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Schedule Risks Associated with Modularity, Agility, and Middle Tier Acquisition

December 2, 2021

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Abstract

Major defense acquisition programs take about eight years to proceed from program initiation to an initial operational capability. This cycle time is longer than it takes adversaries to create new problems for operational military forces. Prior statutory changes have not significantly affected cycle times. Recent changes created middle tier acquisition programs intended to deliver capabilities and products in less than five years.

These middle tier acquisition programs are rapid prototyping and fielding pathways with new governance, acquisition authorities and schedule duration tied to requirements approval dates. The Department of Defense acquisitions continue to evolve, and program offices must concurrently adapt to both emergent guidance and programmatic realities. Including innovations such as system modularity and agile system development methods into these new program types can create additional programmatic schedule risks and opportunities. These in-stride adaptations can affect the capability of a program office to deliver an effective system within promised cycle times.

This research explored schedule growth risks associated with new acquisition pathways and process innovations. It used public data to identify schedule-related risk factors associated with middle tier acquisition and process innovations. We developed quantitative schedule models for middle tier acquisition programs to predict schedule durations and schedule risks associated with application of various innovations within rapid acquisition pathways. We identified and analyzed schedule growth risk mitigation strategies.

This research contributes to the understanding of the risks and opportunities associated with recent acquisition process changes. The research results will be useful to program offices and acquisition leadership in executing current and future rapid acquisition programs.

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Table of Acronyms

AIR	Air commodity Type
AF	United States Air Force
BA	Budget Activity
C3I	Command, Control, Communications and Information (a commodity type)
CDR	Critical Design Review
DoD	Department of Defense
DOTE	Director Operational Test and Evaluation
FAR	Federal Acquisition Regulation
FMR	Financial Management Regulations
GAO	Government Accountability Office
GND	Ground commodity Type
IOC	Initial Operational Capability
IQR	Inter Quartile Range
MDAP	Major Defense Acquisition Program
MOSA	Modular Open System Architecture
MS B	Milestone B
MS C	Milestone C
MSL	Missile commodity Type
MTA	Middle Tier Acquisition
NDAA	National Defense Authorization Act
OSA	Open Systems Architecture
OUSD(C)	Office of the Undersecretary of Defense (Comptroller)
PB	President's Budget
PE	Program Element
R&D	Research and Development
RDT&E	Research, Development, Test and Evaluation (a type of funding)
SR	Schedule Risk
St	Program Start
St.B	Interval from Start to MS B
B.CDR	Interval from MS B to CDR
B.C	Interval from MS B to MS C
B.IOC	Interval from MS B to IOC
CDR.IOC	Interval from CDR to IOC
C.IOC	Interval from MS C to IOC
OT.IOC	Interval from Operational Testing to IOC

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Introduction

This research explored schedule-related risks and opportunities associated with implementing new rapid prototyping and fielding program authorities, modular open system architectures, and Agile development. It assessed the risks and opportunities associated with these innovations, and identified programmatic modifications and measures to manage schedule growth. This research considers three specific statutory changes intended to deliver capabilities and products in less than five years: modular development, Agile development, and Middle Tier Acquisitions. Major defense acquisition programs (MDAPs)[1] take about eight years to proceed from program initiation to an initial operational capability, which is longer than adversaries need to create new problems for operational military forces.

Research Scope

The research applies to MDAPS, including those applying modular development, Agile development, middle tier acquisition (MTA) programs, and specifically excludes programs intended to acquire services or Defense business systems. This research included acquisition policy and management changes enacted in the 2016, 2017 and 2018 National Defense Authorization Acts (NDAAs) and the DoD and service guidance, governance, and execution strategies implementing these changes. The quantitative results are specific for missile and aircraft commodity-type MDAP and MTA programs. The research findings may not be valid for other system commodity types such as ships or ground vehicles or for acquisition practices outside the considered set of innovations.

Research Questions and Objectives

Our research questions explored how specific innovations affected schedule, including:

1. What types of programs have delivered prototypes or fielded systems within five years?
2. What characterized innovative technologies and systems that fielded within five years?

[1] See 10 U.S.C. 2430 for an explicit MDAP definition (10 USC 2430, 2021).

3. How do acquisition process innovations such as agile and modular open systems approaches affect program schedule performance?
4. How do acquisition strategies compare in terms of schedule durations and growth?
5. What development issues were faced by previous acquisitions that used agile, modular, and open systems approaches?

Research Objectives

Our specific research objectives were:

- To develop a program database from publicly available sources suitable for research.
- To identify and quantify indicators for different acquisition strategies, and significant predictors of and risk factors associated with achieving schedule objectives.
- To use these indicators, predictors, and risk factors to develop programmatic strategies capable of delivering prototypes or fielded systems within five years.
- To investigate public policy and management issues directly related to DoD rapid acquisition strategies with a focus on the implications of these policy and management issues on program and systems engineering management.

This paper continues with a review of recent literature in Section 2. A methodology overview in Section 3 describes several databases developed from publicly available sources and the quantitative methods used. Section 4 presents the results of quantitative analysis. Section 5 summarizes research results, and suggests future opportunities.

Literature Review

Schedule is an outcome. We briefly review policy, and highlight recent innovations and research, including open systems architectures, modularity, Agile development, and Middle Tier Acquisitions. We show that successful rapid acquisition programs have factors helping the *system* – meaning the product and processes of the developing, producing, and sustaining entities are collectively capable of meeting required schedules. The literature review follows the general structure shown in Figure 1:

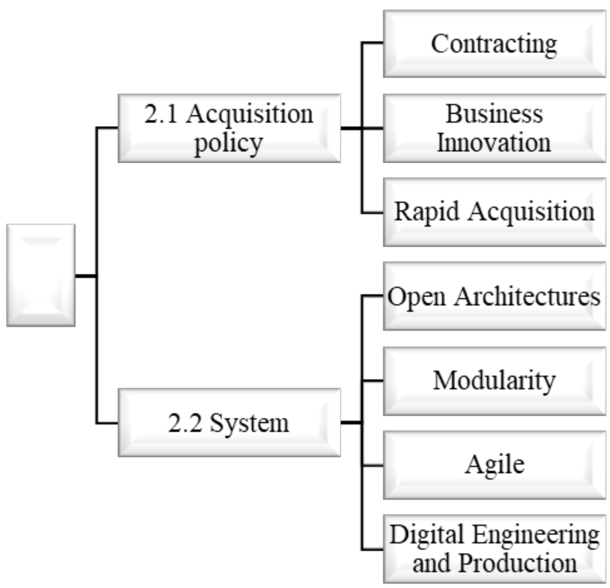

Figure 1. Literature review summary

Rapid Acquisition Policy Innovations

Fox produced a comprehensive summary of defense acquisition reform efforts between 1960 and 2009 (Fox, 2011), and chronicles the interplay between Congress, the DoD, and the defense industry. Significant reforms included:

- McNamara centralized acquisition authorities, and introduced budgeting, programming, and requirements processes within the DoD. These affected cost, performance and schedule tools, policies, and practices, and Fox argues that DoD personnel did not have the expertise to implement and execute these reforms (Fox, 2011).

- Laird and Packard instituted policies related to management by objective, decentralized execution, cost reforms, identifying, managing and reducing technical risks, emphasizing prototyping, and formalizing acquisition training (Fox, 2011). Fox particularly emphasizes the importance of personal interactions between Congressional, DoD and industry leadership in the process and policy changes.
- Congressional legislative initiatives with such as the Nunn-McCurdy Amendment, Federal Acquisition Streamlining Act, and Clinger-Cohen Act increased accountability for results (Fox, 2011).

Recent acquisition reforms emphasized speed of development and delivery, and created new authorities such as Middle Tier Acquisitions for rapid prototyping and rapid fielding of new capabilities (NDAA, 2015). In 2018, Congress authorized a DoD Agile Pilot program (2018 NDAA, 2017), Fifteen programs were inducted into the pilot, and best practices summarized in the Agile Software Acquisition Guidebook (Cummings, 2020). Forney found that larger unit size and less development work increased the likelihood of schedule success, and that *Agile software development methods did not increase success likelihood* (Forney, 2019), Cultural and programmatic factors such as not changing the Program manager during execution and smaller team sizes were also associated with Agile schedule success (Forney, 2019). There exist other software development models (Oakley, 2020) such as iterative (Mortlock, 2019), Lean and DevSecOps (Lord, 2020a), and hybrids of various methods.

Contracting innovations

Most government acquisition contracts conform to the Federal Acquisition Regulations (FAR), some recent uses are innovative, such as using indefinite delivery/ indefinite quantity-type contracts to accelerate ordering and delivery of a "commoditized" F-16 for foreign military sales (Reim, 2020a). McCormick et al. tested reform effectiveness using publicly available contracting data through 2012. Two trends were significant – increased usage of fixed price type contracts and external events affecting acquisitions more than policy reforms (McCormick et al., 2015). Two recent contracting innovations are:

- *Modular* contracting was introduced to reduce investment risk, product delivery times, and barriers to introducing new information technology (OMB, 2012), modular contracting has expanded beyond information technology acquisitions to include software and hardware development and procurements (OUSD(A&S), 2019). Smith suggests contract modularity is a matter of degree driven by information exchange requirements, background contextual legal principles and limits of human understanding (Smith, 2006).

- *Agile* contracting adapts contract management to support agile acquisition processes. Pennington notes that inherently agile attributes such as incomplete requirements, incremental deliverables, and acceptance criteria make for challenging procurements (Pennington, 2018). Contracting officers predominantly use fixed-price type contracts to manage agile procurements; key issues include setting quality standards, definitions of done, and appropriate risk sharing (Ellis et al., 2019).

Congress has provided statutory alternatives to FAR contracts; examples include:

- Procurements for Experimentation is a statute allowing the DoD to buy small quantities of systems for test and experimental use (10 USC 2373, 1993). Variants of this statute historically precede other transaction authorities.
- Commercial Solutions Opening (NDAA, 2016, sec. 879) is a statutory pilot program allowing program offices to procure commercial items using broad agency announcement-type procedures.
- Other Transaction Authority (10 U.S.C. 2371, 1993) are a special case- legally binding agreements other than a contract, grant, or cooperative agreement where generally contract- and grant-related Federal laws and regulations do not apply. There are three common types of other transactions – other transactions for prototypes, other transactions for research, and other transactions for production (10 U.S.C. 2371, 1993).

Business Innovations

Taylor examined federal procurement since 1980 and found while the workforce is smaller and moves more between buyer and seller positions, there are more procurements acquiring more services, and increasing use of other-than-definitive contracts (Taylor, 2019).

The Defense Business Board analyzed core DoD processes including acquisition in 2014. They estimated the overhead costs of current processes, potential savings, and general recommendations on goals and processes for business process improvements (Defense Business Board, 2015). In particular, the Board recommended workforce reduction and retention of specific expertise (Defense Business Board, 2015), while Taylor found the workforce had shrunk and was offset by contracting for functions previously performed by government personnel (Taylor, 2019).

Several advisory panels provided specific recommendations for business process innovations. A recent example was the Section 809 Panel, which provided extensive recommendations intended to accelerate acquisition processes by leveraging commercial marketplaces and processes, simplifying acquisition regulations, changing resource allocation processes, and improving the acquisition workforce (Drabkin et al., 2016). The DoD has implemented less than half their recommendations as of January 2021.

The DoD and Congress created several funding processes designed to accelerate technology transitions from non-traditional performers and are posted in the Defense Innovation Marketplace (OUSD(R&E), 2020). For example, the DoD Rapid Innovation Fund was created by Congress in 2011 and expanded in 2018 to accelerate small business technology transition to the DoD (NDAA, 2011, sec. 2359a). It is managed by staff within the Office of the Undersecretary of Defense for Research and Engineering (OUSD (R&E)), and is structured to complement DoD small business innovative research programs by providing transition funding to move technology into operational use or to an acquisition program within 24 months (OUSD(R&E), 2020). Congress did not appropriate funding for this activity in 2020.

The Defense Innovation Unit is a different effort, embedded in Silicon Valley, reporting to the Undersecretary of Defense for Research and Engineering (USD(R&E)). It is focused on transitioning commercial advanced technologies to DoD, and uses an extension of other transaction agreement authorities (NDAA, 2015, sec. 815) to fund development and transition. It has recently expanded to other locations and continues providing market access and non-dilutive capital for non-traditional defense contractors (*DIU*, 2020).

Industry is an important element in rapid acquisition strategies. We showed in prior research that shorter cycle time (schedule duration) programs tended to have fixed price incentive type contracts, incremental development and fixed production runs, smaller budgets, a government-created market with more than one competent contractor, and use of allowed flexibilities such as Other Transaction Agreements (Etemadi & Kamp, 2021a).

Rapid System Acquisition

Acquisitions are rapid when development and fielding is earlier than a need date. It takes time, nearly eight years on average, to develop and field a new weapons system. Researchers have identified process changes and innovations that lend themselves to moving quickly, such as incremental or evolutionary acquisition strategies (Mortlock, 2019), adopting or reusing existing technologies (Eiband et al., 2013), and modifications to existing systems (Tate, 2016). Van Atta et al. identified defined "accelerated acquisitions" as those with urgency, requirements specificity, and technology availability (Van Atta et al., 2016) They noted that relatively few (18 of about 330 MDAPs[2] reviewed) programs met these criteria; significant examples are summarized in Table 1.

Table 1. Accelerated Acquisition programs 1975-2015 (based on Van Atta et al.)

Commodity Type	N	MDAP	Non-MDAP
Air	7	Common Infrared Countermeasures (CIRCM) Scout Helicopter (ARH-70) Predator Unmanned Air Vehicle (UAV) (MQ-1) *Global Hawk UAV (MQ-4)* *Reaper UAV (MQ-9)*	*Stealth Strike Aircraft (F-117)* *Intelligence, Surveillance and Reconnaissance (ISR) aircraft (MC-12)*
Missile	2	Joint Air-to-Surface Munition (JASSM) *Long Range Air-to-Surface Missile (LRASM)*	
Ground	4	Future Combat System (FCS) *Stryker vehicle* *Mine Resistant Ambush-Protected (MRAP) vehicle*	
Ship	2	Littoral Combat Ship (LCS)	MV CAPE RAY (Chemical weapons demilitarization)
C3I*	3	Warfighter Information Network-Tactical Increment 1 (WIN-T Inc 1)	Command Post of the Future (CPOF) Phraselator

* Command, control, communications, and information

[2] Now also referred to as Major Capability Acquisition(Lord, 2020a). We stayed with the MDAP acronym for consistency.

The programs in *italics* either delivered a prototype or claimed initial operational capability (IOC) within five years of program start. The Global Hawk (RQ-4) Blocks 5 and 10 went from Milestone B (start of Engineering and Manufacturing Development) to IOC in less than 5 years (Rozelsky, 2010), aided by urgent requests for increased reconnaissance and surveillance capability.

The Army demonstrated two accelerated acquisitions – the C-27J Spartan (Joint Cargo Aircraft) and the UH-72 Lakota (Light Utility Helicopter) using commercially available and in-production products (Dodaro, 2008). The UH-72 program proceeded from the decision to replace Vietnam-era helicopters to first unit equipped in less than 40 months (Rubinstein, 2014) and the sixth C-27J delivered in 41 months (Dodaro, 2011). Both were in use in commercial or allied military service, and had acceptable airworthiness certifications and approvals. Both programs changed due to shifting DoD objectives (Rubinstein, 2014) and responsibilities (Alexander, 2012); however, these two programs demonstrate the potential for rapid acquisition of in-production commercial items.

Arellano, Pringle, and Sowell analyzed rapid acquisition programs and noted the importance of direct senior leadership involvement to successful rapid acquisitions (Arellano et al., 2015). Dougherty examined historical successful prototyping, and identified technological maturity and sponsorship as key factors for successful prototyping and transition (Dougherty, 2018). He reviewed six current rapid acquisition offices, identifying common success factors summarized in Table 2.

Table 2. Common prototype success factors (per Dougherty, 2018)

Idea to Prototype	Demonstration to fielding
Leveraged mature technology – based on novel component or combination	Convincing demonstration for key decision makers
Self-funded	Urgency of need (conflict)
Championed by small special interest military community	Champion to defend and support
Top-down requirement	Mature enough to demonstrate a desired capability
	Met needs of focused community

Successful prototypes had sufficiently mature technology to demonstrate the concept and capability, sponsorship from leadership and the institution, and compelling demonstration that the prototype met user needs (Dougherty, 2018).

Wong identified three long-term (replacement, expedited or traditional) and three opportunistic (missed, new, or alternative) acquisition categories (Wong, 2016). In his analysis, rapid acquisition processes depend upon budget reprogramming for initial action, but quantities depend upon capability adoption and use proliferation (Wong, 2016). The recently introduced acquisition pathways or strategies emphasize accelerated demonstration of a prototype or fielding of a new capability and are consistent with Wong's opportunistic categories. Of note, Congress provided statutory relief allowing transfer of procurement funds to rapid fielding accounts (NDAA, 2016, sec. 806), further supporting Wong's analysis.

Middle Tier Acquisition

Congress enacted Middle Tier Acquisition (MTA) processes in 2016 (NDAA, 2015, sec. 804). The intent was for the DoD to create processes allowing fielding and prototyping of new capabilities within two to five years of approval. Key statutory changes enabled service acquisition executives to bypass traditional requirements and acquisition processes, and establish direct-reporting program managers for these rapid acquisition programs. MTA program managers have dedicated program offices staffs, and mandated schedules for prototype or production. The acquisition executive is the program milestone decision authority and has expedited waiver processes available to speed execution (NDAA, 2015).

Between 2016 and 2019, the DoD revised over two dozen acquisition-related directives, instructions, and memoranda[3]. In 2019, the Office of the Under Secretary of Defense for Acquisition and Sustainment issued a new policy directive, "Operation of the Middle Tier of Acquisition (MTA)" (Lord, 2019). This policy introduced two new acquisition paths – rapid prototyping and rapid fielding, which are structured for rapid start, including setting requirements or starting production within six months, and

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[3] These may be found at https://www.esd.whs.mil/Directives/issuances/dodd/ .

delivery of a prototype residual capability or completed fielding, within 5 years of start (Lord, 2019). The services released their own middle acquisition references concurrent with DoD issuance.

In 2020, DoD brought traditional acquisition, urgent acquisition, middle tier acquisitions, software, business and services acquisitions into an Agile Acquisition Framework (Lord, 2020a). The DoD issued extensive acquisition policy revisions in 2020, including "The Defense Acquisition System" (Lord, 2020b), and "Operation of the Adaptive Acquisition Framework" (Lord, 2020a). MITRE Corporation created a comprehensive website collecting the DoD and service acquisition executive policy and guidance (MITRE, 2019).

System process-related research

Jaifer et al. examined effort and time drivers for aerospace new product development (Jaifer et al., 2020). They initially grouped drivers into complexity[4] and proficiency[5] categories, and added an uncertainty category after analyzing a subject matter expert survey (Jaifer et al., 2020). Ingold noted that software schedule durations for small development efforts are approximated by the cube-root of the planned effort in person months, and by the square root of planned effort for large efforts (Ingold, 2014). He argues that while reducing schedule leads to cost growth, Agile processes are able to achieve schedules shorter than predicted by standard software cost estimating models, and are most affected by staff change adaptiveness and stakeholder risk tolerance (Ingold, 2014). Jahr ran an experiment comparing the modification and new product development performance of traditional scrum and hybrid process teams (Jahr, 2014). The hybrid-process teams added planning and management constraints and outperformed scrum teams in terms of schedule and cost growth for both new and modified software development (Jahr, 2014).

Schedule risk has different definitions in the literature, ranging from the likelihood to achieve a predicted duration (Dubos et al., 2007) to an estimate of likelihood and consequence (Tao et al., 2017). Browning used causal loop representations to identify

[4] Such as size, technical difficulty and uncertainty.
[5] Examples include experience, communications and process management competency.

likely sources and consequences of schedule delays, and showed how uncertainty drives risk (Browning, 1998). Thomas et al. extended earned value methods to estimate schedule risk within a detailed cost and schedule Monte Carlo simulation (Thomas et al., 2014). Similarly, Wauters and Vanhoucke used machine learning techniques to simulated project schedule duration within an earned value methodology (Wauters & Vanhoucke, 2017). Such simulations require detailed work project schedules, and duration uncertainty distributions as inputs.

Wirthlin developed a discrete event simulation model[6] that modeled the DoD requirements, acquisition and resource processes as concurrent and interacting processes (Wirthlin, 2009). He modeled the time from program start to Milestone C (Production and Deployment Decision), including activities prior to program start. He included stopping events in his simulation to model program terminations, and had the model reviewed by experts. The simulation showed that the DoD expends significant effort early in the acquisition process without results. Over 60 percent of started programs terminated before reaching Milestone C; one result is that too many programs are competing for resources. Additionally, the overall process diffuses responsibility, with process owners not understanding the processes and their interdependencies. In particular, these interdependencies result in unrecognized systemic risks (Wirthlin, 2009).

Open Architectures

Open systems architectures are an approach simplifying the integration of new capabilities into existing systems. Modular Open Systems Approaches (MOSA) is a design approach requiring the DoD to implement technical and business strategies for modular system designs with validated common interfaces (10 USC § 2446a, 2016). MOSA is an evolution of an Open Systems Architecture, where functions are encapsulated in modules, interfaces conform to consensus standards, and processes exist to ensure conformance to these standards (Firesmith, 2015). The DoD MOSA development strategies emphasize module-level competition, development, testing and

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[6] Known as the Enterprise Requirements and Acquisition Model (ERAM).

deployment, with multiple competing open standards (Engebretson & Frey, 2017). MOSA designs group system functions into discrete cyber-physical modules, composed of hardware and software components, bounding disruptions caused by and within modules. The Acoustic Rapid COTS Insertion (ARCI) process is an example of such an approach (Boudreau, 2006). Ross et al. expressed system changeability as an added cost rather than an inherent property (Ross et al., 2008).

Broniatowski and Moses developed graph-based metrics expressing the flexibility, rework potential and complexity of four basic system architectures, ranging from directed trees to fully interconnected systems. They showed that architectural choices bound available options, choice iterations, and interdependence (Broniatowski & Moses, 2016). Ross et al. expressed system changeability as an added cost rather than an inherent property (Ross et al., 2008). These two views characterize system change as either built-in or additive. In practice, system change has a cost in terms of time and money, and recent initiatives try to minimize these costs. Guertin et al. argued for architectural and organizational transformations that highlight the complexity of DoD open systems processes (Guertin et al., 2018). This builds on prior work relating architectural frameworks and views to development, test and evaluation, and operational use (Guertin & Hunt, 2017).

Modularity

Modularity is a design choice to reduce complexity and a way to change system function or performance without having to create a new system. Modular or opens systems development is an approach to reducing program complexity [7]. Zimmerman et al. identified three elements of effective modular development: an integrated technical and business strategy, stakeholder collaboration to minimize process conflicts, and implementation guidance and tools (Zimmerman et al., 2018). Davendralingam et al. summarized recent modularity and open system literature in order and described the advantages and disadvantages of modularity, and used an example "fractionated

[7] Within the DoD modular development is equivalent to application of Modular Open Systems Architecture (MOSA).

satellite" to highlight some practical design, programmatic, and implementation issues (Davendralingam et al., 2019).

System processes may be modular. Baldwin and Henkel showed how partitioning product knowledge into distinct but related processes and products allows companies to develop products faster, provides others opportunities to provide complementary or competitive products, and either protects or exposes company intellectual property (Baldwin & Henkel, 2015). This partitioning allows programs to use an array of contracts of different types for module development, production and support[8] consistent with the intellectual property structure and an appropriate scale (Anonymous, 2012). Modularity affects supplier interdependence, requiring increased coordination between module design and manufacturing processes. Persson et al. used two case studies to explore different coordinating methods and mechanisms and show that the product character and degree of product change affect the method and mechanism selection (Persson et al., 2016).

Schilling describes a general causal model for system modularity product and organizational (process) modularity (Schilling, 2000). Schilling views modularity providing an ability to adapt the fitness of a system to its operational context[9] and requiring inherent functional separability and generalized recombination properties[10]. The trade between fitness for a specific purpose[11] and reconfigurability is determined by the difficulty of creating functional separability (Schilling, 2000). She includes an inherent system inertia (tendency to remain in the existing configuration) and an urgency to prompt change towards or away from modularity (Schilling, 2000). In this view, modularity results from intentional systems engineering, balancing interactions of conflicting objectives balancing encapsulated functionality and interoperability. These trades help manage system complexity and address conflicting design objectives such as stability and adaptability (Heydari et al., 2016).

[8] This approach is also called modular contracting.
[9] Schilling calls this "the heterogeneity of both inputs and demands" (Schilling, 2000, p. 318).
[10] This presumes that useful combinations are achievable.
[11] She calls this synergistic specificity (Schilling, 2000, p. 316)

Modularity varies in degree and the literature offers case studies showing the practical effects of physical modularization. Hvam et al. define a module as a group of functions in a process flow (Hvam et al., 2017). They offer the LEGO® block as one end of a modularity scale, with functionality derived from block combinations (Hvam et al., 2017).

Modularity affects supplier interdependence, requiring increased coordination between module design and manufacturing processes. Persson et al. used two case studies to explore different coordinating methods and mechanisms and show that the product character and degree of product change affect the method and mechanism selection (Persson et al., 2016). Van Gent and Kassapoglou examined modularizing composite airframes and showed the effects on direct operating costs and fuselage weight with increasing modularity (van Gent & Kassapoglou, 2014). They derived cost and weight values for specific flight load conditions and optimized structural designs. While cost and weight savings were achievable, they were reduced or lost at high modularity levels as modules become heavier (and more expensive) (van Gent & Kassapoglou, 2014).

Berardi and Cameron showed that using open source code (a software version of open standards) is sufficient to prevent *vendor lock-in.*[12] Rehn et al. note that the time and cost saved on a future design requires prior up-front payment for the future design flexibility (Rehn et al., 2018). In their model, change requires an agent (defining the change purpose), a mechanism (process), and path enablers (such as design margin). Using an offshore work ship design as an example, they quantify the relative cost and time reduction for a given purpose change at a common changeability level, and the variation of change opportunities for a given cost and time (Rehn et al., 2018). Watson et al. related design margin (what they called “excess capacity”) to the ability to evolve a military ground vehicle design over time (Watson et al., 2016). They found, given future requirements uncertainty, the optimal design in terms of cost and benefits of excess capacity was related to the expected design service life (Watson et al., 2016), and that for the modeled vehicle, excess capacity was not cost effective when expected service

[12] Lock-in is when a customer is unable to change suppliers without incurring substantial switching costs.

lifetimes were below a certain value (Watson et al., 2016). *The implication is that the DoD would benefit by reducing system design lifetime, in favor of sustained production of incrementally evolving systems.*

Agility

Williams found that conventional program management methods can be inappropriate for programs with *structural complexity, uncertainty in goals and methods*, and *severe time (duration) limits,* and interrelated systemic factors made it difficult to identify single causal factors. (Williams, 2005). Gunderson analyzed what he described as adaptive acquisition – an iterative, recursive process delivering incremental products satisfying user needs. Significant recommendations included reducing redundant documentation, increasing budget and schedule transparency, and using more other transaction agreements (Gunderson, 2017).

Agile processes are used to manage programs with incomplete or unknown requirements, by working on known requirements within a planned duration and effort (Martin & Highsmith, 2016). Nidiffer et al. describe agile programs as "implementation-driven", meaning requirements are dependent on interactions and direct communications to establish short-term requirements, while traditional approaches focus on documented requirements (Nidiffer et al., 2014). Most literature on agile requirements focuses on software requirements. Inayat et al. noted that agile type methods resolve requirements validation issues, and noted that agile processes do not eliminate issues with non-functional requirements (Inayat et al., 2015) Bott et al. found scrum-type[13] agile processes can be used in systems engineering provided controls such as backlogs are used to ensure system stability (Bott & Mesmer, 2020). A significant shortcoming of agile requirements processes for physical systems is rework. Cooper and Sommer proposed a hybrid development process, called Agile Stage-Gate, where agile methods are applied within selected stages, such as studies and technology development, and gated with clear exit or "done sprint" criteria (Cooper & Sommer, 2016).

[13] A software development process or framework.

In 2017 the DoD had few programs using Agile development methods. Rosa et al. developed cost models for traditional ("waterfall") and Agile software processes within the DoD (Rosa et al., 2017). Notwithstanding a small Agile process dataset, they found that product size (source lines of code) is a valid measure of required effort and Agile methods were more productive than traditional (non-agile) software development methods (Rosa et al., 2017). Agile software development has relied on incremental story delivery (OUSD(A&S), 2019). This incrementalism is extended to rapid system development by integrating test points into the development process (Perttula & Kukkamäki, 2020). Nerur et al. identified key organizational obstacles to Agile adoption that while specific for software development, are relevant to any organization considering shifting to agile processes (Nerur et al., 2005).

Adams conducted a literature review and identified DoD and non-DoD related factors affecting DoD Agile software development adoption (Adams, 2017). Significant barriers included contracting, requirements management, training and team organization (Adams, 2017). Schoeni found similar cultural barriers and identified regulatory constraints (Schoeni, 2015). Haberfellner and Weck reviewed agile systems engineering in a series of illustrative case studies highlighting the systems engineering challenges of designing agility (speed of change) into real systems (Haberfellner & Weck, 2005). They showed that agility is valuable for long-lived systems when"…significant switching costs exist coupled with substantial uncertainty[14] in the environment…" (Haberfellner & Weck, 2005). Chen et al. used a commercial case study to show that successful transition to Agile development requires adapting management practices as well as engineering and development processes (Chen et al., 2016).

Islam and Storer examined factors related to safety-critical systems development that conflict with Agile development (Islam & Storer, 2020). While qualitative and from a single case, they identified three broad grounds of challenges: the influence of "waterfall-like" systems engineering processes on agile teams, complex customer interactions, and conflicts between agile process and regulatory standards, such as

[14] Examples include requirements or demand uncertainty.

upfront design requirements for hazard analysis conflicting with incremental agile design (Islam & Storer, 2020). Finally, Krupa examined an agile model-based systems engineering approach to aircraft design (Krupa, 2019). While the resulting design is conceptual, his use of bond graphs to specify relationships and interactions necessary for future safety analyses abstract relationships enables requirements traceability during system design (Krupa, 2019).

Ciampa and Nagel analyzed collaborative multidisciplinary aircraft design and optimization (Ciampa & Nagel, 2020). A key challenge is efficient information management and exchange, they developed design and development tools spanning all phases of and participants in aircraft design and development, resulting in over a 40 percent schedule reduction (Ciampa & Nagel, 2020).

Digital Engineering and Production

Chada et al. examined using additive manufacturing processes in a re-design of a representative missile, as they are modular by design, and their module size and manufacturing complexity are appropriate for additive manufacturing processes (Chadha et al., 2018). They developed a hybrid design method using additive manufacturing processes to simplify system interfaces, module design and expand the design space, then re-designed selected modules, and components to improve reliability and manufacturability. The redesigned missile offered new trade opportunities for module standardization, serviceability, and customization but would still require flight certification, (Chadha et al., 2018).

Digital twins are design models incorporated into system operations, and are a recent development in digital engineering. Bickford et al. prove a good overview of digital twins as part of model-based systems engineering (Bickford et al., 2020). Siedlak et al. merged design, costing, and production into a decision support process, enabling interactive trades of cost and production impacts of wing design changes to lower stall speed (Siedlak et al., 2017).

There is currently limited support for the conceptual design phase of changeable and reconfigurable manufacturing, where critical decisions regarding type, extent, and level of changeability must be made, regardless of high degrees of uncertainty about future demand scenarios. This paper expands previous research on design for changeability and reconfigurability, by explicitly considering changeability as a capability that can be enabled in various ways for various purposes in different industrial contexts. The proposed model and the case implementations provide important knowledge on the transition toward changeability in industry. (Andersen et al., 2018)

Hawkins and Gravier analyzed journal papers related to using Commercial Off The Shelf (COTS) technologies within the DoD and industry, presenting a summary of trends related to accelerating or slowing product delivery for programs adopting or using COTS, and present a Likert-type decision tool to estimate the appropriateness of COTS for a particular end use (Hawkins & Gravier, 2019).

Hardware and software both require development and testing prior to production. Software production is by digital replication and validation and avoids the rapid fielding. instead of rapid production. Furthermore, software components related to hardware were more likely to change frequently compared to general software components. Xiao et al. found software components change faster and more frequently than hardware systems, and suggest that it is feasible to identify a subset of hardware-driven modularity violations using techniques adapted from pure software systems. (Xiao et al., 2020)

The U.S. Air Force recently announced flight testing of a Next Generation Air Dominance prototype, developed using a "digital engineering"[15] based development process, asserting this to be a faster path to prototype demonstration than prior methods (Reim, 2020b). The development time is not stated, but the program office was activated in October 2019, suggesting a prototype development cycle of less than one year (Waldron, 2019).

DoD production (inventory) quantities for traditional acquisition programs are defined by requirements (Wicecarver, 2017). In such cases, firms have no incentive to produce more than contract requirements. Desai et al. considered the problem for

[15] Also called a digital thread (Bone et al., 2019).

commercial durable goods production and found inventory holding costs and durability incentivize lower inventory (Desai et al., 2007). Davis and Tate provide several examples of how acquisition quantities change over time, and that systems change over time such that later production versions may be quite different than initial deliveries (Davis & Tate, 2020).

Deshpande investigated relationships between advanced manufacturing technology, absorptive capacity, mass customization capability, competitive advantage, and organizational performance measures. His surveys found that absorptive capacity and advanced manufacturing technology affect mass customization, which positively affects time to market (Deshpande, 2018).

Reconfigurable manufacturing systems reduce short-run production overhead and retooling costs by modularizing production processes for an intended parts family. Commercial modular production firms use mechanisms such as cost-sharing agreements, hedged delivery dates[16], and premiums for early deliveries[17] to incentivize rapid acquisitions (Zhai et al., 2016), and spot and future markets can be created for premium demand purchases (Cai et al., 2020). Asghar et al. developed a multi-objective algorithm to optimize module (machine) sequencing and usage (scheduling) as production demands change. (Asghar et al., 2018, p. 4397). The research was specific for a part production line using programmable multi-axis milling machines. Efficient production sequencing minimized production downtime.

Scaling physical system production capacity still requires large production facilities. Truly rapid acquisitions such as the Mine-Resistant Ambush Protected (MRAP) vehicles may need multiple suppliers to deliver production quantities at scale (Sullivan, 2009). In such cases, leader-follower production strategies may be useful. Physical system production at scale requires extensive facilities. For example, in December 2019, Boeing delivered 29 and Airbus 138 large commercial aircraft

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[16] In this case, hedging consists of setting module delivery dates earlier than need dates, thus covering the module production process time uncertainty.
[17] Zhai et al. call these premiums "crashing money."

(Oestergaard, 2020). Boeing's Everett production facility covers nearly 100 acres (Boeing, 2020), and Airbus has five final assembly lines world-wide (Airbus, 2020).

Discussion and Summary

The literature review identified a few types of programs that delivered prototypes or fielded systems within five years of starting. These "fast-to-field" programs typically had an urgency of need, ,senior leader sponsorship and rapid access to available funding (Van Atta et al., 2016). Additionally, they used proven technologies, minimized requirements, and exploited their sponsorship and funding to reduce program timelines. Such actions reduced the likelihood of schedule growth due to immature system integration (Kamp, 2019). Commercial product adaptations, such as the C-27J Spartan and UH-72 Lakota programs, delivered quickly as the barriers to use were largely discretionary. Commercial-software-based systems can deliver operational capabilities within five years. The Air Force cancelled the Air Operations Center Weapon System 10.2 program after spending more than half a billion dollars and over ten years in development (Insenna, 2017), transitioned system development to a Middle Tier Acquisition program, and delivered a prototype in two years (Behler, 2019). We found examples of programs that delivered prototypes or fielded systems within five years, and provided analysis and explanations for shorter schedule durations. Better practices and decisions associated with shorter schedules included:

- Reducing requirements to meet capability and deliver something sooner.
- Starting with a proven technologies, interfaces, and standards.
- Having a competent team and capable suppliers.
- Adjusting work to retire schedule risk, and segmenting integration risk.
- Having a plan to get to contract award and production sooner.

A review of new product development literature review identified some organizational culture issues such as anticipatory development (Shaner et al., 2020) not often found in discussions of DoD research and development. Farmer developed an approach to identify efficient organizational characteristics and structures based upon the DoD development context (Farmer, 2018). The literature review also identified development issues faced by previous acquisitions that used agile or modular development approaches. Common issues included the additional collaboration, interactions, and management needed for agile approaches, and the experience and technical expertise, and discipline needed for effective modular development.

The literature does not in general quantify the effect of DoD rapid acquisition process and policy innovations on schedule performance. Modularity, Agility, and Middle Tier Acquisitions are examples of process changes intended to reduce schedule durations. There is a gap in explaining how specific process changes affect schedule duration, and predictors for what programmatic factors affect schedule durations. Based on the literature review, the research addressed the following research hypotheses:

- Research Hypothesis 1: Modular, Agile, and Middle Tier Acquisition programs have shorter schedules than comparable MDAPs without these attributes.
- Research Hypothesis 2: Modular, Agile, and Middle Tier Acquisition programs have less schedule risk than comparable MDAPs without these attributes.

The next two sections of this paper describe the research methods used and results, including schedule risk estimation, and changes in schedule risk due to modularity, agility, and middle tier acquisition strategies.

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Methodology

Research design overview

We relied on several publicly available data sources for this research: General Accountability Officer (GAO) annual weapon system assessments, released Selected Acquisition Reports (SARs), Director, Operational Test and Evaluation (DOTE) Annual Reports, and data from FPDS.gov and usaspending.gov websites. We created a dataset using the 2020 GAO annual weapon system assessment (Dodaro, 2020) (n= 63). We eliminated space-related entries (n=4) entries with insufficient data (n= 3) and programs changing structures (n=2). We further reduced this to consider only Air and Missile commodity types, leaving 27 entries. This results in a small number of shown in Table 3.

Table 3. Selected GAO 2020 Air and Missile programs

Program ID	Service (SVC)	Commodity Type (Type)	Program ID	Service (SVC)	Commodity Type (Type)
APT	AF	AIR	ITEP	Army	AIR
B2DMSM	AF	AIR	VC25.RECAP	AF	AIR
AARGM-ER	Navy	MSL	VH92	Navy	AIR
CIRCM	Army	AIR	JAGM	Army	MSL
CRH	AF	AIR	B52RMP	AF	AIR
F15EPAWSS	AF	AIR	IFPC.Inc2	Army	MSL
CH-53K	Navy	AIR	PrSM	Army	MSL
KC46A	AF	AIR	P8A.INC3	Navy	AIR
IRST.BLK2	Navy	AIR	ARRW	AF	MSL
SDB.INC2	AF	MSL	B52CERP	AF	AIR
UH-1N.REP	AF	AIR	F22CP	AF	AIR
MQ25	Navy	AIR	HCSW	AF	MSL
MQ4C	Navy	AIR	F35	DOD	AIR
NGJ-MB	Navy	AIR			

We modeled Air and Missile system commodity types to identify and characterize influential variables, and test model predictive performance. We included the Fiscal Year 2019 through 2021 budget documentation to identify rapid acquisition programs. We compiled data into comma separated variable files that are available upon request.

Contract data was substantial, programmatic data sparse. We manually validated the smaller datasets. In some cases, policy delayed public release. We used FY 2020 and FY 2021 budget data to characterize Middle Tier Acquisition program performance and FY 2022 budget data to update our performance estimates[18]

Research terms and definitions

We categorized program types based upon budget document text searches to identify programs. We used Microsoft and Adobe text search engines to search for programs with the following text strings: "Agile," "Modular," "MOSA," "Middle Tier," "Rapid Fielding," "Rapid Prototyping," "Open System," and "Section 804". We reviewed search results in context to ensure consistent labeling. Some searches were ambiguous[19]. We labeled dataset programs as modular, Agile, or MTA as shown in Table 4.

Table 4. Mapping selected GAO 2020 dataset programs to labels

Program ID	Modular	Agile	MDAP/ MTA	Program ID	Modular	Agile	MDAP/ MTA
APT	Not	Not	MDAP	ITEP	Not	Not	MDAP
B2DMSM	Modular	Not	MDAP	VC25.RECAP	Not	Not	MDAP
AARGM-ER	Not	Not	MDAP	VH92	Not	Not	MDAP
CIRCM	Modular	Not	MDAP	JAGM	Modular	Not	MDAP
CRH	Not	Not	MDAP	B52RMP	Modular	Not	MDAP
F15EPAWSS	Modular	Agile	MDAP	IFPC.Inc2	Modular	Not	MDAP
CH-53K	Modular	Not	MDAP	PrSM	Not	Not	MDAP
KC46A	Not	Not	MDAP	P8A.INC3	Modular	Agile	MDAP
IRST.BLK2	Not	Agile	MDAP	ARRW	Not	Agile	MTA
SDB.INC2	Modular	Agile	MDAP	B52CERP	Modular	Not	MTA
UH-1N.REP	Not	Not	MDAP	F22CP	Not	Agile	MTA
MQ25	Not	Not	MDAP	HCSW	Not	Not	MTA
MQ4C	Modular	Agile	MDAP	F35	Modular	Agile	MDAP
NGJ-MB	Modular	Not	MDAP				

[18] President's Budget data was released to Congress in 2019 (FY 2020) and 2020 (FY 2021). Fiscal year 2022 data was not released until May 2021.
[19] For example, prior to the 2016 National Defense Authorization Act, the DoD used "Agile" "rapid fielding" and "rapid prototyping" within budget documentation descriptions of program plans and strategies, which meant different things than the above labels.

We grouped programs by commodity type (such as Air and Missile programs), and by MDAP, Modularity, Agility, and MTA identifications. Because of the data sources, all programs were either MDAP or MTA; and some programs were both modular and Agile development. Table 5 shows the label distribution for AIR and Missile systems.

Table 5. Program type label summary (GAO 2020 dataset - AIR & Missile Systems)

	MDAP		MTA	
	Not Agile	**Agile**	**Not Agile**	**Agile**
Modular	7	5	1	0
Not Modular	10	1	1	2

We used the programs listed in Table 3 as the basis for initial program statistics and developed simplified schedule models, and used both interpolation and regression modeling techniques to understand likely relationships and distributions. Because of the small number of programs in the dataset, we ran Monte Carlo simulations using initial distribution statistics to estimate schedules and schedule risks for different program types (Hubbard, 2009). We performed outlier tests and re-ran simulations with three programs removed from the dataset[20]. We ran simulations using statistics for both the Table 4 ("GAO 2020 AIR & MSL") and reduced datasets, with equivalent results at a significant level of $\alpha = 0.05$. The cited simulation results in this report used statistics for the Table 4 dataset.

Schedule, schedule risk, and inter-event duration modeling

We defined *schedule risk* as the likelihood of exceeding a specified schedule duration*:*

$$schedule\ risk = 1 - p(schedule\ \leq specific\ duration)$$

The right-hand-side probability is the schedule cumulative distribution function. We fit program schedule data to a Normal or Weibull distribution and tested goodness of fit using Anderson-Darling or Kolmogorov-Smirnov tests. This method compares

[20] Trial removed IFPC.Inc2, P8A.INC3 (follow-on increments after IOC), and F-35 (cost and schedule outlier).

program progress against an aggregate performance. We developed two types of schedule risk estimators: program type specific, that compared a specific program schedule risk against a cumulative distribution function of comparable programs, and a broad estimate that included all program types in the distribution model. We did not assess risk context, severity, or treatment, as these are program-dependent.

We decomposed programs into a generic sequence from program start through fielding. Figure 2 shows an example block diagram for a MDAP with average interval durations.

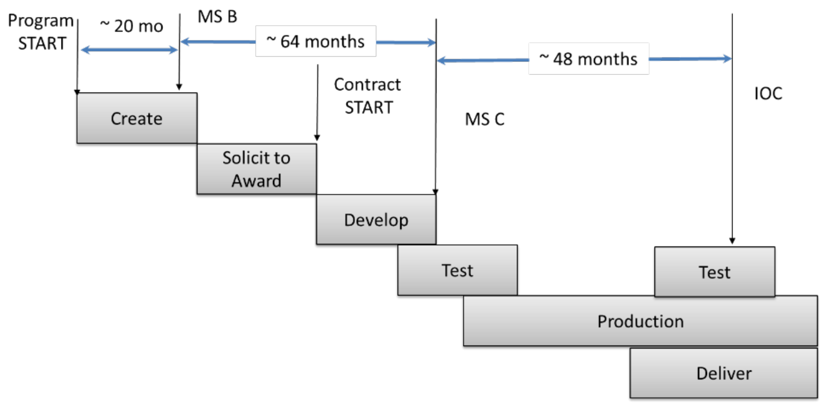

Figure 2. Program type block diagram

We developed similar block diagrams for modular, Agile, and MTA programs. The basic sequence followed an approve, develop, produce, test, and deliver sequence. Programs did not consistently report or follow this sequence. We simplified models by treating the following common event terms (names) as functionally equivalent:

- Milestone B (MS B), development contract award, and start of development,
- Design complete, design review, and Critical Design Review (CDR),
- Production start, low-rate production decision, production contract award and Milestone C (MS C), and
- Delivery, IOC, and full-rate production decision.

Some programs did not use certain events or release certain event dates such as IOC, and we were sometimes unable to find dates within the publicly released information for other program events. Table 6 summarizes inter-event duration variables.

Table 6. Inter-event duration variables

Variable	Description	Source
St.B	Start date to MS B (Award)	GAO
B.C	MS B to MS C	GAO/SAR
B.CDR	MS B to CDR (Develop)	GAO/SAR
C.CDR	CDR to MS C	GAO/SAR
C.IOC	MS C to IOC	GAO
CDR.IOC	CDR to MS C (Deliver)	GAO/SAR

We tested inter-event durations for significance using qualitative assessments of fit, and schedule growth / no-growth in an interval using Mood's median test. Program cycle time and schedule duration estimates are linear sums of these variables; the simplest estimator of cycle time using these intervals is B.IOC. Other estimates need adjustment for concurrency. We performed Monte Carlo simulations of inter-event durations and the Table 3 subset, simulated both Weibull and normally distributed durations, and scaled them to represent various schedule durations. We tested for significant program type differences between inter-event durations. We ran Monte Carlo simulations for each specific program type (MDAP, modular development, Agile development, and MTA). Figure 3 shows an example set of normal cumulative distribution functions for MTA programs where the planned durations vary from 60 months (MTA-60) to 24 months (Z.24).

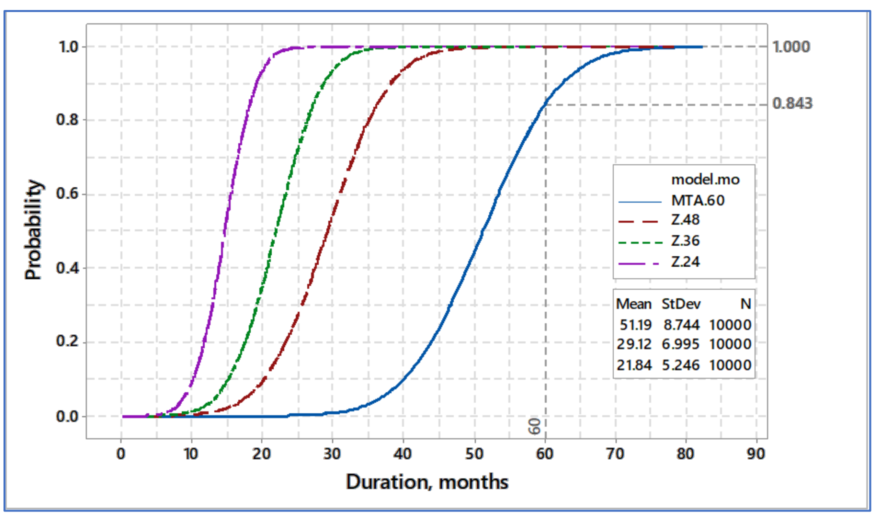

Figure 3. Monte Carlo simulation results- MTA duration cumulative distributions

In this example, the schedule risk is about 0.15 for the simulated 60-month (blue curve) duration models. We examined program schedule performance by plotting published program inter-event durations against the appropriate program type and duration, providing a qualitative representation of how well the program data fits simulated performance, as shown in Figure 4.

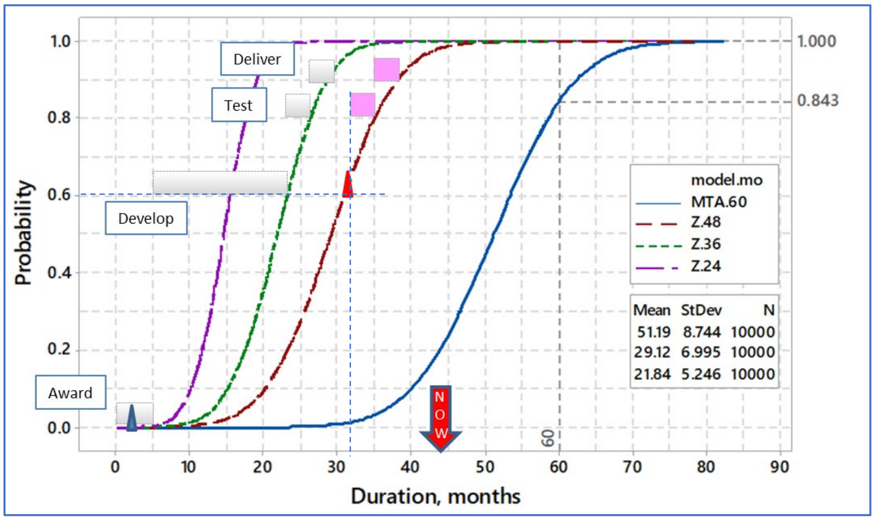

Figure 4. Example mapping of program plan to simulation model distributions

In Figure 4, the grey boxes represent published program events for a 36-month MTA simulation. The expectation is that schedule risk at 30 months should be about 0.2, consistent with a 36-month project. The red triangle is an example of a late completion, and aligns with event completion (develop), and the duration at development done (32 months). The remaining events (pink boxes) slip until the earliest start matches development done, while preserving sequence and overlap. The schedule slips to a new curve (36 months, red dash), a delay of 12 months. The schedule risk at development completion was 0.4, and the program should be nearly complete if test and delivery completed per the shifted estimate. This differs from earned-value-type methods (Bruchey, 2012) as we compare progress to a distribution as opposed to a planned baseline.

Schedule-related programmatic factors

We used two schedule-related factors as response variables, summarized in Table 7.

Table 7. Schedule-related response variables

Variable ID	Description	Source	Type
Cycle.Mo	cycle time in months	GAO	continuous
Cy.Mo.PCT	Percent change in cycle time since program start	GAO	continuous
SR	Schedule Risk (calculated from Cycle.Mo)	calculated	continuous

Cycle time (Cycle.Mo) is equivalent to B.IOC, (the sum of inter-event durations plus a concurrency factor)[21]. The second variable reflects the schedule change since program start (ST). We used these when considering interval significance. Significant programmatic predictor variables are in Table 8.

Table 8. Significant predictor variables

Variable ID	Description	Source	Notes	Type
RD.M	research and development (R&D) funding, $M	GAO		continuous
UC.M	Reported unit cost, $M	GAO		continuous
RD.M.PCT	Percent change in R&D budget since program start	GAO		continuous
LN.RD.M	Natural log transform of RD.M	Calculated	LN(RD.M+1)	continuous
LN.UC.M	Natural log transform of UC.M	Calculated	LN(UC.M+1)	continuous
ACQ_CODE	Acquisition type (MDAP/MTA)	GAO/ PB	GAO primary source	binary
Modular	Modular development	GAO/ PB	Based on review	binary
Agile	Agile development	GAO/ PB	Based on review	binary
MTA	Middle Tier Acquisition	GAO/ PB	Based on review	binary
ST	Start date	GAO/SAR		continuous
CMPCT.Gp	Schedule growth group	Calculated	"No growth" if Cy.Mo.PCT ≤ 0	binary

We used these variables to develop quantitative schedule predictors. Table 9 summarizes significant budget variables for RDT&E procurements.

[21] We did not calculate a schedule concurrency factor for this research.

Table 9. Significant budget variables

Variable ID	Description	Source	Notes	Type
Account	Appropriation Account number	OUSD(C)		categorical
BA	Budget Activity	OUSD(C)	Defined per FMR	categorical
BA.Title	Descriptive name	OUSD(C)		Text
PE.BLI	Program Element designator	OUSD(C)		Text
PE.Name	Descriptive name	OUSD(C)		Text
Modular	Modular development	PB	Based on review	binary
Agile	Agile development	PB	Based on review	binary
MTA	Middle Tier Acquisition	PB	Based on review	binary
FY2020	FY 2020 budget	OUSD(C)	Actual	continuous
FY2021	FY 2021 budget	OUSD(C)	Enacted	continuous
FY2022	FY 2022 budget	OUSD(C)	Request	continuous
ORG	Reduced set of organizations	PB/FMR	Defense agencies = DoD except Missile Defense Agency =MDA	categorical

We used these variables to analyze between-service differences and both sets of variables to test the research hypotheses.

Results and Analysis

Budget data exploration

We performed text searches of budget documents between fiscal years 2010 to 2022 inclusive to provide a qualitative estimate of activity for modular, agile and Middle Tier acquisition activity. Figure 5 shows cumulative use frequency in Army, Navy, and Air Force budget documents between FY2010 and FY2021 for reference.

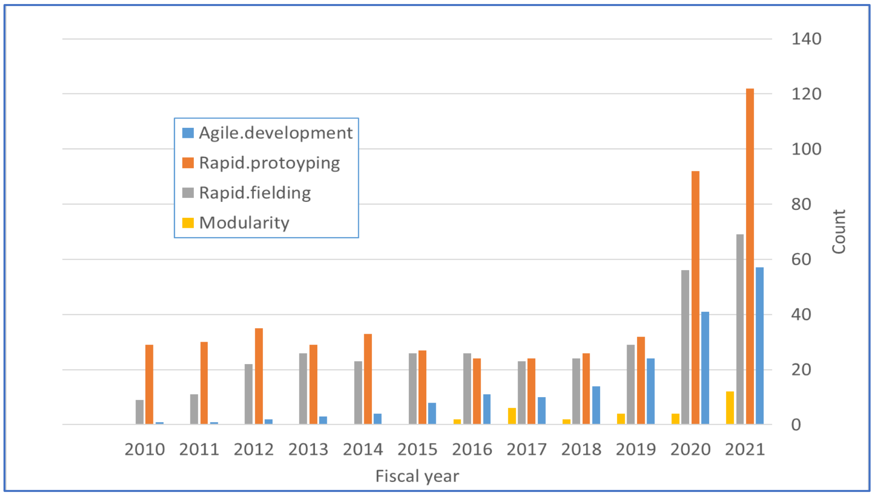

Figure 5. Term use frequency

Note that usage frequency changed in FY 2020 when the DoD implemented the Adaptive Acquisition Framework. The underlying meanings likely changed over time. For example, most "Agile development" projects were for either software or ground-based infrastructure, and used both Agile software development and Agile program management concepts. Figure 6 shows the use frequency and association at the Program Element (PE) level.

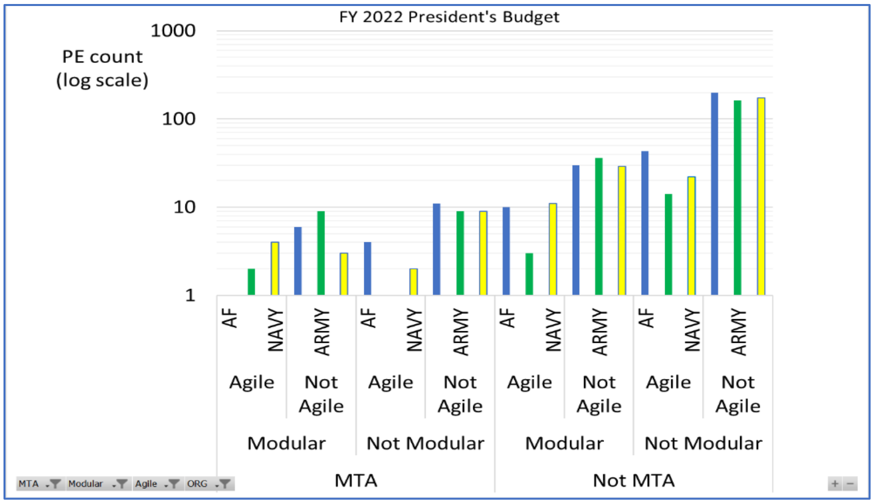

Figure 6. FY 2022 count by Service of RDT&E PEs with modular, Agile or MTA efforts

In this figure, blue bars represent the Air Force, green bars the Army, and gold and blue outlined bars the Navy PE counts for each category. Most PEs did not use modular, Agile or MTA within program descriptions (far right column, not MTA, not modular, not Agile), and only the Army and Navy had programs with all 3 within program descriptions (far left column). Tables of MTA projects in the FY 2022 budget submissions are included in the Appendix. Figure 7 shows how MTA projects are distributed by service, BA, and commodity type.

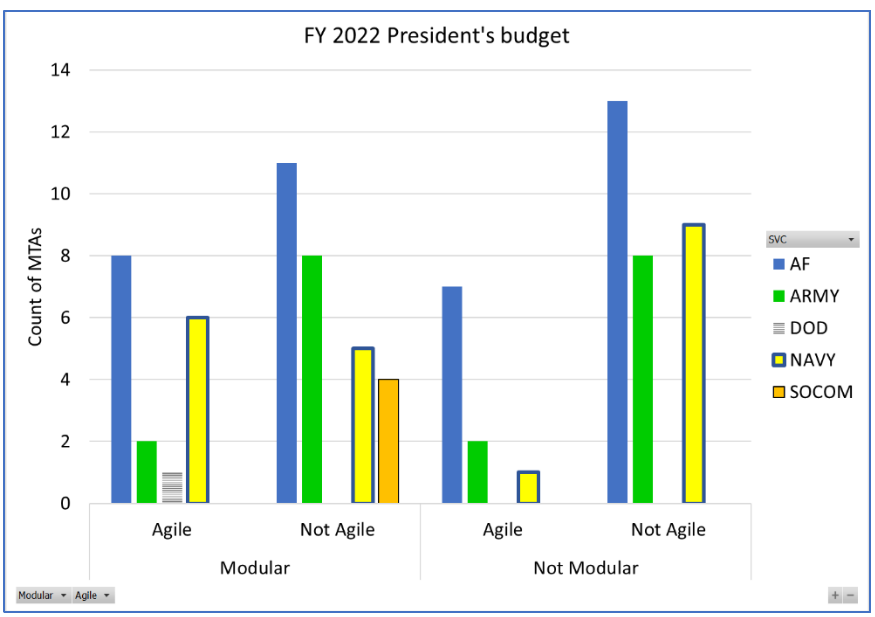

Figure 7. FY 2022 MTA Project-level summary

Figure 7 shows small differences between use of Agility and modularity, indicating services made intentional decisions to achieve specific program outcomes.

Modularity

Modern platform design and construction methods reduce system complexity. Programs may establish a common architecture and build variants with different capabilities. Figure 7 summarizes between-event duration differences for modular development programs.

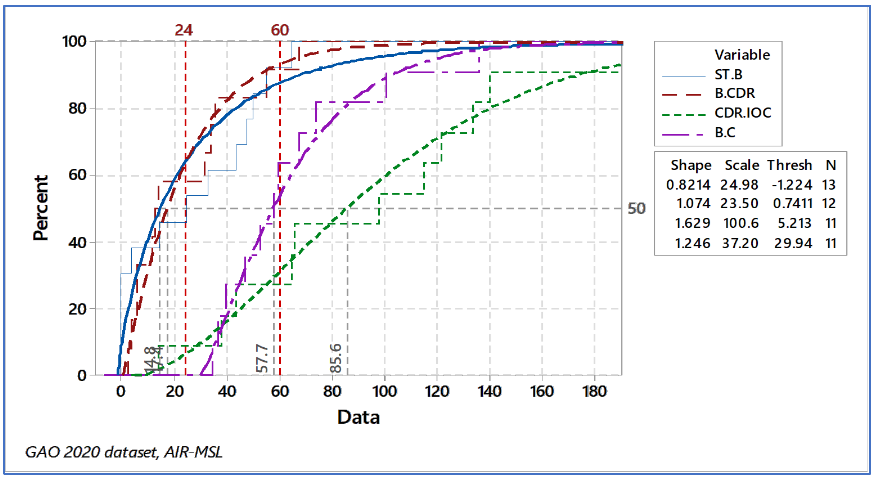

Figure 8. Modular development inter-event durations, Weibull distribution

For modular developments, the duration between MS B and MSC (B.C) grew slower than the intervals between MS B and CDR (B.CDR) and CDR and IOC (CDR.IOC), implying most schedule growth occurred after CDR and before IOC. This is consistent with needing additional time to build and test the actual system. Figure 9 shows a notional modular program schedule from start to IOC with heuristic interval durations.

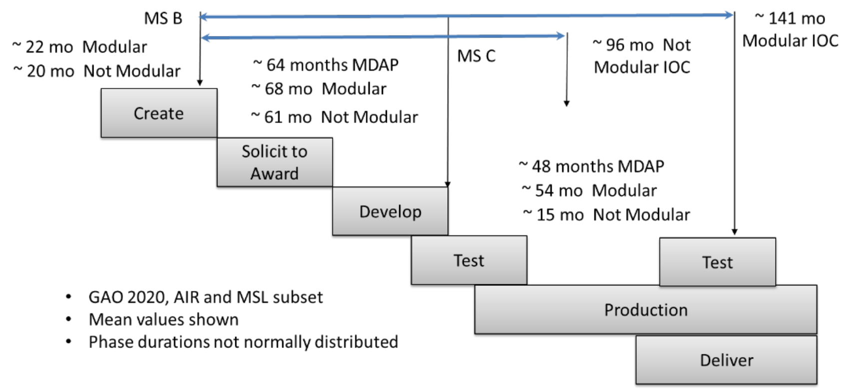

Figure 9. Comparison of modular and not-modular program schedules

Modular programs may need additional testing prior to initial delivery, resulting in a qualitatively longer cycle time. Follow-on changes typically require less time, provided the scope of change does not invalidate prior certifications or architectural conformance.

The services differ by average budget activity (BA) in their relative RDT&E investments, reflecting their differing priorities and needs. Figure10 summarizes modular development budgets by BA and service for FY 2020-2022.

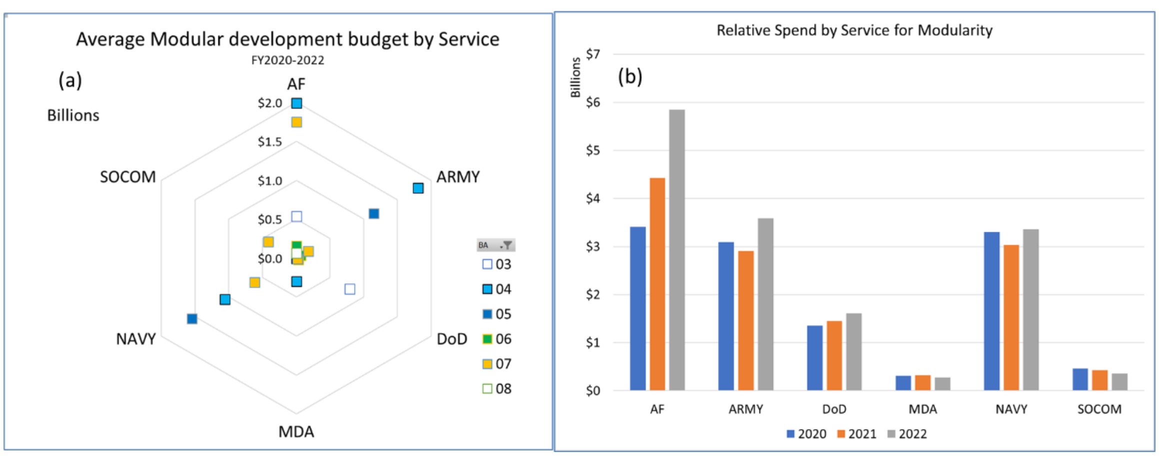

Figure 10. Modular development summary - RDT&E, BA, and Service level

The Army and Navy have roughly equivalent investments in modular development; the Air Force increased the budget associated with modular development between 2020 to 2022. Most modular development is occurring in three budget activities (BAs): BA-04 Advanced Component Development and Prototypes; BA-05; System Development and Demonstration; and BA-07- Operational System

Development. Table 10 summarizes FY 2022 modular development projects by service and BA.

Table 10. Count of FY 2022 service PEs with modular development projects by BA

Modular	AIR	C3I	GND	MSL	Other	SHIP	SPACE	Total
AF	12	9		3	10		4	38
04		3		2	2		3	10
05		1			4			5
07	12	5		1	4		1	23
ARMY	7	16	10	4	10		1	48
04	2	5	4		4			15
05	1	10	6	2	5		1	25
07	4	1		2	1			8
NAVY	10	11	2	1	13	9	1	47
04	1	2			5	8		16
05	6	6		1	4			17
07	3	3	2		4	1	1	14
Total	29	36	12	8	33	9	6	133

Across all services, modular investments are mainly in electronics (C3I) and ground-based command and control and training systems (other).

Agile

Figure 11 shows inter-event durations for Agile development projects in the GAO 2020 Air and Missile dataset.

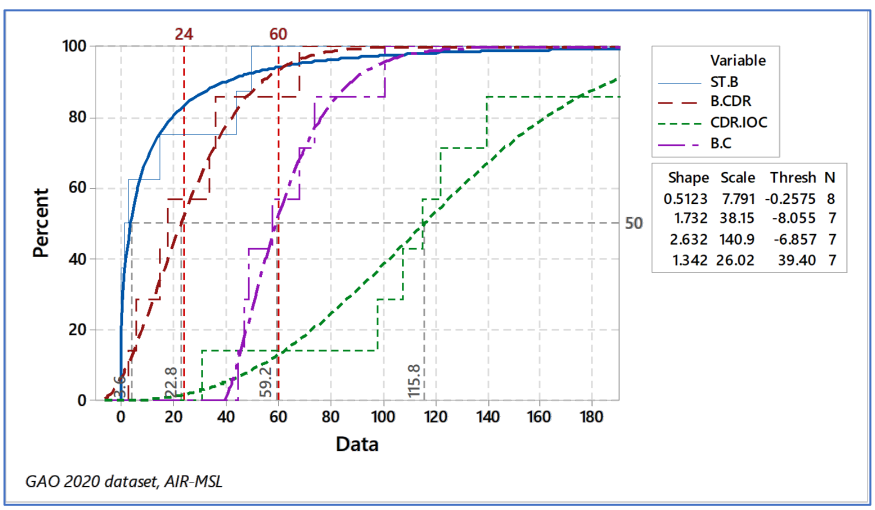

Figure 11. Agile-inter-event durations, Weibull distribution

Agile development programs tend to start quickly through MS B and CDR, then slow through IOC. Figure 12 provides a notional schedule.

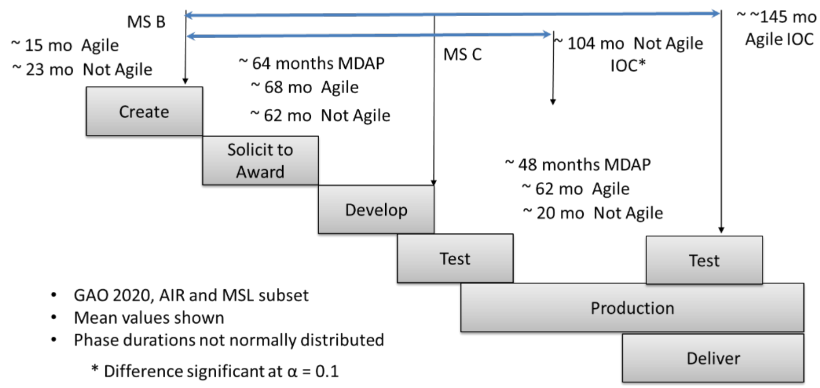

Figure 12. Agile and Not-Agile development schedules

Agile development programs did not always have a clear end date or IOC, and may be related to determining the "definition of done" (Cummings, 2020), essentially when the accumulated product value meets the customer requirement. While "definition of done" is normally a software development issue, it may also reflect in-service use, date of authority to operate, or another defined state. This definition problem exists in Agile development and Middle Tier acquisition programs. If IOC was not stated, we chose either the latest specified product delivery date or the last date in the budget submission, which contributes to this extended duration. Figure 13 summarizes Agile development budgets by BA and service for FY 2020-2022.

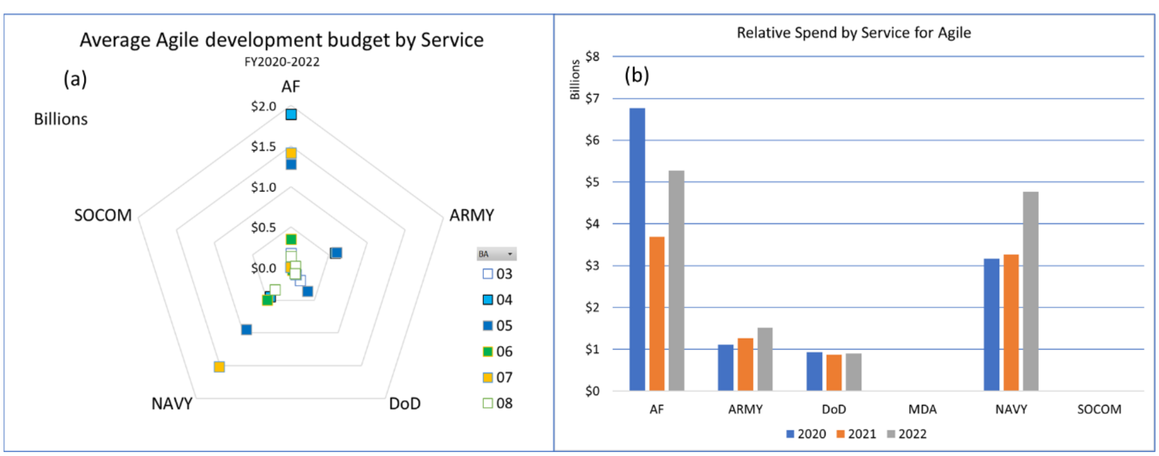

Figure 13. Agile development summary - RDT&E, BA, and Service level

Most Agile development activity aligns with Air Force efforts; the Navy increased budget allocated to Agile development in 2022. Most Agile developments are associated with C3I and Other commodity type efforts within PEs by BAs as shown in Table 11.

Table 11. Count of FY 2022 service PEs with Agile development by BA

Agile	AIR	C3I	GND	MSL	Other	SHIP	SPACE	Total
AF	4	14		3	19		8	48
04	1	5		1	8		2	17
05	1	2		2	3		2	10
07	2	7			8		4	21
ARMY	1	7			10		1	19
04	1	1			4		1	7
05		4			6			10
07		2						2
NAVY	6	11	1		8	6	2	34
04		3			3	3		9
05	1	4			2	3		10
07	5	4	1		3		2	15
Total	11	32	1	3	37	6	11	101

Agile development often includes Agile software development, which is supporting for software maintenance and sustainment of Other and C3I systems in Table 11. The stated reasons for Agile development are speed and reducing cost.

Middle Tier Acquisitions

Middle Tier Acquisitions are far from standardized. The services, led by the Air Force, are experimenting with the exceptional authorities. Figure 14 shows fitted Weibull curves for the GAO 2020 dataset MTAs. There are no explicit rapid fielding MTAs in this dataset; not all MTAs had a stated CDR and IOC, resulting in an incomplete representation.

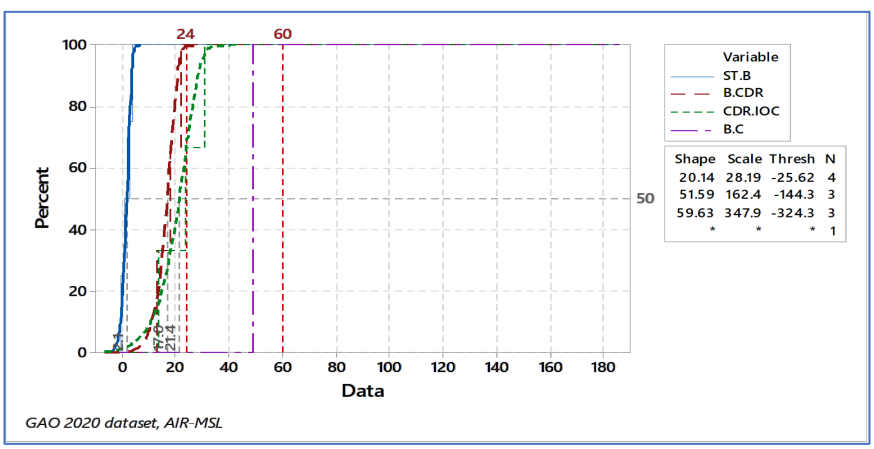

Figure 14. MTA inter-event durations, Weibull distribution

The Figure shows a very quick start (St.B) and progress to IOC. This indicates common use of fast solicitation, source selection, and contracting approaches are common for MTAs. Figures 15 and 16 provide notional models of the two types of MTAs.

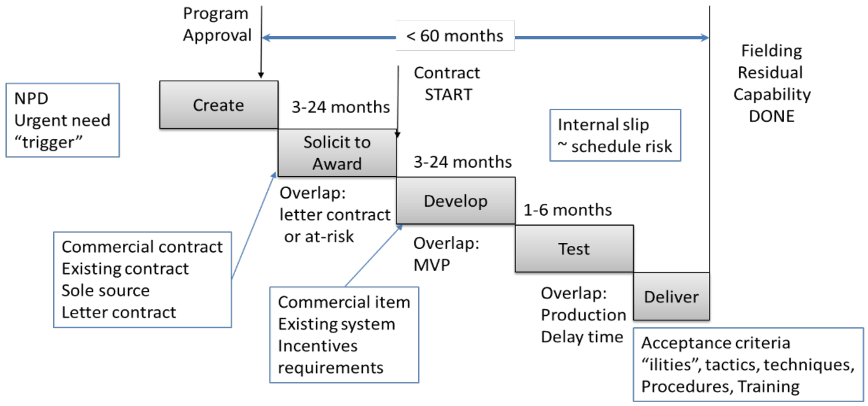

Figure 15. MTA Rapid Prototyping schedule model

The Rapid Prototyping MTA is the most common model. The product is a prototype or residual capability. The text blocks describe key factors in the MTA process. Figure 16 summarizes the MTA Rapid Fielding model.

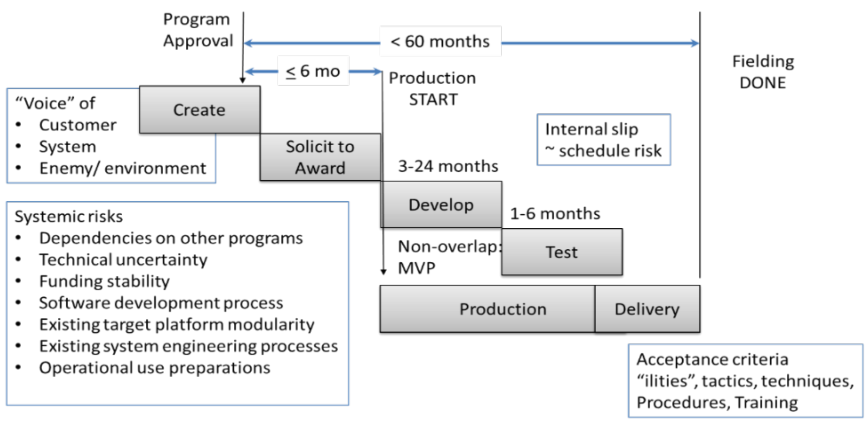

Figure 16. MTA rapid fielding schedule model

Unlike the Rapid Prototyping model, the MTA Rapid Fielding is intended for delivery of operational products. Figure 17 shows the MTA budgets by PE and service.

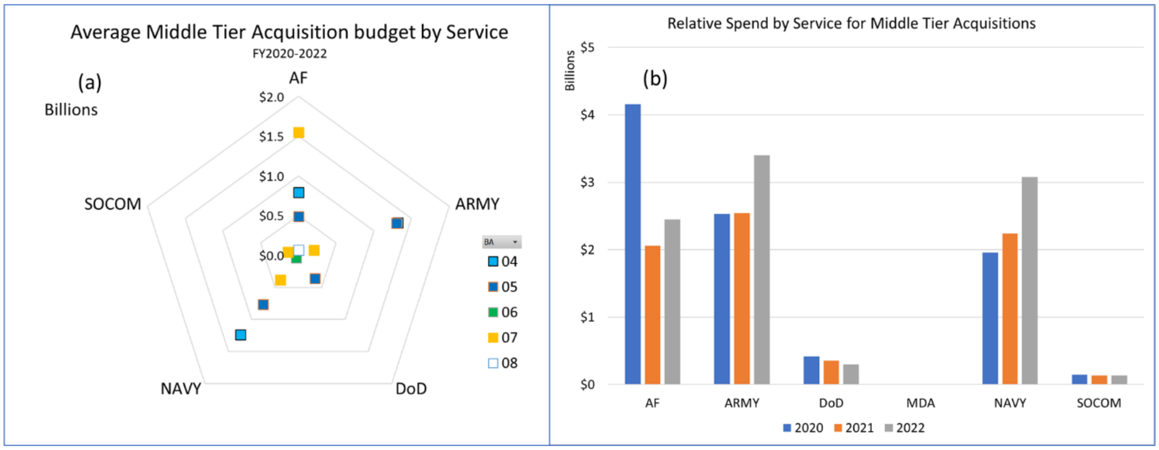

Figure 17. MTA development summary - RDT&E, BA, and Service level

The Air Force had the largest budget and effort in MTAs in 2020, suggesting a different risk appetite. The Army had the largest budgets associated with MTAs in 2021 and 2022. Navy had the smallest MTA investment of the three services, but steadily increased between 2020 to 2022.. Table 12 provides a summary of the distribution by Service, BA, and commodity type of PEs with MTA activity in FY 2022.

Table 12. Count of FY 2022 service PEs with MTAs by BA

MTA	AIR	C3I	GND	MSL	Other	SHIP	SPACE	Total
AF	6	6		2	1		6	21
04	1	1		2			5	9
05							1	1
07	5	5			1			11
ARMY	3	6	7	2	3			21
04	3	1	2		1			7
05		5	4	2	2			13
07			1					1
NAVY	1	4	2	4	4	1		16
04			1	2	1	1		5
05	1	1		1	3			6
07		3	1	1				5
Total	10	16	9	8	8	1	6	58

The Air Force has significant investment in advanced (BA-4) and operational systems (BA-7) development. Again, the services show different investment strategies and areas of emphasis in their approach to MTAs, and project level detail is in the Appendix. The tabular counts are different as the Appendix is at the project and not PE level.

We assessed Air Force MTA investment activity at the project level, summarized in Figure 18.

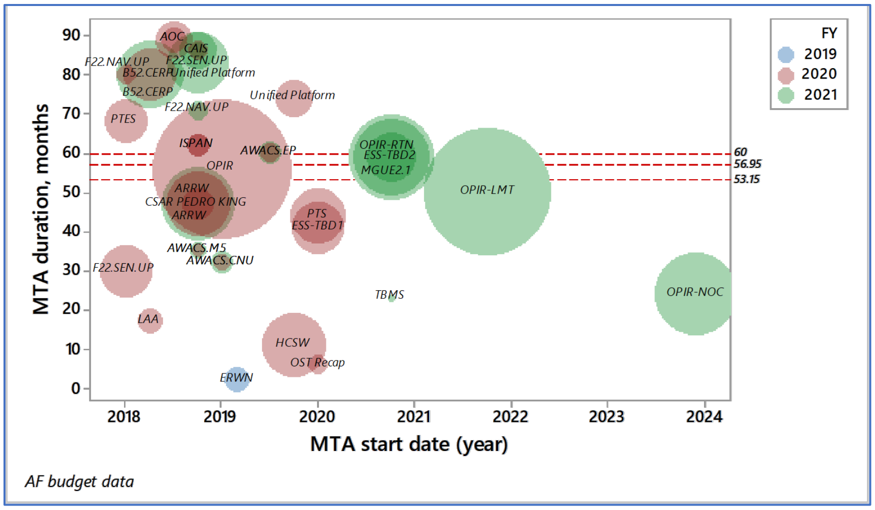

Figure 18. Air Force MTA portfolio summary

MTAs without explicit end dates in budget documentation are above the 60-month limit line. Figure 18 shows an evolving strategy, as the service becomes familiar with MTAs. Space systems such as OPIR are a significant portion of the overall activity.

These budget comparisons show the Air Force allocated more RDT&E funds to modular and Agile developments and MTA programs than either the Army or the Navy. We included other DoD agencies to provide a sense of proportion. Most RDT&E modular, Agile and MTA efforts are within the three services. Agile development and Modular system are found in procurement documents, and Middle Tier and Open System are more common in research and development documents. The Air Force has more recent Agile development and Middle Tier acquisition term usage that the other services. Agile development and open system activities are growing in all services. Open systems are a sustained emphasis in research and development, and Middle Tier acquisitions are a recent development.

At the PE level, most modular, Agile and MTA RDT&E funding is in three budget activities (BAs) – BA-4 (Advanced Component Development and Prototype), BA-5 (System Development and Demonstration), and BA-7 (Operational Systems Development). The next sections provide additional detail by BA and service for modular, Agile and MTA activities documented in the FY 2020 FY 2022 President's Budgets and in publicly released records.

Modeling program schedule duration for modular, agile and MTA programs

We developed several schedule models, including programmatic factors, inter-event durations, and hybrid models. These models are summarized in the following sections.

Cycle time and schedule duration regression modeling

We previously developed multivariate regressions relating cycle time to programmatic factors (Etemadi & Kamp, 2021b), summarized in Table 13.

Table 13. Cycle time (schedule) regression model summary

Factor	Coefficient	Contribution	p-value	VIF
Intercept	1.6			
LN(R&D budget)	12.66	25.87%	0.000	1.13
PCT change (R&D)	37.74	20.32%	0.000	1.17
LN(Unit cost estimate)	4.97	6.75%	0.013	1.03
MTA = TRUE	***-39.28***	11.94%	0.000	1.03
S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**	
34.74	64.88%	61.90%	51.23%	

This model provides little insight into when schedule growth occurs. We measured inter-event durations from the FY 2020 dataset. Figure 19 shows the cumulative distribution functions for MDAP inter-event durations, fitted to 3 parameter Weibull distributions.

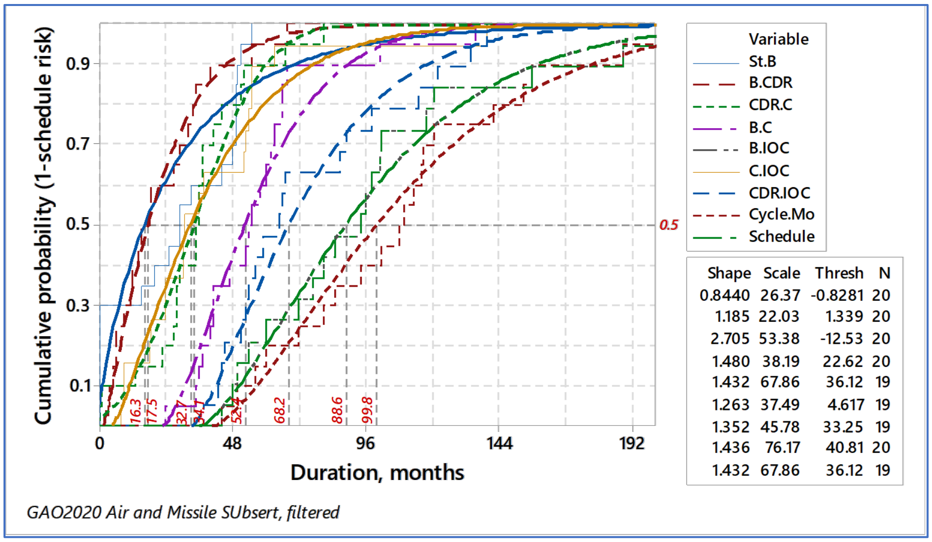

Figure 19. MDAP inter-event durations, Weibull distribution

We define a term, *schedule*, as the sum of B.CDR and CDR.IOC. It hides the B.IOC curve in Figure 19, and is within 20 months of reported cycle time (Cycle.Mo). Table 14 summarizes inter-event distribution statistics for the GAO 2020 dataset Air and Missile commodity type MDAPs.

Table 14. Inter-event duration statistics (GAO 2020 dataset)

Interval	N	Mean	StDev	Min	Med	Max	IQR	Scale	Shape	Threshold
St.B	20	27.3	21.38	0	29	55	49	0.844	26.37	-0.8281
B.CDR	20	22.1	17.81	3	16.5	68	26.75	1.185	22.03	1.339
CDR.C	20	35.05	19.22	0	35.5	81	16	2.705	53.38	-12.53
B.C	20	57.15	25	24	54.5	136	25	1.48	38.19	22.62
CDR.IOC	19	75.05	32.49	38	65	140	47	1.352	45.78	33.25
Cycle.Mo	20	110.3	48.2	44	109	237	62.5	1.436	76.17	40.81

Some terms are equivalent to cycle time (Cycle.Mo) and are not included in Table 14[22]. Not all programs report CDR, Milestone C (MS.C), or IOC[23]. Table 15 summarizes significant Pearson correlation results between program schedule (Cycle.Mo), schedule growth (Cy.Mo.PCT) and inter-event durations for the Table 14 dataset.

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[22] We used these and similar statistics to seed Monte Carlo simulations discussed in section 4.2.2.
[23] There was no good equivalent for CDR. Table 14 used a reported Low-Rate Initial Production Decision as a proxy for Milestone C, and a reported Full Rate Production decision date as a proxy for IOC.

Table 15. Schedule and schedule growth correlations to inter-event durations

	Cycle.Mo	Cy.Mo.PCT	St.B	B.CDR	CDR.C	B.C
Cy.Mo.PCT	0.589**					
St.B						
B.CDR	0.794***					
CDR.C		0.553*				
B.C	0.622***	0.690***		0.643**	0.705***	
CDR.IOC	0.820***	0.832***		0.584**	0.425*	0.750***

0.xxx - ≤ 0.1* *0.xxx** ≤ 0.01* *0.xxx*** ≤ 0.001*

Note that time from program start to development start (St.B) is not correlated with cycle time, as MDAPs may start at Milestone B or C (Lord, 2020a). Similarly, the time from CDT to Milestone C (CDR.C) is also not correlated with cycle time. We developed simple regression models for the Table 14 dataset, relating inter-event durations to programmatic factors, summarized in Table 16.

Table 16. Inter-event regression MDAP model summary[24]

Term	B.CDR	CDR.IOC	Schedule
constant	224.4	***-51.7***	***-101***
LN.UC.M	4.09		
ST (start date)	***-0.005***		
LN.RD.M		15.16	23.98
RD.M.PCT		47.7	60.5
R-sq(pred)	56.18%	70.20%	80.07%

These models satisfied regression assumptions[25]. Negative numbers are in ***bold italic*** for clarity. In general, increasing unit cost (LN.UC.M) is associated with longer B.CDR, and increasing R&D budgets (LN.RD.M) and R&D budget growth (RD.M.PCT) increases CDR.IOC.

Monte Carlo simulation results-Weibull distribution

We compared simulation results for the four major program types – MDAP, modular development (modular), Agile development (Agile), and Middle Tier Acquisition (MTA), and provide analysis for three inter-event durations. We performed these simulations to estimate the likely durations of key intervals. The simulations show that

[2424] Air and Missile commodity types, less IFPC.Inc 2 and P-8 Inc 3.
[25] Agile-coded programs were outliers. Filtered Agile to remove outliers and reflect traditional MDAP attributes.

the program types are statistically different, which is reasonable given the starting samples.

A key observation is that MTAs are quite different from traditional MDAPs, modular development, and Agile development programs. Additionally, for most examined intervals, there are intersection points where several program types achieve similar results.

The following Figures summarize schedule risk for MDAPs, modular development, Agile development, and MTAs for each interval. The interval from program start to Milestone B (St.B) is programs define requirements, mature technologies, retire risks, and obtain approval to start development. Figure 20 shows St.B simulation results.

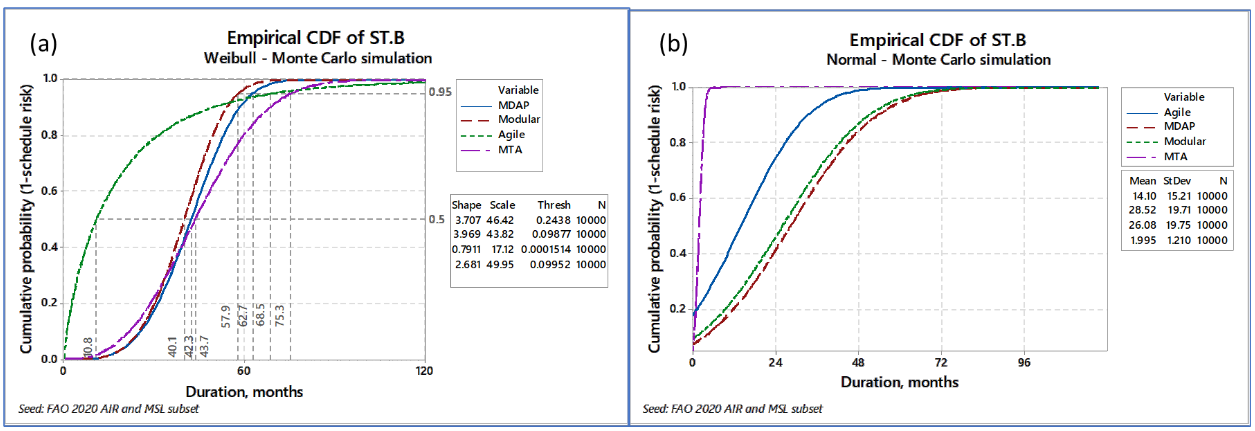

Figure 20. Monte Carlo simulation of start to MS B (St.B) durations by program type

The Figure 20a simulation results show that Agile development starts quickly, but shows other models, including MTAs, will take over 4 years to reach MS B. We assess this is an anomaly due to the small seed populations overweighting Weibull extremes. Figure 20b assumed a normal distribution, and produced results consistent with observed interval durations and consistent with differences in requirements specificity (Agile development accepts incomplete and uncertain requirements) needed for development start. *A rapid development program should constrain requirements engineering and plan for contract modifications during development.* These results may not be correct for rapid fielding-type MTAs, or MTAs using rapid contract and agreement award processes. *Programs have successfully reduced time to development start by using commercially available or in-use systems.*

We analyzed the interval schedule risk B.CDR and CDR.IOC, as these two intervals account for most schedule growth. We looked at schedule risk in terms of absolute schedule and scaled (relative) schedules. Figure 21 shows simulation results for B.CDR.

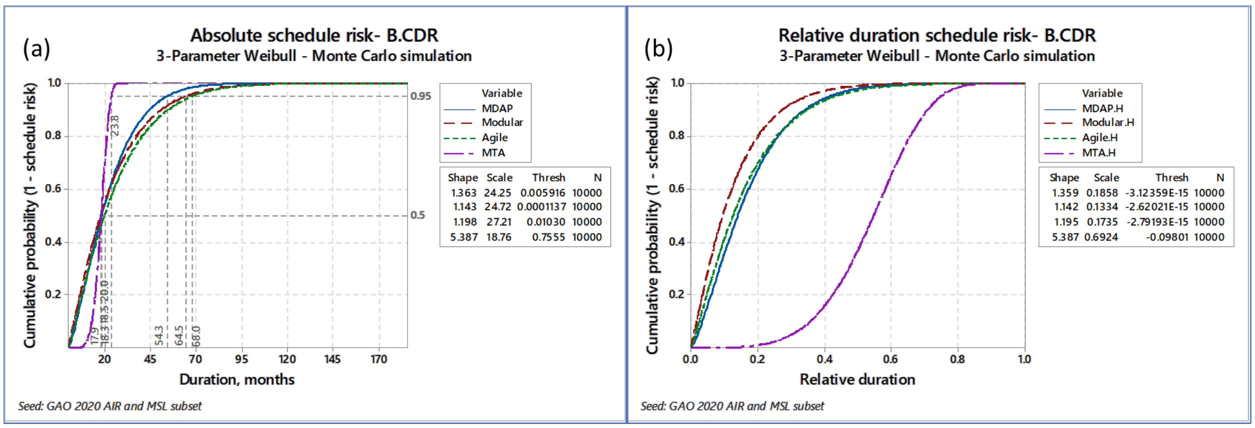

Figure 21. Monte Carlo simulation of B.CDR durations by program type

Figure 21a shows that MTAs have the lowest absolute B.CDR schedule risk, and Figure 21b, shows that MTAs have the highest B.CDR interval schedule risk. In Figure 21a, modular and Agile programs have slightly more schedule risk than MDAPs; in Figure 21b, modular programs have the lowest relative interval schedule risk.

About half of all programs[26] complete CDR within 20 months of MS B, and 95 percent of MTAs will reach CDR in less than two years, whereas the other modeled programs would take 3 to 4 more years. MTAs may not have an explicit design review (CDR), but any design review or approval would likely occur between 8 and 20 months after development start to meet an overall 60-month schedule limit. This interval is a proxy for *design complexity*, with more complex designs requiring more time before CDR. One approach to reduce time to complete CDR is to plan for a minimum viable product, where the CDR and initial IOC are for a less complex version, and then

[26] Including MDAPs, MTAs, and Modular and Agile development programs.

program for follow-on versions. This strategy does add complexity to certification and testing.

Figure 221 shows simulation results for the interval between CDR and IOC.

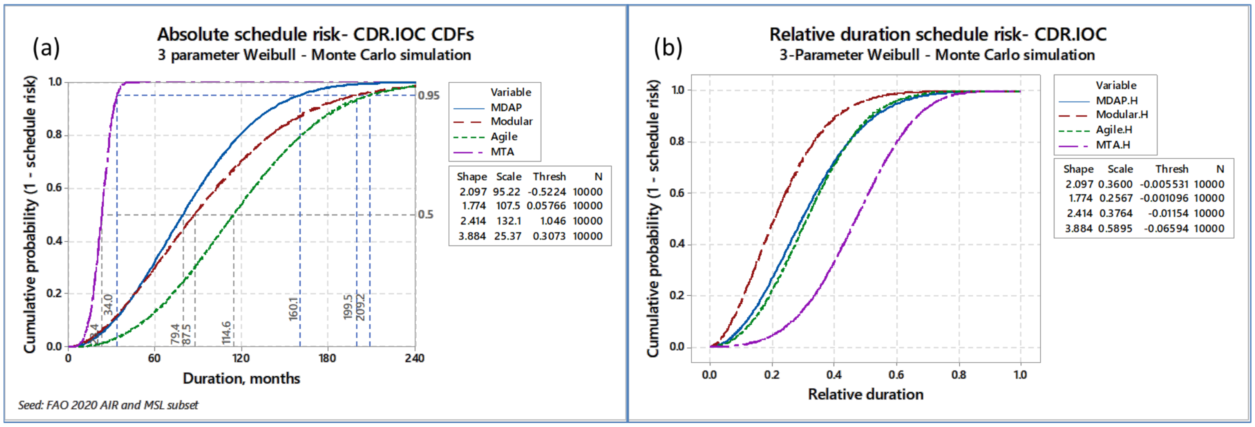

Figure 22. Monte Carlo simulation of CDR.IOC durations by program type

In Figure 22a, MTAs have the lowest, and Agile the highest absolute CDR.IOC interval schedule risk. In Figure 22b, modular programs have the lowest, and MTAs the highest relative CDR.IOC interval schedule risk.

Again, MTAs may not have a CDR or IOC, but they should have a short time to completion (prototype delivery). Modular and Agile development programs have longer times to IOC relative to a traditional MDAP. We assess this is due to increased testing requirements for an initial modular development. These extended durations reflect delivery of additional capability increments or versions, for example multiple versions of a fighter aircraft which IOC at different times. This duration relates to the program definition of IOC. Services have accelerated IOC by early fielding with contractor training and support and combined development and operational testing, and by waiving specific requirements. An example would be waiving long-term storage (shelf life) requirements for munitions planned for operational use within a year, if such requirements add time to production and testing.

Finally, Figure 23 summarizes overall simulation results by program type.

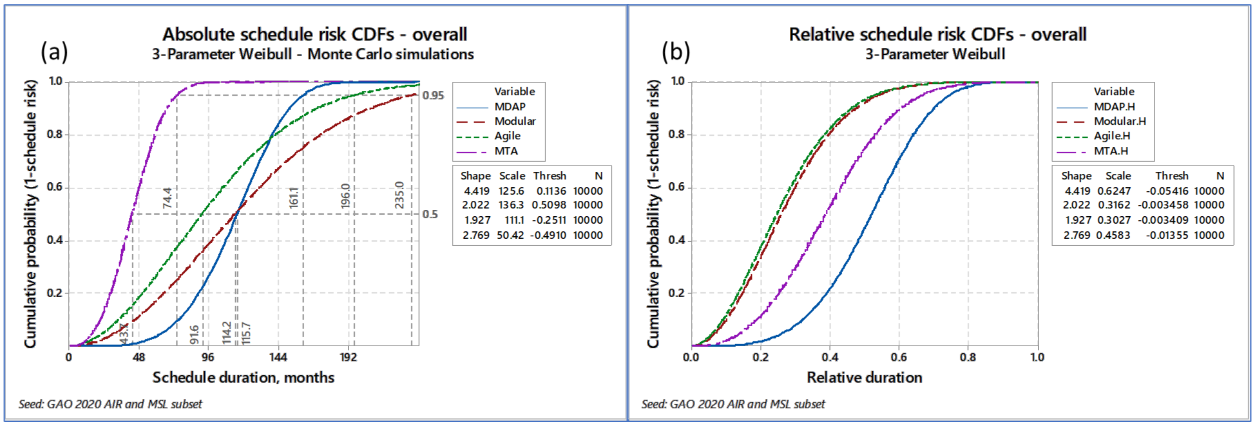

Figure 23. Overall schedule Monte Carlo simulation results

Figure 23a shows that MTAs have the lowest absolute schedule risk, while modular and Agile programs have lower schedule risk for shorter programs than MDAPs. This is due to their pronounced right skewed distributions. Figure 23b shows that modular and Agile programs carry the lowest, and MDAPs the highest relative schedule risk

Effect of Modularity, Agility, and MTA on program schedule performance

We assessed the effect of software development type on inter-event durations. We divided software development methods into Agile (meaning incremental development and deliveries) and other (single step or waterfall). Figure 24 summarizes testing results.

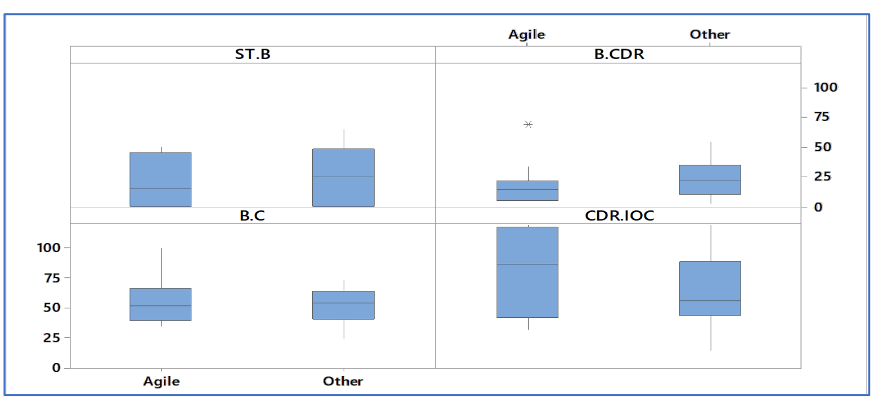

Figure 24. Comparison of inter-event durations by software development type

Agile software development is significant during B.CDR. This is consistent with the emphasis on incremental design and development. The CDR.IOC results reflect that most programs have other factors affecting IOC. A Mood's Median test shows only B.CDR is significant at α = 0.05.

We tested empirical intervals for significance using Welch's method t-tests. The MTA data is sparse, so a p-value < 0.05 implies a large test statistic. Table 17 shows two-sample t-test results comparing program types.

Table 17. Inter-event interval and duration testing by program type

	REF1	ALT (2)	μ1	μ2	σ1	σ2	N1	N2	TValue	DF	PValue
B.CDR	MDAP	MTA	21.24	17.67	16.16	4.51	18	4	0.81	18	0.430
	MDAP	AGILE	21.24	15.2	16.16	12.19	18	6	0.96	11	0.356
	MDAP	MODULAR	21.24	13.78	16.16	11.61	18	9	1.37	21	0.184
C.CDR	MDAP	MDAP20	32.94	34.78	17.49	17.92	18	27	-0.34	37	0.734
	MDAP	MTA	32.94	31	17.49	0	18	4	0.47	17	0.644
	MDAP	AGILE	32.94	44.8	17.49	15.45	18	6	-1.57	9	0.150
	MDAP	MODULAR	32.94	40	17.49	15.45	18	9	-1.07	18	0.299
CDR.IOC	MDAP	MDAP20	83.4	75.79	48.7	45.78	18	27	0.53	34	0.602
	MDAP	MTA	83.4	23	48.7	8.54	18	4	4.93	19	*0.000*
	MDAP	AGILE	83.4	94.8	48.7	36.8	18	6	-0.60	11	0.559
	MDAP	MODULAR	83.4	70.3	48.7	38.5	18	9	0.76	19	0.456
C.IOC	MDAP	MDAP20	54.2	45.64	47.5	42.29	18	27	0.62	33	0.541
	MDAP	MTA	54.2	0	47.5	0	18	4	4.84	17	*0.000*
	MDAP	AGILE	54.2	50	47.5	29.6	18	6	0.25	14	0.802
	MDAP	MODULAR	54.2	35.86	47.5	22.64	18	9	1.36	24	0.187
B.C	MDAP	MDAP20	56.83	57	36.19	23.71	18	27	-0.02	26	0.986
	MDAP	MTA	56.83	49	36.19	0	18	4	0.92	17	0.371
	MDAP	AGILE	56.83	60	36.19	23.5	18	6	-0.25	13	0.809
	MDAP	MODULAR	56.83	53.88	36.19	21.24	18	9	0.27	24	0.792
Cycle.Mo	MDAP	MDAP20	96.4	97.6	45.5	52.1	18	27	-0.08	39	0.935
	MDAP	MTA	96.4	25.25	45.5	44	18	4	2.91	4	*0.044*
	MDAP	AGILE	96.4	98	45.5	51.2	18	6	-0.07	7	0.948
	MDAP	MODULAR	96.4	104.9	45.5	45.5	18	9	-0.46	16	0.653

The table shows a difference between MDAP and MTA cycle times, and no significant difference between MDAP and modular or Agile development program schedule durations and schedule growth. Modular and Agile development did not statistically change program growth performance. We used Mood's Median Test to test for significant schedule growth/no growth within an interval as shown in Table 18.

Table 18. Mood's Median test - Interval growth testing

Interval	Schedule Growth	Overall median	Median	≤ Median	> Median	DF	Chi-Square	P-Value
St.B	Growth	25	33	6	7	1	0.33	0.568
	No growth		12	8	6			
B.CDR	Growth	18	29	5	8	1	3.38	**0.066**
	No growth		15	9	3			
CDR.C	Growth	35	35	7	6	1	0.03	0.855
	No growth		35.5	5	5			
CDR.IOC	Growth	62	77.5	4	8	1	2.67	0.102
	No growth		48	8	4			
B.C	Growth	54	60	5	8	1	2.25	0.133
	No growth		47	7	3			
Cycle.Mo	Growth	102	117	3	10	1	8.32	**0.004**
	No growth		66	11	3			

Program growth was significant at α = 0.1 in B.CDR, and at α = 0.15 in CDR.IOC and B.C. Table 19 shows two sample t-test results of comparing schedule risk between program types.

Table 19. Schedule risk testing between program types

	REF1	ALT (2)	μ1	μ2	σ1	σ	N1	N2	TValue	DF	PValue
SR	MDAP	MDAP20	0.516	0.465	0.269	0.288	18	24	0.59	38	0.561
	MDAP	MTA	0.516	0.072	0.301	0.096	18	4	5.19	16	*0.000*
	MDAP	AGILE	0.516	0.533	0.301	0.329	18	6	-0.11	7	0.914
	MDAP	MOD	0.516	0.570	0.301	0.275	18	10	-0.48	20	0.634

The MTA result requires explanation. The MDAP distribution does not include MTAs, and the MDAP20 distribution does include MTAs. This is comparing MTA performance against a distribution without MTAs. The shorter schedule of an MTA would make the schedule risk appear low relative to a traditional MDAP. This reinforces the need to compare programs against distributions of similar programs when estimating schedule risk.

Predicting schedule risk

We plotted FY 2022 dataset programs by B.CDR and CDR.IOC intervals in Figure 25.

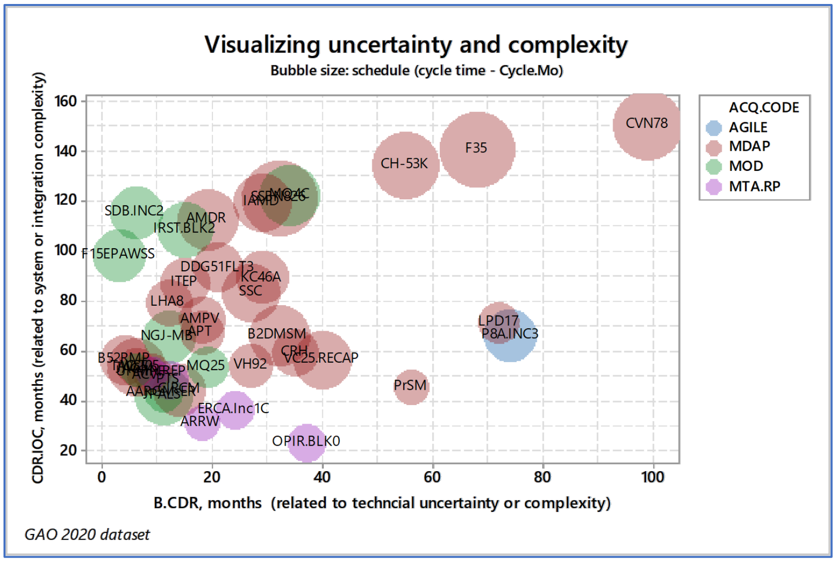

Figure 25. Visualizing relative uncertainty and complexity

Figure 25 shows that modular development programs have lower relative technical uncertainty or complexity, as they are clustered to the lower end of the B.CDR scale, as are MTAs, while MDAPs are spread across the scale. In a similar fashion, Modular and Agile development programs have similar CDR.IOC spreads to MDAPs, while MTAs are clustered at the low end of the CDR.IOC scale, reflecting their lower integration or system complexity.

We fitted Weibull distributions and polynomials to GAO cycle time (schedule), estimated overall schedule risk, and calculated inter-event durations. Figure 26 shows overall schedule risk compared to these durations.

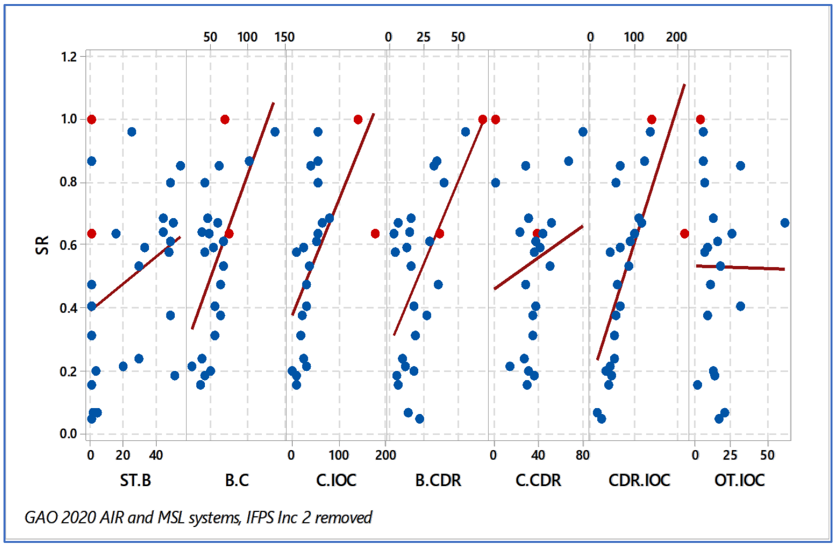

Figure 26. Schedule risk (SR) for inter-event durations

The red lines are linear regression fits. The red dots are influential points, specifically the F-35 (nearly 6 years to CDR), the CH-53K (nearly 7 years from CDR to MS C), and the P-8A Increment 3 (nearly 15 years from MS C to IOC). Four durations are qualitatively more associated with schedule risk – B.C, C.IOC, B.CDR, and CDR.IOC. Of these, B.CDR and CDR.IOC span program development.

We developed simple univariate schedule risk regressions based on this data. Table 20 summarizes schedule univariate risk regressions.

Table 20. Schedule risk regressions by inter-event duration

Term	Equation	constant	coefficient	P-value	R-sq(pred)
CDR.IOC	SR= 0.0220 + 0.00680 *CDR.IOC	0.022	0.0068	0.000	62.38%
C.IOC	SR= 0.2171 + 0.00870* C.IOC	0.217	0.0087	0.000	43.62%
B.C	SR= 0.183 + 0.00607* B.C	0.183	0.0061	0.003	26.97%
B.CDR	SR= 0.2819 + 0.01037* B.CDR	0.282	0.0104	0.012	13.68%
St.B	SR= 0.3222 + 0.00531* St.B	0.322	0.0032	0.026	4.91%
C.CDR	SR= 0.311 + 0.00580 * C.CDR	0.311	0.0058	0.068	0.00%

As SR considers only remaining schedule, adding terms (suggesting more time is needed to define requirements, mature technologies, and retire risks) does not necessarily estimate overall schedule risk. We also did not explicitly model any milestone concurrency or additional milestones. Figure 27 graphically shows how SR is related to B.CDR and CDR.IOC.

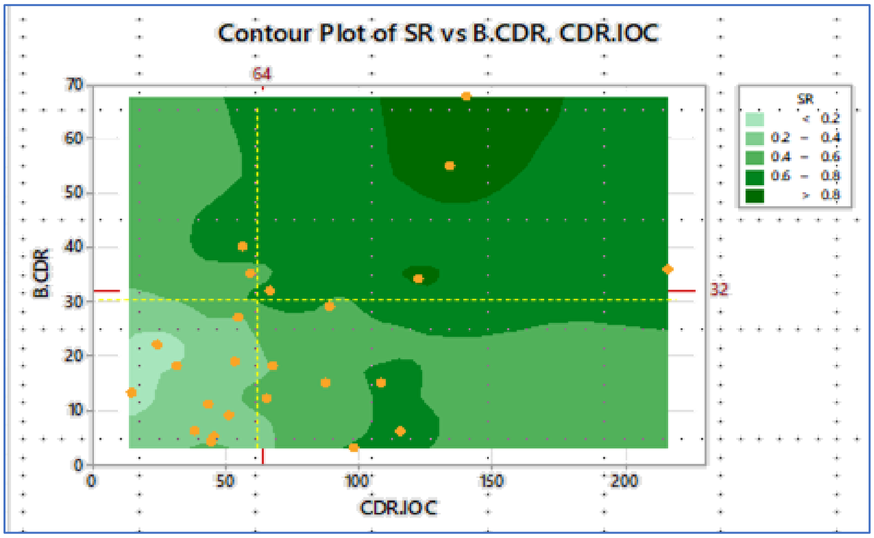

Figure 27. Schedule risk versus significant growth intervals

Figure 27 suggests a heuristic for this dataset, namely schedule risk is higher (greater than 0.6) for air and missile systems, if the interval between milestone B and CDR (B.CDR) is more than 30 months, and the interval between CDR and IOC (CDR.IOC) is more than 60 months. We summarized regression models in section 4.2 (Table 16) relating schedule risk to programmatic factors, and repeat them here in equation form:

$$B.CDR = 224.4 + 4.09 * LN.UC.M - 0.005 * ST$$
$$CDR.IOC = -51.7 + 15.16 * LN.RD.M + 47.7 * RD.M.PCT$$

These show that B.CDR is related to unit cost (LN.UC.M) and start date (ST), and CDR.IOC is related to R&D budget (LN.RD.M) and change in R&D budget (RD.M.PCT). Figure 28 shows the relationship between schedule risk, program R&D budget, and software delivery rate for air and missile systems.

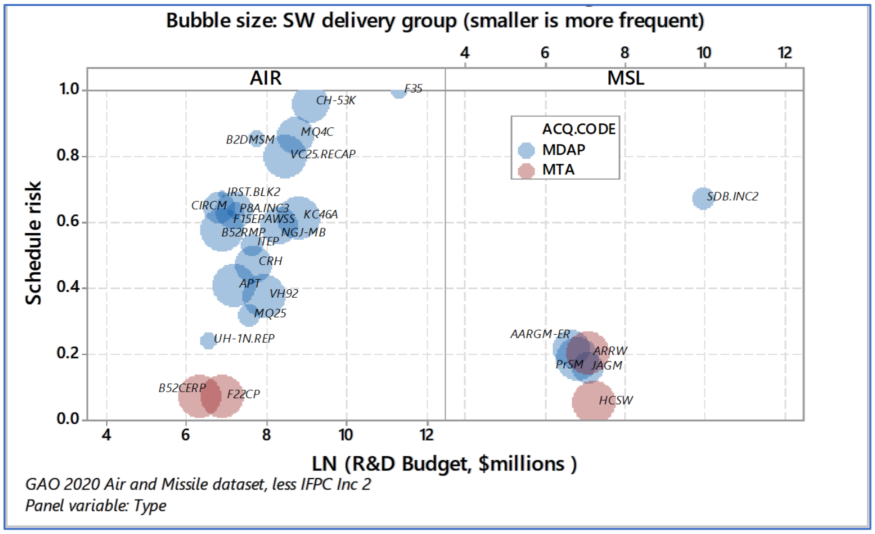

Figure 28. Schedule risk vs. R&D budget

There is a general trend of increasing schedule risk with larger R&D budgets. Software delivery rates are not qualitatively related to schedule risk. Middle Tier acquisition programs have less schedule risk than MDAPs at similar R&D budget levels. Mapping as before between B.CDR and LN.RD.M associates schedule risk with an inter-event duration and a programmatic variable as shown in Figure 29.

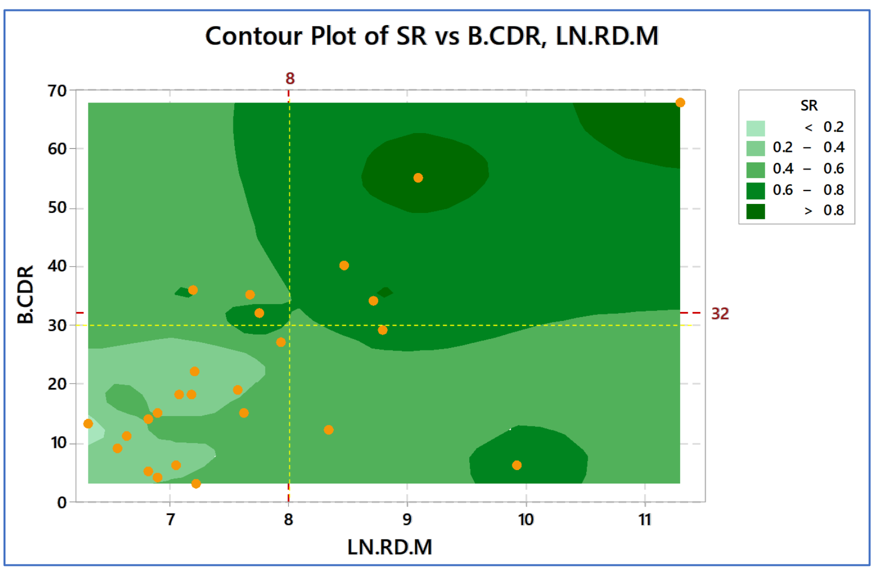

Figure 29. Schedule risk versus B.CDR and R&D budget

This suggests that schedule risk for Air and Missile systems programs, is higher (greater than 0.6) when B.CDR is greater than 30 months and the natural log of the R&D budget is greater than 8.

We fitted polynomials to GAO cycle time (schedule) data for MDAPs MTAs. In these models, MDAPs were the least likely and MTA programs were the most likely to have durations less than 60 months. This is consistent with intuition and data. We examined model fits by both R-squared and absolute error. Models were generally second or third order polynomials. For example, the schedule risk estimator for a MDAP

$$SR = 0.7949 + 0.00002 * D^2 - 0.0087 * D \quad (1)$$

Where D is the duration value in months. Excel R-squared was over 0.95; this model is not valid for durations less than 26 months, or for durations greater than 218 months[27]. A logarithmic model provided a better fit to MTA data:

$$SR = 0.1504 + 0.4284 * \ln(D) \quad (2)$$

This model is not valid for durations less than 8 months or greater than 74 months. All reported MTA program schedules are less than 60 months, and none reported completion as of this report. We ran three Monte Carlo simulations to estimate the likelihood of MTA programs exceeding 60 months.

Modularity: Systems may have physical modularity, modular software, or both. Adding hardware and software modularity to existing systems has a "one-time" schedule cost for system re-integration and re-certification. Follow-on modifications exhibit shorter schedules.

Most air and missile systems have modular architectures. Aircraft payload methods include internal (bays) and external (hardpoints) stations. We analyzed an Air Force maintenance dataset after adding program cycle times. Program cycle times were not related to the type of modularity. Cycle times were related to normalized

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[27] The model is greater than 1 for durations less than 26 months, and reaches a minimum at 218 months. Model inputs are bounded to prevent cycle times less than 0 and the output is set to SR = 0 at the first value where the model estimates P(< D) =1.

weight (empty take-off weight divided by aircraft length – R-sq(adjusted) = 50.74%, p=0.002).

Agility: We labeled GAO 2020 data by software development approach (Agile, Incremental, Waterfall, other) and contract type (Cost type or Fixed Price). Figure 30 shows the cycle time distributions for these groups.

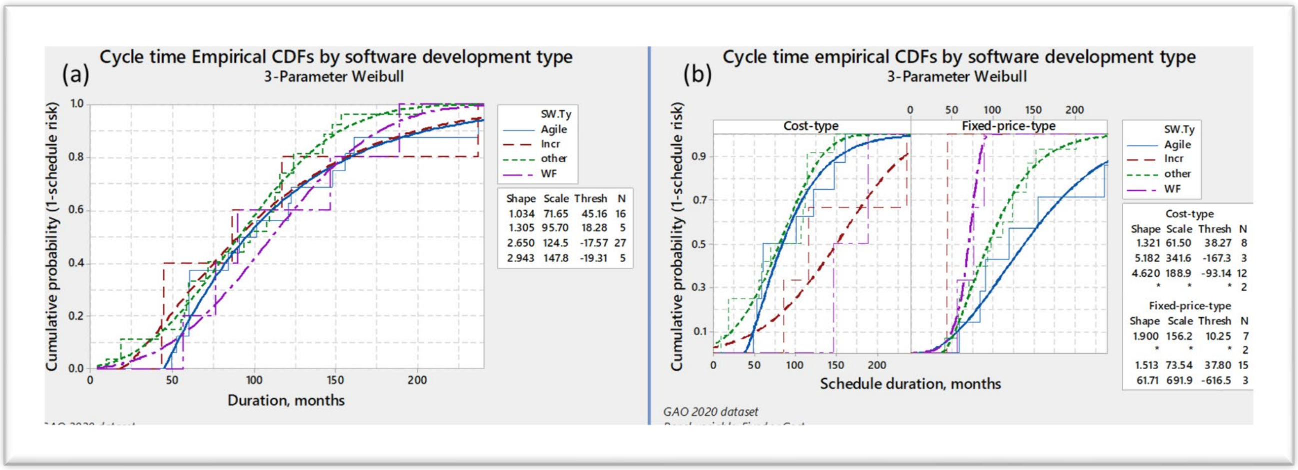

Figure 30. Cycle times by software development and contract types

In Figure 30a, the schedule risk is similar for the different types of software development approaches. Figure 30b shows that Incremental software development carries the highest schedule risk for cost-type contracts, and Agile software development, the largest schedule risk for fixed price type contracts.

Schedule risk and observed and predicted performance

We qualitatively estimated schedule risk for selected MTA and MDAP programs using public budget documentation. We developed an initial estimate for Air and Missile programs in the FY 2020 budget documentation, and examined budget, GAO, and open-source journalism to assess progress and performance. We used MTA- and MDAP-specific schedule risk simulation results to baseline estimates of individual project performance against expected SR cumulative distribution functions. In the following section we present our assessment of the SR for two MTAs: The B-52 Commercial Engine Replacement Program (CERP) and the Integrated Visual

Augmentation systems (IVAS). We conclude with our assessment of the SR evolution for two MDAPs: the HH-60W helicopter and the MQ-25 Stingray.

The B-52 Commercial Engine Replacement Program (CERP) includes two serial MTA efforts, a 24-month virtual power pod prototyping effort followed by a longer prototype power pod. Figure 31 summarizes how the B-52 virtual prototyping MTA is proceeding relative to simulation and FY 2020- 2021 budget documentation.

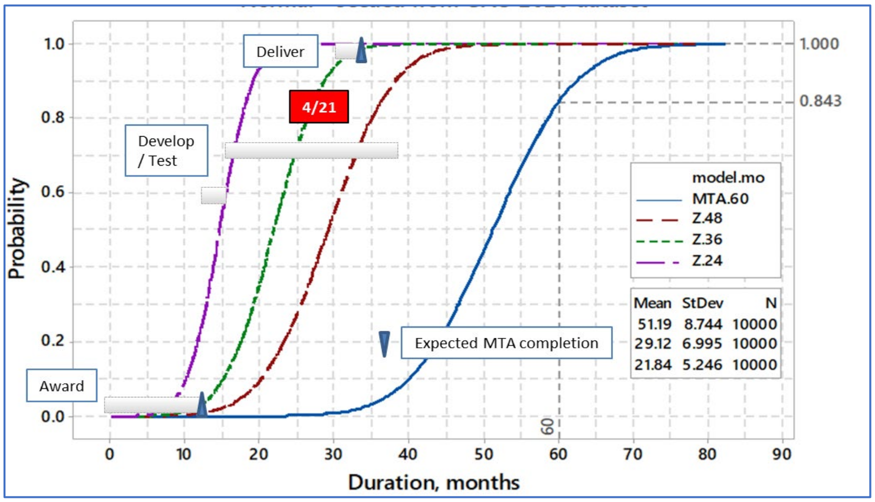

Figure 31. B-52 CERP simulation and reported milestones

Contract data shows delivery order tasks to Boeing in 2020. Increment (or spiral) one schedule risk is about 80 percent, suggesting the effort is unlikely to achieve planned schedule, but should complete by December 2022. However, this assessment is based on contract data and does not have later contradicting evidence. The recent budget data[28] supports a delayed spiral one completion. Figure 32 shows the Army Integrated Visual Augmentation System (IVAS) MTA simulation and milestone data.

[28] PE 0101113F/ B-52 squadrons (Department of the Air Force, 2021)

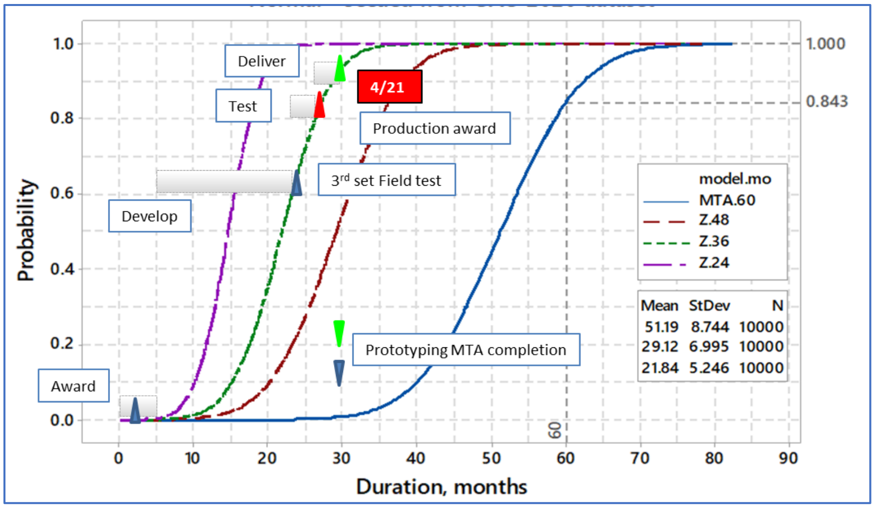

Figure 32. Army IVAS MTA simulation and reported milestones

Covid-19 impacts delayed IVAS third set field testing. The Army awarded a fixed price production contract to Microsoft in March 2021[29]. The SR of meeting first unit equipped dates is less than 0.1. The IVAS MTA is likely to achieve planned schedule.

We applied this method to the HH-60W and MQ-25, and estimated their schedule risk based upon program updates, as shown in Table 21.

Table 21. Schedule risk predictions for selected programs

Program	SR-2020	SR-2021	Est. IOC	GAO IOC	SAR IOC
Combat Rescue Helicopter (HH-60W)	0.4	0.1	Apr-22	Apr-22	Oct-21
MQ-25 Stingray	0.3	0.6	Aug-25	Aug-24	2025

The Air Force HH-60W Combat Rescue Helicopter program SR went down, as the program completed developmental testing in April 2021, and FY 2022 procurement documentation supports sufficient assets delivered by April 2022. We estimate the HH-60W will achieve Required Asset Availability (equivalent to IOC) by April 2022, after delivery of production assets.

The FY 2021 budget documentation[30] showed the MQ-25 Stingray IOC in the 4th quarter of 2024, roughly 72 months after program start. FY 2022 budget documentation[31] showed Engineering Development Model (EDM) deliveries slipping

[29] https://www.peosoldier.army.mil/News/Article-Display/Article/2556870/ivas-production-contract-award/
[30] PE 0605414N (Department of the Navy, 2021)
[31] PE 0605414N (Department of the Navy, 2020)

about 12 months, and caused the increase in schedule risk from 0.3 to 0.6. With a follow-on schedule of 42 months, the estimated IOC is August 2025 without further changes or delays.

Conclusions and Future Work

Program schedule growth occurs primarily during the B.CDR and CDR.IOC intervals. Schedule growth in the B.CDR interval may be due to technical uncertainty or complexity, while it may be due to integration or production complexity during the CDR.IOC interval. The research tested the two research hypotheses and are summarized below.

Research Hypothesis 1: *Modular, Agile, and Middle Tier Acquisition programs have shorter schedules than comparable MDAPs without these attributes.* First, Middle Tier Acquisition programs have shorter schedules that traditional MDAPs. Modular and Agile development programs are statistically like MDAPs, and tend to have schedules and cycle times longer than 60 months. However, both Modular and Agile programs have attributes affecting schedule performance, including:

- MTA: statutory imperative pushing design work to fit within a short development window of about two years. This may reduce the amount of technical debt a program has to retire prior to use. It becomes critically important to be able to translate qualitative opinions about performer technical competence and readiness into quantitative interval B.CDR and CDR.IOC durations.
- MTA: the statutory duration limit with consequences may incentive programs to reduce the amount of production and test risk, reducing CDR.IOC durations.
- Modular: the initial time to convert or field a modular system is longer than a traditional MDAP, due to longer integration and test windows. Subsequent changes within the existing design changeability take fewer resources and less integration time than a similar change on a non-modular system.
- Agile: The initial time from program start to development start is faster due to application of rapid program development, solicitation, and award processes.
- Agile: Agile development programs may proceed faster with incremental development, but blur distinctions between development and sustainment. This can potentially result in “requirements creep” or expansion of initial objectives, and when a particular development is in-service.[32]

[32] The “definition of done” problem.

Research Hypothesis 2: *Modular, Agile, and Middle Tier Acquisition programs have less schedule risk than comparable MDAPs without these attributes*. Simulations show that modular and Agile development programs have statistically similar schedule risks at the same relative schedule duration for Air and Missile commodity types. MTAs have more schedule risk than these two types, but less relative schedule risk than MDAPs at the same relative schedule duration. Modular, Agile and MTA programs all have lower schedule risk than traditional MDAPs.

Conclusions

Historically, commercial-based programs and programs starting with in-service systems[33] have delivered prototypes or new fielded capabilities within five years. New incremental capabilities may be planned, developed, and fielded once a system is adapted to modular change[34]. Programs adopting commercial software practices may provide faster change provided functional modularity is maintained and testing identifies no new interactions or dependencies.

The literature review provided an overview of program better practices and decisions associated with shorter schedules, including:

- Reducing requirements to meet capability and deliver something sooner.
- Starting with a proven technologies, interfaces, and standards.
- Having a competent team and capable suppliers.
- Adjusting work to retire schedule risk, and segmenting integration risk.
- Having a plan to get to contract award and production sooner.

Most programs can apply these general principles. Rapid Acquisition programs such as MTAs add constrained schedule durations, oversight, and stakeholder involvement to incentivize on-time deliveries. Simulations showed there is some risk in even MTA programs exceeding their constrained schedules.

The literature review also identified development issues faced by previous acquisitions that used agile or modular development approaches. Organizational

[33] Such as the Air Force T-7A Red Hawk for the Advanced Pilot Training program, which derives from a Saab design.
[34] Such as the Navy Acoustic Rapid COTS Insertion/Advanced Processor Build program.

cultural issues were most common, as these approaches require more collaboration, interactions, and management than traditional approaches. Experience, technical expertise, creativity, optimism, and a sense of urgency matter; program offices will manage qualitatively higher levels of uncertainty in terms of requirements and objectives, which is challenging given a constrained budget and schedule.

Our testing of research hypotheses provided surprising results. The conclusions were nuanced by the acquisition types and the relative data newness. We introduced a concept of relative schedule risk, scaling durations to between 0 and 1. Monte Carlo simulations show that distribution skew affects when schedule risks are higher, and is emphasized by the relative schedule risk method. We showed that acquisition process innovations such as agile and modular open systems approaches do not of themselves improve program schedule performance relative to MDAPs, but do reduce relative schedule risk. MTAs have shorter schedules by design, and have higher relative schedule risk than modular or Agile programs, but lower relative schedule risk than MDAPs.

Modular development. We showed that creating a modular design (modularity) is not associated with a shorter schedule duration. Simulations show that the interval from initial development to fielding of a new modular system will be longer than an equivalent integrated system, perhaps due to the greater integration complexity related to making and validating system modularity. We showed that the time from CDR to IOC is significantly different and results in longer overall schedules for modular programs. Preserving modularity constraints reduce the integration time for subsequent changes, provided changes do not alter the modularity, design envelope, or impose new certifications and tests. The overall design envelope constrains modular change, and modifications beyond envelope boundaries likely results in additional integration time.

Agile development is not associated with a shorter schedule duration. Data shows that Agile software development is faster than waterfall development, but that the time from CDR to IOC limits Agile system schedules, suggesting that system integration and testing and definitions of “done” are controlling Agile development schedules.

This research provides insight into the schedule risk behavior of modular development, Agile development, and Middle Tier acquisition programs relative to a MDAP. For example, at 60 months after program start, a Middle Tier acquisition program schedule risk should be less than 10 percent, and over 80 percent for a MDAP. This is in part because at 60 months, the MDAP has years of schedule left, while the Middle Tier acquisition is (should be) completed. Middle Tier acquisition programs do exhibit shorter inter-event durations; however, this is over a small dataset with little visibility into schedule milestones. Assuming the means and variances are representative of the MTA population, we developed schedule risk profiles for nominal program durations. We compared actual reported program events against these profiles and we quantified the risk to achieve a schedule duration based on reported performance.

Schedule growth occurs during three inter-event intervals: B.CDR, CDR.IOC and B.C. Of these, B.CDR and CDR.IOC span the program cycle time. These are the development and test intervals. Programs can minimize growth in these intervals by several strategies including: reducing system dependence on new or emerging technology; reducing the number of functional requirements; and reducing design choices leading to complex tightly integrated system designs.

Relevance and contribution to the practice

This research provides new insights into rapid acquisitions, and practical recommendations for program management. We developed a schedule risk measure and demonstrated applicability and utility using publicly available data.

We developed quantitative schedule simulations for modular development, Agile development, and MTA-type programs. We identified two inter-event durations, B.CDR and CDR.IOC, as specifically contributing to schedule growth and schedule risk. We identified and analyzed schedule growth risk mitigation strategies.

This research contributes to the understanding of the risks and opportunities associated with recent acquisition process changes. The research results will be useful to program offices and acquisition leadership in executing current and future rapid acquisition programs.

Future Work

The schedule risk estimation process is extensible to other rapid acquisition innovations. We explored relationships between programmatic factors, schedule intervals, and schedule risk. Future work should include replicating this effort using restricted datasets and program-level data, validating schedule risk predictions and predictor significance with to-be program performance, and developing context and severity estimators. Additional research is needed on calibrating interval simulations, and developing common measurement methods for schedule progress for the different program types. Future research on modular and Agile development should include establishing relationships between programmatic strategies, processes, and decisions, and schedule-related outcomes.

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References

Adams, L. (2017). *Agile Software Development in the Department of Defense Environment* (Senior Service College Fellowship Report, p. 61). Defense Acquisition University. https://www.dau.edu/training/career-development/sscf/Documents/Adams_SRP%20Final%20Draft_29%20Mar%2017--Edited%20and%20Corrected%20Final.pdf

Airbus. (2020). Airbus [Corporate]. *Airbus*. https://www.airbus.com/aircraft/how-is-an-aircraft-built.html

Alexander, M. E. (2012). *The C-27J Spartan Procurement Program: A Case Study in USAF Sourcing Practices for National Security* (AFIT/IMO/ENS/12-01; p. 63). Air Force Institute of Technology Graduate School of Engineering and Management. https://apps.dtic.mil/sti/citations/ADA566116

Andersen, A.-L., Brunoe, T. D., Nielsen, K., & Bejlegaard, M. (2018). Evaluating the investment feasibility and industrial implementation of changeable and reconfigurable manufacturing concepts. *Journal of Manufacturing Technology Management*, *29*(3), 449–477. https://doi.org/10.1108/jmtm-03-2017-0039

10 U.S. Code § 2373—Procurement for experimental purposes, Pub. L. No. 113–160, 2372 10 (1993).

10 U.S.C. § 2371—Research projects: Transactions other than contracts and grants, Pub. L. No. 103–160, 2371 10 (1993).

Anonymous. (2012). *Contracting Guidance to Support Modular Development*. The White House, Washington DC. https://obamawhitehouse.archives.gov/sites/default/files/omb/procurement/guidance/modular-approaches-for-information-technology.pdf

National Defense Authorization Act For Fiscal Year 2017—MOSA, Pub. L. No. 114–328, 10 10 USC § 2446a 970 (2016). https://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title10-section2446a&num=0&edition=prelim

10 U.S.C. §2430—Major Defense Acquisition Program Defined, Pub. L. No. 111–84, 10 U.S.C. § 2430 U.S. Code (2021). https://www.gpo.gov/fdsys/pkg/USCODE-2006-title10/html/USCODE-2006-title10-subtitleA-partIV-chap144-sec2430.htm

Arellano, R. L., Pringle, R. G., & Sowell, K. L. (2015). *Analysis of Rapid Acquisition Processes to Fulfill Future Urgent Needs* (p. 81). Naval Postgraduate School. https://apps.dtic.mil/dtic/tr/fulltext/u2/1009069.pdf

Asghar, E., Zaman, U. K. uz, Baqai, A. A., & Lazhar Homri. (2018). Optimum machine capabilities for reconfigurable manufacturing systems. *The International Journal of Advanced Manufacturing Technology*, *95*(9–12), 4397–4417. ProQuest Central. https://doi.org/10.1007/s00170-017-1560-y

Baldwin, C. Y., & Henkel, J. (2015). Modularity and intellectual property protection. *Strategic Management Journal*, *36*(11), 1637–1655. https://doi.org/10.1002/smj.2303

Bickford, J., Van Bossuyt, D. L., Beery, P., & Pollman, A. (2020). Operationalizing digital twins through model-based systems engineering methods. *Systems Engineering*, *23*(6), 724–750. https://doi.org/10.1002/sys.21559

Boeing. (2020). Everett Production Facility [Corporate]. *Boeing*. https://www.boeing.com/company/about-bca/everett-production-facility.page

Bone, M. A., Blackburn, M. R., Rhodes, D. H., Cohen, D. N., & Guerrero, J. A. (2019). Transforming systems engineering through digital engineering. *The Journal of Defense Modeling and Simulation*, *16*(4). https://doi.org/10.1177/1548512917751873

Bott, M., & Mesmer, B. (2020). An Analysis of Theories Supporting Agile Scrum and the Use of Scrum in Systems Engineering. *Engineering Management Journal*, *32*(2), 76–85. https://doi.org/10.1080/10429247.2019.1659701

Boudreau, M. (2006). *Acoustic Rapid COTS Insertion: A Case Study in Spiral Development* (NPS-GSBPP-06-016; p. 88). Naval Postgraduate School. https://calhoun.nps.edu/handle/10945/592

Broniatowski, D. A., & Moses, J. (2016). Measuring Flexibility, Descriptive Complexity, and Rework Potential in Generic System Architectures. *Systems Engineering*, *19*(3), 207–221. https://doi.org/10.1002/sys.21351

Browning, T. R. (1998). 2.2.2 Sources of Schedule Risk in Complex System Development. *INCOSE International Symposium*, *8*(1), 213–220. https://doi.org/10.1002/j.2334-5837.1998.tb00031.x

Bruchey, W. J. (2012). *A Comparison of Earned Value and Earned Schedule Duration Forecast Methods on Department of Defense Major Defense Acquisition Programs* (No. ADA567071; p. 59). Naval Postgraduate School. https://apps.dtic.mil/sti/citations/ADA567071

Cai, D., Agarwal, A., & Wierman, A. (2020). On the Inefficiency of Forward Markets in Leader–Follower Competition. *Operations Research*, *68*(1), 35–52. https://doi.org/10.1287/opre.2019.1863

Chadha, C., Crowe, K. A., Carmen, C. L., & Patterson, A. E. (2018). Exploring an AM-Enabled Combination-of-Functions Approach for Modular Product Design. *Designs*, *2*(37), 24. https://doi.org/10.3390/designs2040037

Chen, R. (Ronxin), Ravichandar, R., & Proctor, D. (2016). Managing the transition to the new agile business and product development model: Lessons from Cisco Systems. *Business Horizons*, *59*(6), 635–644. https://doi.org/10.1016/j.bushor.2016.06.005

Ciampa, P. D., & Nagel, B. (2020). AGILE Paradigm: The next generation collaborative MDO for the development of aeronautical systems. *Progress in Aerospace Sciences*, *119*, 100643. https://doi.org/10.1016/j.paerosci.2020.100643

Cooper, R. G., & Sommer, A. F. (2016). The Agile–Stage-Gate Hybrid Model: A Promising New Approach and a New Research Opportunity. *The Journal of Product Innovation Management*, *33*(5), 513–526. https://doi.org/10.1111/jpim.12314

Cummings, S. (2020). *Agile Software Acquisition Guidebook*. Department of Defense. https://www.dau.edu/cop/it/_layouts/15/WopiFrame.aspx?sourcedoc=/cop/it/DAU%20Sponsored%20Documents/AgilePilotsGuidebook%20V1.0%2027Feb20.pdf&action=default

Davendralingam, N., Guariniello, C., Tamaskar, S., DeLaurentis, D., & Kerman, M. (2019). Modularity research to guide MOSA implementation. *Journal of Defense Modeling and Simulation*, *16*(4), 389–401. https://doi.org/10.1177/1548512917749358

Davis, G. A., & Tate, D. M. (2020). Complexity in an Unexpected Place: Quantities in Selected Acquisition Reports. *Defense AR Journal*, *27*(1), 28–59. ProQuest Central; Research Library. https://doi.org/10.22594/dau.19832.27.01

Defense Business Board. (2015). *Transforming DoDs Core Business Processes for Revolutionary Change* (No. 15–01; p. 148). Department of Defense. https://dbb.defense.gov/Portals/35/Documents/Reports/2015/DBB%20FY15-01%20Core%20Business%20Processes.pdf

Defense Innovation Unit. (2020). Defense Innovation Unit. diu.mil

Department of the Air Force. (2021, May). *Air Force Financial Management and Comptroller, Air Force President's Budget FY 22*. https://www.saffm.hq.af.mil/Portals/84/documents/FY22/RDTE_/FY22%20DAF%20J-Book%20-%203600%20-%20AF%20RDT%20and%20E%20Vol%20IIIa.pdf?ver=Dj1pwQTgDWrZk-bSiDw-8Q%3d%3d

Department of the Navy. (2020, February). *Navy Financial Management and Budget, Navy President's Budget FY 21*. https://www.secnav.navy.mil/fmc/fmb/Documents/21pres/RDTEN_BA5_Book.pdf

Department of the Navy. (2021, May). *Navy Financial Management and Budget, Navy President's Budget FY 22*. https://www.secnav.navy.mil/fmc/fmb/Documents/22pres/RDTEN_BA5_Book.pdf

Desai, P. S., Koenigsberg, O., & Purohit, D. (2007). Research Note—The Role of Production Lead Time and Demand Uncertainty in Marketing Durable Goods. *Management Science*, *53*(1), 150–158. https://doi.org/10.1287/mnsc.1060.0599

Deshpande, A. (2018). Relationships between advanced manufacturing technologies, absorptive capacity, mass customization, time to market and financial and market performance. *Asia - Pacific Journal of Business Administration*, *10*(1), 2–20. ProQuest Central. https://doi.org/10.1108/APJBA-03-2017-0024

Dodaro, G. L. (2008). *GAO-08-467SP Defense Acquisitions_ Assessments of Selected Weapon Programs* (GAO-08-476SP; p. 205). GAO.

Dodaro, G. L. (2011). *GAO-11-233SP Defense Acquisitions_ Assessments of Selected Weapon Programs* (GAO-11-233SP; p. 195). GAO.

Dodaro, G. L. (2020). *Defense Acquisitions Annual Assessment Drive to Deliver Capabilities Faster Increases Importance of Program Knowledge and Consistent Data for Oversight* (GAO-20-439; p. 251). Government Accountability Office. https://www.gao.gov/products/GAO-20-439

Dougherty, G. M. (2018). Promoting Disruptive Military Innovation: Best Practices for DoD Experimentation and Prototyping Programs. *Defense Acquisition Research Journal: A Publication of the Defense Acquisition University*, *25*(1), 2–29. tsh.

Drabkin, D., Ahern, D., Branch, E., Dyer, J., Hoskin, M., Merchant, K. D., Trowel, L., Raney, T. L., Thompson, N. R., Blake, C. D., Burman, A. V., Garman, C. D., LaPlante, W. A., Metzger, D. P., & Scott, D. A. (2016). *Section 809 Panel*. Defense Technical Innovation Center. https://discover.dtic.mil/section-809-panel/

Dubos, G., Saleh, J., & Braun, R. (2007, September 18). *Technology Readiness Level, Schedule Risk and Slippage in Spacecraft Design: Data Analysis and Modeling*. https://doi.org/10.2514/6.2007-6020

Eiband, M., Eveleigh, T. J., Holzer, T. H., & Sarkani, S. (2013). Reusing DoD Legacy Systems: Making the Right Choice. *Defense Acquisition Research Journal: A Publication of the Defense Acquisition University*, *20*(2), 154–173. a9h.

Ellis, W., Molloy, M., Cohen, J., & Crozier, P. (2019). Contractng for Agile. *KPMG*. https://assets.kpmg/content/dam/kpmg/uk/pdf/2019/08/contracting-for-agile.pdf

Engebretson, K., & Frey, T. (2017). Push for shared standards on military platforms. *Aerospace America*, *55*(11), 50.

Etemadi, A. H., & Kamp, J. (2021a). Market and contractor factors affecting rapid acquisition strategies. *Systems Engineering*. https://doi.org/10.1002/sys.21577

Etemadi, A. H., & Kamp, J. (2021b, May). Schedule Risks Associated with Middle Tier Acquisition. *Proceedings of the 18th Annual Acquisition Research Program*. Acquisition Research Symposium, Monterey, CA. https://dair.nps.edu/handle/123456789/4397

Farmer, C. M. (2018). *Constructing Program Management Offices for Major Defense Acquisition Programs: Factors to Consider* [The George Washington University]. https://scholarspace.library.gwu.edu/concern/gw_etds/rb68xc32c?locale=en

Firesmith, D. (2015, October 19). Open System Architectures: When and Where to be Closed. *Open System Architectures*. https://insights.sei.cmu.edu/sei_blog/open-systems-architectures/

Forney, S. J. (2019). *An Agile Success Estimation Framework for Software Projects* [The George Washington University]. https://scholarspace.library.gwu.edu/concern/gw_etds/ft848r240?locale=en

Fox, J. R. (2011). *Defense acquisition reform 1960-2009 an elusive goal* (GOVDOC : D 114.2:AC 7). Center of Military History, U.S. Army. https://permanent.fdlp.gov/gpo27025/CMH_Pub_51-3-1.pdf

Guertin, N. H., & Hunt, G. (2017). *Transformation of Test and Evaluation: The Natural Consequences of Model-Based Engineering and Modular Open Systems Architecture* (SYM-AM-17-081; p. 21). Naval Postgraduate School. https://calhoun.nps.edu/handle/10945/58959

Guertin, N. H., Schmidt, D. C., & Scherlis, W. (2018). *Capability Composition and Data Interoperability to Achieve More Effective Results Than DoD System-of-Systems Strategies* (SYM-AM-18-045; pp. 1–20). Naval Postgraduate School; Calhoun. http://hdl.handle.net/10945/58724

Gunderson, C. (2017). *Adaptive Acquisition: An Evolving Framework for Tailoring Engineering and Procurement of Defense Systems* (p. 90). Air Force Institute of Technology. https://apps.dtic.mil/dtic/tr/fulltext/u2/1038030.pdf

Haberfellner, R., & Weck, O. (2005). 10.1.3 Agile SYSTEMS ENGINEERING versus AGILE SYSTEMS engineering. *INCOSE International Symposium*, *15*(1), 1449–1465. https://doi.org/10.1002/j.2334-5837.2005.tb00762.x

Hawkins, T. G., & Gravier, M. J. (2019). Integrating COTS technology in defense systems. *European Journal of Innovation Management*, *22*(3), 493–523. https://doi.org/10.1108/ejim-08-2018-0177

Heydari, B., Mosleh, M., & Dalili, K. (2016). From Modular to Distributed Open Architectures: A Unified Decision Framework. *Systems Engineering*, *19*(3), 252–266. https://doi.org/10.1002/sys.21348

Hubbard, D. W. (2009). *The Failure of Risk Management: Why It's Broken and How to Fix it*. John Wiley & Sons, Incorporated.

Hvam, L., Herbert-Hansen, Z. N. L., Haug, A., Kudsk, A., & Mortensen, N. H. (2017). A framework for determining product modularity levels. *Advances in Mechanical Engineering*, *9*(10), 168781401771942. https://doi.org/10.1177/1687814017719420

Inayat, I., Salim, S. S., Marczak, S., Daneva, M., & Shamshirband, S. (2015). A systematic literature review on agile requirements engineering practices and challenges. *Computers in Human Behavior*, *51*(Part B), 915–929. https://doi.org/10.1016/j.chb.2014.10.046

Ingold, D. (2014). *A Model for Estimating Schedule Acceleration in Agile Software Development Projects* [University of Southern California]. https://search.proquest.com/docview/2066832925?pq-origsite=summon

Islam, G., & Storer, T. (2020). A case study of agile software development for safety-Critical systems projects. *Reliability Engineering & System Safety*, *200*, 106954–18. https://doi.org/10.1016/j.ress.2020.106954

Jahr, M. (2014). A Hybrid Approach to Quantitative Software Project Scheduling Within Agile Frameworks. *Project Management Journal*, *45*(3), 35–45. https://doi.org/10.1002/pmj.21411

Jaifer, R., Beauregard, Y., & Bhuiyan, N. (2020). New Framework For Effort And Time Drivers In Aerospace Product Development Projects. *Engineering Management Journal*, 1–20. https://doi.org/10.1080/10429247.2020.1772950

Kamp, J. (2019). *Integrating Immature Systems and Program Schedule Growth*. The George Washington University.

Krupa, G. P. (2019). Application of Agile Model-Based Systems Engineering in aircraft conceptual design. *Aeronautical Journal*, *123*(1268), 1561–1601. https://doi.org/10.1017/aer.2019.53

Lord, E. M. (2019). *Operation of the Middle Tier of Acquisition (MTA)*. Department of Defense. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500080p.PDF?ver=2019-12-30-095246-043

Lord, E. M. (2020a). *Operation of the Adaptive Acquisition Framework*. Department of Defense. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500002p.pdf?ver=2019-10-25-134150-283

Lord, E. M. (2020b). *The Defense Acquisition System*. Department of Defense. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/500001p.pdf?ver=2020-09-09-160307-310

Martin, R. C., & Highsmith, J. (2016, July). *Manifesto for Agile Software Development*. Manifesto for Agile Software Development. http://agilemanifesto.org/

McCormick, R., Cohen, S., & McQuade, M. R. (2015). *Measuring the Outcomes of Acquisition Reform by Major DoD Components* [#HQ0034-12-A-0022]. Center for Strategic and International Studies. https://csis-website-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/150930_McCormick_MeasuringOutcomesAcquistionReform_Web.pdf

MITRE. (2019). *AiDA- MITRE Acquisition in the Digita Age*. https://aida.mitre.org/middle-tier/

Mortlock, R. F. (2019). *Acquisition Strategy Formulation: Evolutionary/Incremental Development Approach* (p. 110) [NPS-PM-19-179]. Naval Postgraduate School Monterey United States. https://dair.nps.edu/handle/123456789/2768

Nerur, S., Mahapatra, R., & Mangalaraj, G. (2005). Challenges of migrating to agile methodologies. *Communications of the ACM*, *48*(5), 72–78. https://doi.org/10.1145/1060710.1060712

Nidiffer, K. E., Miller, S. M., & Carney, D. (2014). *Potential Use of Agile Methods in Selected DoD Acquisitions: Requirements Development and Management* (Technical Note CMU/SEI-2013-TN-006; p. 58). Carnegie Mellon University. https://apps.dtic.mil/dtic/tr/fulltext/u2/a609864.pdf

Oakley, S. S. (2020). *GAO-20-439 Defense Acquisitions Annual Assessment Drive to Deliver Capabilities Faster Increases Importance of Program Knowledge and Consistent Data for Oversight* (GAO-20-439; p. 251). Government Accountability Office. https://www.gao.gov/assets/gao-20-439.pdf

Oestergaard, J. K. (2020, September 29). Airbus and Boeing Report December and Full-Year 2019 Commercial Aircraft Orders and Deliveries. *Defense & Security Monitor, an Aerospace & Defense Blog*. https://dsm.forecastinternational.com/wordpress/2020/01/21/airbus-and-boeing-report-december-and-full-year-2019-commercial-aircraft-orders-and-deliveries/#:~:text=Boeing%20recently%20raised%20the%20monthly,up%20from%20136%20in%202017.

OMB. (2012). *Contracting guidance to support modular development.* [White House, Office of Management and Budget]. https://obamawhitehouse.archives.gov/sites/default/files/omb/procurement/guidance/modular-approaches-for-information-technology.pdf

OUSD(A&S). (2019). *Contracting Considerations for Agile Solutions Key Agile Concepts and Sample Work Statement Language Version 1.0*. Department of Defense. https://www.dau.edu/cop/it/DAU%20Sponsored%20Documents/Contracting%20Considerations%20for%20Agile%20Solutions%20v1.0.pdf

OUSD(R&E). (2020, August). *Defense Innovation Marketplace Connecting Industry and the Department of Defense*. Defense Innovation Marketplace. https://defenseinnovationmarketplace.dtic.mil/business-opportunities/rapid-innovation-fund/

Pennington, R. (2018). Agile: A New Frontier for Contract Management. *Contract Management*, *58*(08), 28–37.

Persson, M., Eklind, M. J., & Winroth, M. (2016). Coordinating External Manufacturing of Product Modules. *Decision Sciences*, *47*(6), 1178–1202. https://doi.org/10.1111/deci.12197

Perttula, A., & Kukkamäki, J. (2020). Enabling rapid product development through improved verification and validation processes. *Technology Innovation Management Review*, *10*(3), 24–35. ProQuest Central.

Rehn, C. F., Pettersen, S. S., Garcia, J. J., Brett, P. O., Erikstad, S. O., Asbjørnslett, B. E., Ross, A. M., & Rhodes, D. H. (2018). Quantification of changeability level for engineering systems. *Systems Engineering*, *22*, 80–94.

Reim, G. (2020a, September 4). How Lockheed Martin plans to speed up sales with commoditised F-16. *FlightGlobal*. https://www.flightglobal.com/fixed-wing/how-lockheed-martin-plans-to-speed-up-sales-with-commoditised-f-16/140055.article

Reim, G. (2020b, September 15). USAF secretly builds and flies next-generation fighter demonstrator. *FlightGlobal*. https://www.flightglobal.com/fixed-wing/usaf-secretly-builds-and-flies-next-generation-fighter-demonstrator/140183.article

Rosa, W., Madachy, R., Clark, B., & Boehm, B. (2017). Early Phase Cost Models for Agile Software Processes in the US DoD. *ESEM*, 30–37. https://doi.org/10.1109/ESEM.2017.10

Ross, A. M., Rhodes, D. H., & Hastings, D. E. (2008). Defining changeability: Reconciling flexibility, adaptability, scalability, modifiability, and robustness for maintaining system lifecycle value. *Systems Engineering*, *11*(3), 246–262. https://doi.org/10.1002/sys.20098

Rozelsky, K. (2010). *Selected Acquisition Report (SAR) RQ-4A/B UAS GLOBAL HAWK* (Selected Acquisition Report (SAR) RCS: DD-A&T(Q&A)823-252; p. 45). Department of the Air Force. https://www.esd.whs.mil/Portals/54/Documents/FOID/Reading%20Room/Selected_Acquisition_Reports/FY_2010_SARS/RQ-4A_B_UAS_GLOBAL_HAWK-SAR-25_DEC_2010.pdf

Rubinstein, J. (2014). *Study of the Light Utility Helicopter (LUH) acquisition program as a model for defense acquisition of non-developmental items* [Naval Postgraduate School]. Calhoun. http://hdl.handle.net/10945/44655

Schilling, M. A. (2000). Toward a General Modular Systems Theory and Its Application to Interfirm Product Modularity. *The Academy of Management Review*, *25*(2), 312–334. https://doi.org/10.2307/259016

Schoeni, D. E. (2015). Long on rhetoric, short on results: Agile methods and cyber acquisitions in the Department of Defense. *Santa Clara High-Technology Law Journal*, *31*(3), 385.

Shaner, M. B., Fenik, A. P., Noble, C. H., & Lee, K. B. (2020). Exploring the need for (extreme) speed: Motivations for and outcomes of discontinuous NPD acceleration. *Journal of Marketing Management*, *36*(7–8), 727–761. https://doi.org/10.1080/0267257X.2020.1741428

Siedlak, D. J. L., Pinon, O. J., Schlais, P. R., Schmidt, T. M., & Mavris, D. N. (2017). A digital thread approach to support manufacturing-influenced conceptual aircraft design. *Research in Engineering Design*, *29*(2), 285–308. https://doi.org/10.1007/s00163-017-0269-0

Smith, H. E. (2006). Modularity in Contracts: Boilerplate and Information Flow. *Michigan Law Review*, *104*(5), 1175–1222.

Sullivan, M. J. (2009). *Rapid Acquisition of MRAP Vehicles* (GAO-10-155T; p. 15). Government Accountability Office. https://www.gao.gov/assets/130/123503.pdf

Tao, L., Wu, D., Liu, S., & Lambert, J. H. (2017). Schedule risk analysis for new-product development: The GERT method extended by a characteristic function. *Reliability Engineering & System Safety*, *167*, 464–473. https://doi.org/10.1016/j.ress.2017.06.010

Tate, D. M. (2016). *Acquisition Cycle Time: Defining the Problem (Revised)* (NS D-5762). Institute for Defense Analyses. https://www.jstor.org/stable/resrep22689?seq=1#metadata_info_tab_contents

Taylor, A. J. (2019). The revolution in federal procurement, 1980–present. *Business and Politics*, *21*(1), 27–52. ProQuest Central; Social Science Premium Collection. https://doi.org/10.1017/bap.2018.9

Thomas, D., Kunc, W., Barth, S., Smart, C., Watern, K., & Comstock, D. (2014). *Joint Agency Cost Schedule Risk and Uncertainty Handbook*. Department of the Navy.

National Defense Authorization Act of Fiscal Year 2011, Pub. L. No. 111–383, 2359a 10 (2011). https://www.law.cornell.edu/uscode/text/10/2359a

National Defense Authorization Act for Fiscal Year 2016, Pub. L. No. 114–92 (2015), S.1356. https://www.congress.gov/114/plaws/publ92/PLAW-114publ92.pdf

National Defense Authorization Act for Fiscal year 2017, Pub. L. No. 114–328, 10 970 (2016). https://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title10-section2446a&num=0&edition=prelim

National Defense Authorization Act for Fiscal Year 2018, Pub. L. No. 115–91, 740 (2017). https://www.congress.gov/115/plaws/publ91/PLAW-115publ91.pdf

Van Atta, R. H., Kneece, R. R., & Lippitz, M. J. (2016). *Assessment of Accelerated Acquisition of Defense Programs* (P-8161; p. 96). Institute for Defense Analyses (IDA) Alexandria United States. https://apps.dtic.mil/dtic/tr/fulltext/u2/1028525.pdf

van Gent, I., & Kassapoglou, C. (2014). Cost-weight trades for modular composite structures. *Structural and Multidisciplinary Optimization*, *49*(6), 931–952. https://doi.org/10.1007/s00158-013-1019-1

Waldron, G. (2019, October 4). USAF sets up advanced fighter technology office. *FlightGlobal*. https://www.flightglobal.com/defence/usaf-sets-up-advanced-fighter-technology-office/134672.article

Watson, J. D., Allen, J. D., Mattson, C. A., & Ferguson, S. M. (2016). Optimization of excess system capability for increased evolvability. *Structural and Multidisciplinary Optimization*, *53*, 177–1294. https://doi.org/10.1007/s00158-015-1378-x

Wauters, M., & Vanhoucke, M. (2017). A Nearest Neighbour extension to project duration forecasting with Artificial Intelligence. *European Journal of Operational Research*, *259*(3), 1097–1111. https://doi.org/10.1016/j.ejor.2016.11.018

Wicecarver, J. M. (2017). *Joint Requirements Oversight Council Procurement Quantity Validation Process for Major Defense Acquisition Programs* (Inspector General

Report DODIG-2017-117; p. 46). Department of Defense. https://media.defense.gov/2017/Sep/11/2001806280/-1/-1/1/DODIG-2017-117.PDF

Williams, T. (2005). Assessing and moving on from the dominant project management discourse in the light of project overruns. *IEEE Transactions on Engineering Management*, *52*(4), 497–508. https://doi.org/10.1109/TEM.2005.856572

Wirthlin, J. R. (2009). *Identifying Enterprise Leverage Points in Defense Acquisition Program Performance* [Massachusetts Institute of Technology]. https://apps.dtic.mil/sti/pdfs/ADA525357.pdf

Wong, J. P. (2016). *Balancing Immediate and Long-Term Defense Investments* [RAND]. https://www.rand.org/pubs/rgs_dissertations/RGSD378.html.

Xiao, L., Pennock, M. J., Cardoso, J. L. F. P., & Wang, X. (2020). A case study on modularity violations in cyber-physical systems. *Systems Engineering*, *23*(3), 338–349. https://doi.org/10.1002/sys.21530

Zhai, Y., Zhong, R. Y., Li, Z., & Huang, G. (2016). Production lead-time hedging and coordination in prefabricated construction supply chain management. *International Journal of Production Research*, *55*(14), 3984–4002. https://doi.org/10.1080/00207543.2016.1231432

Zimmerman, P., Ofori, M., Barrett, D., Soler, J., & Harriman, A. (2018). Considerations and examples of a modular open systems approach in defense systems. *The Journal of Defense Modeling and Simulation*, *16*(4), 373–388. https://doi.org/10.1177/1548512917751281

Appendix

Middle Tier Acquisition Projects in FY 2022 Budget documentation

Table 22. Air Force 2022 MTA summary

BA	Line	PE.BLI	MTA.Name	GAO.21.page	MTA.Start	MTA.End	Duration	Modular	Agile	FY2020	FY2021	FY2022	Type	Type.MTA
04	43	0604033F	ARRW	121	May-18	Mar-23	58	0	1	286000	386157	238262	MSL	RP
04	48	0604327F	M-Code/EAJ Developme		Oct-20	Sep-21	11	0	0	0	2150	0	MSL	RP
04	53	0207100F	Light Attack Armed airc		Oct-20	Sep-21	11	0	0	1982	0	0	AIR	RP
04	55	0207455F	3DELRR		Jan-20	Dec-22	35	0	1	22469	19321	0	C3I	RP
04	67	1203164F	MGUE2	133	Nov-20	Sep-25	58	0	0	308215	0	0	SPACE	RP
04		3 1203164SF	MGUE2	133	Dec-20	Sep-25	57	0	0	0	205923	281191	SPACE	RP
04	70	1206425F	Deep Space Advanced F		Jan-22	Mar-25	38	0	0	29013	0	0	SPACE	RP
04		7 1206425SF	Deep Space Advanced F		Jan-22	Mar-25	38	0	0	0	33359	123262	SPACE	RP
04	74	1206760F	PTES	137	Nov-18	Dec-21	37	0	0	101583	0	0	SPACE	RP
04	75	1206761F	PTS	139	Jun-19	Jun-26	84	1	0	154237	0	0	SPACE	RP
04		12 1206761SF	PTS	139	Sep-20	Jun-24	45	1	0	0	200178	243285	SPACE	RP
04	76	1206855F	Evolved Stra	125	Sep-20	Sep-25	60	1	0	161882	0	0	SPACE	RP
04		13 1206855SF	Evolved Stra	126	Sep-20	Sep-25	60	1	0	0	71395	160056	SPACE	RP
05	121	1206442F	OPIR	135	Oct-18	Oct-23	60	0	1	1470278	0	0	SPACE	RP
05		22 1206442SF	Next-Gen O	135	Oct-18	Oct-23	60	0	1		11128900	1137393	SPACE	RP
05		22 1206442SF	Next-Gen O	135	Oct-18	Oct-26	96	0	1	0	482013	661098	SPACE	RP
05		7 1206442SF	FORGE	131	Sep-20	Sep-24	48	1	1		498283	514577	SPACE	RP
07		34 1203001SF	Force Element Termina		Feb-19	Mar-24	61	1	1	0	156736	98979	C3I	RP
07	167	0101113F	CERP (RVP)	123	Sep-18	Apr-22	43	1	0	175359	273020	484068	AIR	RP
07	167	0101113F	CERP Rapid Physical Pro		Apr-22	Jun-25	38	1	0	0	0	0	AIR	RP
07	177	0102326F	NCR-IADS		Apr-21	Jun-22	14	0	1	0	4795	0	C3I	RP
07	183	0207040F	Spectrum Warfare Attac		Oct-22	Jan-23	3	1	0	0	0	36607	C3I	RP
07	188	0207138F	F-22 Capabi	129	Sep-18	Sep-21	36	1	1	537232	663825	647296	AIR	RP
07	188	0207138F	Sensor Systems		Jun-22	Dec-26	54	1	1	75685	260921	262972	AIR	RP
07	188	0207138F	Navigation Systems		Oct-19	Sep-26	83	1	1	5224	9000	25540	AIR	RP
07	188	0207138F	Communication System		Oct-19	Sep-26	83	1	1	0	0	131270	AIR	RP
07	202	0207417F	AWACS		Oct-19	Sep-22	35	1	1	67341	123925	171014	AIR	RP
07	239	0302015F	Survivable SHF		Oct-19	Jun-24	56	0	0	24583	3462	25581	AIR	RP
07	240	0303131F	CVR Inc 2		Jul-21	Sep-26	62	1	0	12067	22284	0	C3I	RP
07	240	0303131F	Global ASNT Inc 2		Jul-21	Jun-25	47	1	0	117	21391	19729	C3I	RP
07	246	0304260F	Common SIGINT Develo		Oct-20	Sep-22	23	0	0	85157	127832	97546	C3I	RP
07	250	0305015F	C2AOS-C2IS modificatio		Oct-19	Sep-20	11	0	1	5206	0	0	C3I	RP
07	267	0305206F	Next Generation Senso		Jan-21	Sep-22	20	1	0	17338	54841	30198	AIR	RP
08	318	0608410F	AOC.WS	119	Jul-19	Jun-24	59	1	1	0	0	186915	C3I	RP
	01	57 3010F	F-15EX	127	Mar-20	Jun-23	39	0	0	621100	1367147	1334822	AIR	RF
	04	20 3010F	LAA		Jul-18	Sep-22	50	0	0	30000	0	0	AIR	RP
	05	32 3010F	Link-16		Jun-21	Oct-25	52	0	0	46031	153083	52702	AIR	RF
	05	33 3010F	Sensor Enhancements (		Jun-20	Jun-23	36	0	0	49002	122283	196825	AIR	RF
	05	38 3010F	Rapid Global Mobility		Oct-18	Sep-22	47	1	0	3617	1106	100	AIR	RP

Table 23. Army 2022 MTA summary

BA	Line	PE.BLI	MTA.Name	GAO.21.page	MTA.Start	MTA.End	Duration	Modular	Agile	FY2020	FY2021	FY2022	Type	Type.MTA
04	52	0603619A	Area Denial Capability		Mar-22	Mar-25	36	1	0	0	4995	34761	GND	RP
04	53	0603639A	Advanced Armor-Piercir		Oct-18	Mar-24	65	1	0	8572	0	0	GND	RP
04	60	0603801A	FLRAA Virtual Prototype		Aug-22	Mar-24	19	1	0	0	0	102648	AIR	RP
04	69	0604037A	TITAN		Sep-21	Jun-23	21	0	0	0	0	28347	C3I	RP
04	72	0604113A	FTUAS		Sep-22	Jun-25	33	1	1	0	33758	48197	AIR	RP
04	73	0604114A	LTAMDS	161	Oct-19	Sep-22	35	0	0	364154	308805	327690	C3I	RP
05	91	0604601A	NGSW-FC program		Apr-20	Sep-21	17	1	0	14095	9782	11107	GND	RP
05	94	0604622A	Leader Follower		Oct-21	Sep-25	47	1	0	4294	10249	21918	GND	RP
05	97	0604645A	Mobile Prot	163	Dec-19	Jun-22	30	0	0	273433	123992	137256	GND	RP
05	98	0604710A	IVAS	159	Nov-19	Apr-21	17	1	1	60599	7495	4934	GND	RP
05	108	0604802A	Precision Munition (Sni		Oct-21	Sep-23	23	0	0			9275	GND	RP
05	108	0604802A	Small Caliber Ammo fo		Oct-18	Jun-23	56	0	0	17432	26483	28372	GND	RP
05	113	0604818A	Unified Network Opera		Apr-19	Jun-21	26	0	1	3499	3522	3366	C3I	RP
05	132	0605042A	Integrated Tactical Net		Jan-21	Mar-26	62	1	0	22411	9754	17762	C3I	RP
05	136	0605052A	Enduring IFPC Inc 2		Jan-21	Sep-23	32	0	0	186369	153362	233512	C3I	RP
05	137	0605053A	Small Multipurpose Eq		Jul-19	Sep-21	26	1	0	8768	28555	29448	GND	RP
05	142	0605148A	TITAN		Jul-21	Sep-24	38	0	0	0	0	28347	C3I	RP
05	148	0605232A	LRHW		Oct-22	Sep-24	23	0	0	0	0	111473	MSL	RP
05	153	0605625A	OMFV	165	Jul-21	Sep-24	38	1	0	197304	171890	225106	GND	RP
07	208	0203743A	ERCA Incren	157	Jul-19	Sep-23	50	0	1	191076	217959	213281	GND	RP

Table 24. Navy 2022 MTA summary

BA	Line	PE.BLI	MTA.Name	GAO.21.page	MTA.Start	MTA.End	Duration	Modular	Agile	FY2020	FY2021	FY2022	Type	Type.MTA
04	36	0603502N	Medium Unmanned Su		Jul-20	Jun-27	83	1	0	22964	0	0	SHIP	RP
04	58	0603635M	Armored Reconnaissan		Jul-21	Sep-22	14	0	0	7465	17599	48563	GND	RP
04	59	0603654N	Expeditionary Diving Sy		Oct-19	Sep-25	71	1	0	911	1765	822	SHIP	RP
04	78	0604028N /	LIONFISH SUUV		Oct-19	Sep-22	35	0	0	0	4577	15881	SHIP	RP
04	92	0604659N	Convention	209	Oct-19	Jun-23	44	0	0	502435	0	0	MSL	RP
04	95	0605512N	Medium Unmanned Su		Jan-21	Sep-22	20	1	0	5200	3200	3500	SHIP	RP
04	99	0605518N	CPS prototy	209	Oct-19	Jun-23	44	0	0	0	766637	1372340	MSL	RP
05	125	0604366N	SM-2 Block IIIC		Oct-19	Sep-22	35	0	0	69180	56144	33412	MSL	RP
05	140	0604601N	Encapsulated Effector (		Oct-19	Sep-22	35	0	0	0	27000	40300	SHIP	RP
05	160	0605215N	Next Generation Naval		Oct-19	Sep-22	35	1	1	25420	35500	37606	C3I	RP
05	160	0605215N	Standardized Tester of		Oct-19	Apr-22	30	1	0	12975	14546	17772	C3I	RP
05	161	0605217N	MAGTF Agile Networkin		Jan-21	Apr-22	15	1	1	0	21133	18872	AIR	RP
05	174	0304785N	Integrated Communicat		Dec-19	Sep-22	33	1	1	8300	6095	1548	C3I	RP
06	191	0605873M	Marine Corps Wargami		May-19	Sep-22	40	0	1	11027	15000	23518	C3I	RP
06	194	0305327N	Counter Insider Threat		Oct-19	Sep-22	35	0	0	2592	2293	2581	C3I	RP
07	201	0605520M	Medium Range Intercep		Jun-20	Sep-22	27	0	0	15300	52400	7800	MSL	RP
07	205	0101226N	Compact Rapid Attack V		Oct-21	Sep-26	59	0	0	0	13363	44854	C3I	RP
07	210	0204311N	Deployable Surveillanc		Oct-19	Sep-23	47	1	0	8500	26385	16592	C3I	RP
07	221	0206313M	Air Battle Management		Oct-19	Jun-22	32	1	1	6164	1290	1204	C3I	RP
07	223	0206623M	MEGFoS		Jun-20	Jun-22	24	1	1	3922	5753	12934	C3I	RP
07	223	0206623M	WSATCOM MCWS-X		Mar-21	Oct-21	7	1	1	20432	200	0	C3I	RF

Table 25. Other DoD/Agency 2022 MTA summary

SVC	BA	Line	PE.BLI	MTA.Name	GAO.21.page	MTA.Start	MTA.End	Duration	Modular	Agile	FY2020	FY2021	FY2022	Type	Type.MTA
DOD	05	131	0604384BP	Rapid Opioid Counterm		Oct-19	Jun-22	32	1	1	13297	8417	11380	GND	RP
SOCOM	07	264	1160431BB	Weapons		Jan-20	Sep-23	44	1	0	1509	1604	1514	GND	RP
SOCOM	07	264	1160431BB	C-UAS		Mar-20	Sep-22	30	1	0	9671	5796	5195	GND	RP
SOCOM	07	264	1160431BB	Ground Organic Precisio		Oct-19	Sep-26	83	1	0	7989	2290	15963	GND	RP
SOCOM	07	268	1160483BB	SOF Combat Diving (CBD		Dec-19	Nov-25	71	1	0	2580	2161	3183	SHIP	RP

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