.mil/FOIA/Reading-Room/Reading-Room-List_2/Selected_Acquisition_Reports/.

Figure 9. RDT&E (BA 2-4) Actuals by Fiscal Year

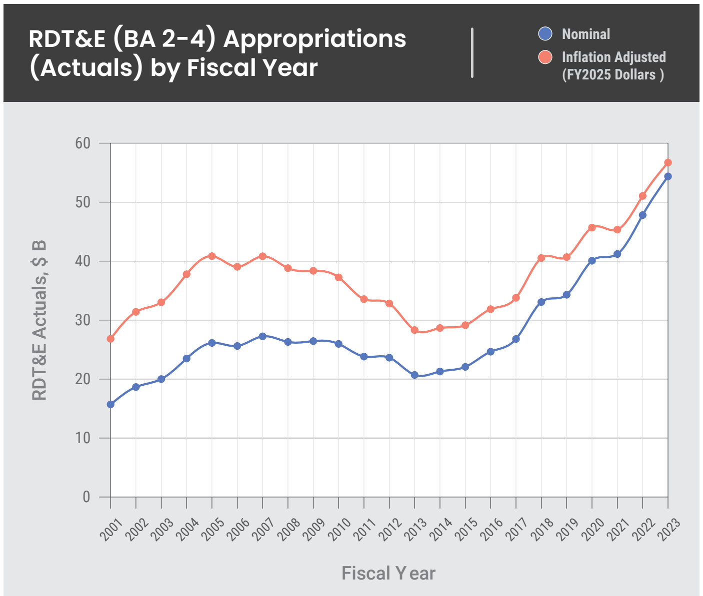
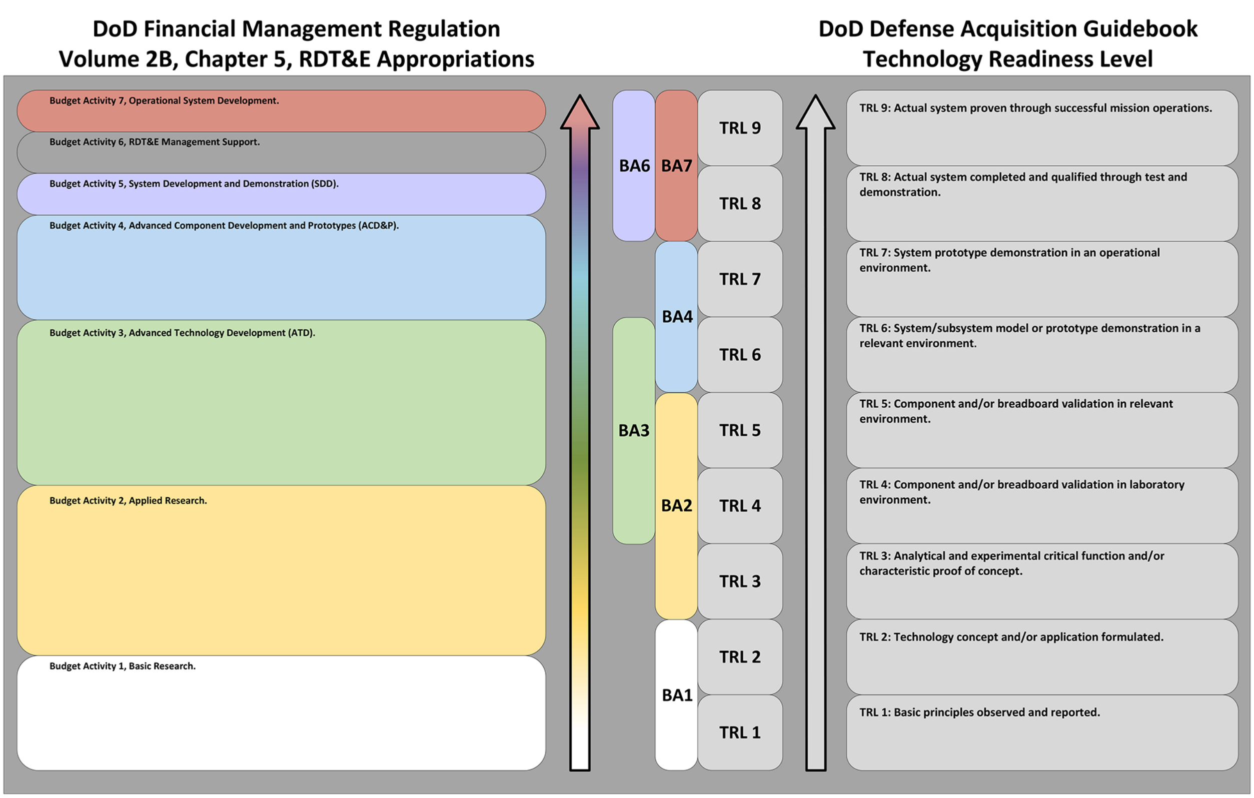


Figure 10. Budget Activity Codes and Technology Readiness Levels



Adapted from Defense Acquisition University, *Crosswalk Card–Budget Activity to TRL*, https://www.dau.edu/sites/default/files/Migrated/Cop-Documents/Crosswalk%20Card%2C%20Budget%20Activity%20to%20TRL.pdf, accessed on October 27, 2024

Table 2. Readiness Levels Other than Technology

Software Readiness Levels (SRL)	SRLs follow the TRL framework closely.
Manufacturing Readiness Levels (MRL)	MRLs are tied to TRLs and described in the Manufacturing Readiness Level Deskbook. which is not an official DoD publication but offered on a .com website as best practices.*
Integration Readiness Levels (IRL)	IRLs measure the maturity level of systems integration. Surprising, this is not used more often since many prototyping activities are for existing weapon systems.
Sustainment Maturity Levels (SMLs)	SMLs are included in the Product Support Manager Guidebook. Of note, SMLs do not address critical sustainment challenges that could be addressed in technology development like Modular Open Systems Approach (MOSA), Diminish Manufacturing Sources and Material Shortages (DMSMS), or Supply Chain Risk Management (SCRM).

* Office of the Secretary of Defense Manufacturing Technology Program, Manufacturing Readiness Level Deskbook, October 2022, https://www.dodmrl.com/MRL_Deskbook_2022__20221001_Final.pdf

comes of prototyping efforts makes it is difficult to assess the return on investment of this increase in funding over the years. (See Figure 10.)

TECHNOLOGY READINESS LEVELS[9]

Technology Readiness Levels (TRLs) are closely associated with appropriations funding. TRLs assess the technology maturity of RDT&E activities. First developed by NASA, the same definitions are used by industry, academia, and DoD.[10]

Technology Readiness Levels (TRL) classify the progression of technology from basic research through prototyping and finally into a program with 1 being the least mature technology and 9 being the most mature. An organization that focuses on the earlier stages of RDT&E may have different expectations of the next steps than an organization that participates in later stage efforts. To consider this, the survey asked about the maturity level, or TRL, of the respondents' prototyping activities.

OTHER READINESS LEVELS

DoD policies and guidebooks include readiness level frameworks for software, manufacturing, integration, systems, and even sustainment maturity. (See Table 2) Only software readiness levels get top billing while the others are relegated to the ends of the documents or appendices.[11] Unlike TRLs, other readiness levels are not employed in formulating DoD's budget request or appropriations. For this reason, these useful frameworks are rarely used in conversations or decisions about the future viability of prototyping efforts.

9. Department of Defense, Office of the Under Secretary of Defense for Research and Engineering, *Technology Readiness Assessment Guidebook*, Washington, D.C., June 2023.https://www.cto.mil/wp-content/uploads/2023/07/TRA-Guide-Jun2023.pdf.

10. National Institutes for Health uses a technology readiness level hierarchy like DoD with definitions tailored for medical research.

11. In DoD's Technology Readiness Assessment Guidebook, Technology Readiness Levels and Software Readiness Levels are the core of the document. Manufacturing, integration, systems, and even sustainment maturity are in the final chapter. In GAO reports, other readiness levels are listed in the appendix.

6

Next Steps for DoD, Congress, and Industry

To fully capitalize on the power of prototyping, Congress, DoD, and industry should take the necessary steps to resolve conflicting definitions, define and measure success, evaluate outcomes and model successful organizations. In addition, DoD, Congress, and industry should collaborate to better leverage all readiness levels and seek better alignment of prototype efforts. Through all this, a concerted effort to capture and share the knowledge gained from prototyping must be accomplished. Finally, to unlock the full power of prototyping, adoption of the best practices identified in this report is imperative.

Next Steps for DoD, Congress, and Industry

- Resolve Conflicting Definitions
- Measure Success, Evaluate Outcomes, Model Successful Organizations
- Leverage All Readiness Levels
- Align Efforts with Stakeholders
- Capture and Share Knowledge
- Adopt Prototyping Best Practices

RESOLVE CONFLICTING DEFINITIONS

DoD should update its definition of prototyping to include activities that put a program on a path to production so there is a direct connection to the customer who might use the end item patterned after the original model. Congress should support and encourage DoD's efforts. Resolving the definition disconnect between DoD, Congress, and industry would be a first step to provide clarity of purpose, focus of effort, and evaluation of outcomes of prototyping activities. To reiterate, DoD's definition is focused on rapid learning and "failing fast." It does not include any of the other benefits of prototyping, especially not transitioning to production.

MEASURE SUCCESS, EVALUATE OUTCOMES, MODEL SUCCESSFUL ORGANIZATIONS

DoD should establish clear criteria for what constitutes success of a prototyping effort and then require all organizations engaged in prototyping to report to these measures of success. To this end, Congress should expand the requirements of Sec. 217 of the FY21 NDAA and establish publicly accessible reporting requirements in the vein of those required for testing and acquisition efforts.

What constitutes success for one organization might be different than another but holding organizations accountable for a return on investment is essential. This is an effort DoD can benefit from immediately. Funding for prototyping activities doubled in the past 20 years but the return on this investment remains unclear (See Figure 10.).

Over time, DoD can use this information to evaluate the most successful prototyping organizations, duplicate their best practices, and resource accordingly. Congress should support this effort of realigning resources to the most successful organizations.

LEVERAGE ALL READINESS LEVELS

DoD should begin better leveraging all readiness levels (e.g., software, manufacturing, systems integrations, sustainment) for program management by formally establishing in policy a process to integrate the other readiness levels with TRLs. Congress should support this effort by directing GAO to evaluate DoD's use of all readiness levels as they relate to prototyping activities. Prototyping efforts would benefit from prioritizing the use of all the available readiness levels in addition to technology readiness levels to include manufacturing, integration, system, and sustainment maturity. This would guarantee the research communities keep the acquisition lifecycle top of mind when working to transition prototypes.

ALIGN EFFORTS WITH STAKEHOLDERS

DoD should ensure that acquisition leaders and stakeholders are cognizant of proposed and ongoing prototyping efforts. Successful prototypes are aligned with the priorities of Service acquisition leaders and stakeholders to support the customer. Service acquisition leaders and stakeholders set the requirements to solve the customer's problem, and prototyping efforts should be aligned to respond to those requirements.

CAPTURE AND SHARE KNOWLEDGE

DoD and industry should develop a useful knowledge capture system based on the latest technology. To truly further knowledge and learn at the speed of relevance, capturing and sharing this information is critical. The lack of knowledge capture and information sharing was raised multiple times by workshop participants from industry and academia. Even individual research organizations noted a lack of an internal comprehensive knowledge capture system.

ADOPT PROTOTYPING BEST PRACTICES

DoD should update its Prototyping Guidebook with the best practices identified by this report. At the same time, current prototyping efforts should commit to the best practices now to ensure the power of prototyping is realized from breakthroughs to battlefields.

About the Authors

Stephanie Halcrow, Senior Fellow at Costello College of Business' Greg and Camille Baroni Center for Government Contracting, is also President of The Halcrow Group. She most recently served as a Professional Staff Member on the House Armed Services Committee (HASC) where she led the efforts to develop, position, and implement the HASC Ranking Member's acquisition reform strategies into tangible legislative solutions, garnering bipartisan and bicameral support as well as soliciting industry and federal government input.

Stephanie is deep-rooted in the academic and public policy community and currently serves as a Senior Fellow for Defense Industrial Base Health and Resiliency with the National Defense Industrial Association (NDIA) and as an external advisor to the Department of Defense's Acquisition Innovation Research Center (AIRC).

Dr. Arun A. Seraphin is the Executive Director of the Emerging Technologies Institute at the National Defense Industrial Association. He previously worked as a Professional Staff Member at the United States Senate Committee on Armed Services covering acquisition and technology issues; as the Principal Assistant Director for National Security and International Affairs at the White House Office of Science and Technology Policy (OSTP); as the Special Assistant for Policy Initiatives to the Director of DARPA; and as a researcher in the Science and Technology Division of the Institute for Defense Analyses.

He earned a Ph.D. in Electronic Materials from the Massachusetts Institute of Technology. He also holds bachelor's degrees in political science and engineering science from the State University of New York at Stony Brook.

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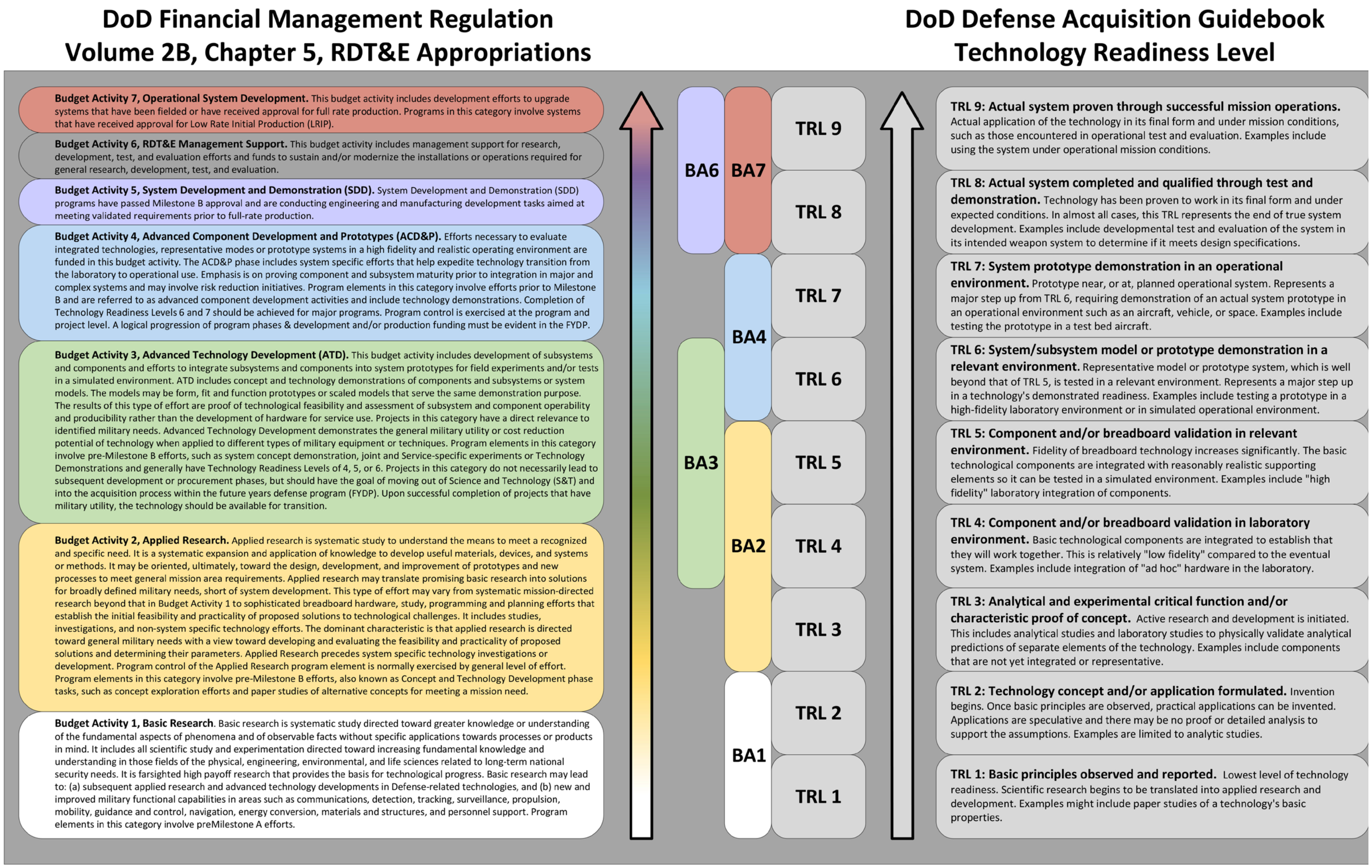
Appendix



Adapted from Defense Acquisition University, *Crosswalk Card–Budget Activity to TRL*, https://www.dau.edu/sites/default/files/Migrated/Cop-Documents/Crosswalk%20Card%2C%20Budget%20Activity%20to%20TRL.pdf, accessed on October 27, 2024

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