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Estimating Middle Tier Acquisition Schedule Risk

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Abstract

Congress recently created Middle Tier Acquisition (MTA) programs, which provide the military services rapid prototyping and fielding pathways with new program flexibilities and an explicit schedule constraint. The services are executing multiple MTAs, resulting in a set of MTA experiments related to development, execution, and governance. There is little published information on MTA performance; we use public data to quantify planned schedules. We introduce a quantified schedule risk measure based on Monte Carlo simulations. The simulations provide insights into MTA programs' schedule risk and program performance relative to a statistically based reference.

Research Results Statement: This research provides quantitative assessments of the effectiveness of Middle Tier Acquisition policy on schedule growth.

Keywords: Middle Tier Acquisition, defense acquisition, innovation

Introduction

Five economic and strategic policy changes occurred over the last 50 years affecting defense acquisitions. First, most research and development today is performed outside the United States. In 1960, the United States funded nearly 70% of world research and development (Sargent, 2018). By 2019, the percentages were reversed, and the U.S. defense share had shrunk to 3% of total global spend (Sargent & Gallo, 2021). Second, technical innovation shifted to primarily commercial sponsorship, and the Department of Defense (DoD) is now competing for emergent technologies (Sargent & Gallo, 2021). Third, the supporting industrial base of defense-unique suppliers shrank, affecting defense market competition and innovation (Etemadi & Kamp, 2021). Fourth, U.S. military strategy to emphasize technological and operational superiority (Grant, 2016), predisposing the United States to technology-dependent military operations. Finally, U.S. military operational priorities evolved to include military operations against peer competitors and non-state actors, and non-combat missions on a global scale. Gansler and Lucyshyn stated in 2010 that the "DoD's normal way of doing business … is totally incompatible with adversaries using available commercial technologies in new and different ways."

In 2016, Congress enacted new laws, referred to as Middle Tier Acquisitions (MTAs), addressing institutional (cultural) barriers, providing expedited processes available to speed execution, increasing discretionary authorities, and imposing direct accountability to deliver prototypes or fielded systems within five years of approval (National Defense Authorization Act, 2015).

Background

Reforms over the last 50 years tended to focus on authorities, governance, and performance (Fox, 2011) instead of the organizational culture. Williams (2005) considered that poor defense program performance resulted from systemic failures, in particular when conventional program management approaches were used for *complex, uncertain, and time-constrained* programs. Bower and Hout (1988) considered companies as systems, and shorter schedule durations (cycle times) came from improving organizational processes, such as adopting flexible manufacturing and focusing on small production runs responsive to customer demands.[1]

In 1992, the General Accounting Office[2] (GAO) observed that important programs struggled with cost and schedule growth and technical performance challenges, while successful programs avoided the "oversell and resulting performance bias" (GAO, 1992) of typical programs. Flyvbjerg (2006) noted most program forecasts are biased by psychological ("optimism bias") and political ("strategic misrepresentation") interests and proposed reference class forecasting to improve forecasting performance. Grau et al. (2017) found forecasting performance associated with organizational factors, such as early response to unfavorable trends and incentives for program management and control. Klein Woolthius et al. (2005) identified cultural issues such as regulatory and normative failures and groupthink or lock-in–type failures as limiting innovation policies and responses. Weber and Rohracher (2012) identified systemic failure causes for slow fielding of development projects, including early lock-in to suboptimal technology,[3] and challenges with change and adaption.[4]

Prior research identified factors related to "fast-to-field" programs, such as an urgency of need, senior leader sponsorship, and rapid access to available funding (Van Atta et al., 2016), and program strategy decisions associated with shorter schedules include using proven systems or developing and fielding systems with incremental performance improvements (Tate, 2016). The overall competence or proficiency of an organization[5] affects their ability to plan and execute development and production (Jaifer et al., 2020).

Technical maturity is commonly defined in the DoD using an ordinal scale of Technology Readiness Levels (TRLs; Mankins, 2009). In this context, maturity is a marker of successful use in conditions approaching the intended environment and purpose, where increasing TRL values indicate increasing maturity. Technical maturity is a commonly identified cause of schedule growth, where schedule growth decreases as a product becomes more mature (Katz et al., 2015). Markham and Lee (2013) analyzed commercial new product development; as seen with the DoD, radical innovations take longer and are more likely to experience schedule and cost growth relative to incremental innovations.[6] Dougherty (2018) identified technological maturity and sponsorship[7] as key factors for rapid prototyping, but additionally noted urgency of need and a compelling demonstration as important for rapid fielding. He recognized that rapid programs need only be "good-enough" to satisfy the sponsor's immediate performance needs.

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[1] These remain appropriate for improving process efficiency.

[2] Now the Government Accountability Office.

[3] Identified as a policy coordination failure.

[4] Identified as a reflexive failure.

[5] Organization in this context includes suppliers and "testers."

[6] Radical innovations are presumed to be less technically mature than incremental innovations.

[7] Sponsorship includes championing and protecting or obtaining resources.

New product development literature discusses gated management methods, such as Agile Stage Gate (Cooper, 2017). Lingens et al. (2016) proposed using estimates of potential impact and uncertainty to frame management decisions. Van Oorschot et al. (2018) argued that how fast a new product goes to market is a trade-off between cycle time and product quality, and requires understanding how many new (unexpected) tasks are identified in the front-end stage, how many are discovered just prior to the decision gate, and how many customers will wait for the new product. This approach makes sense when trying to maximize profit. The recent pandemic provides some insights into *rapid* new product development. Battaglia et al. (2021) identified three key factors for rapid development: *technical competence*, a*gile work practices* in order to produce and demonstrate a working prototype, and a*ccess to networks*[8] and scale to meet production, certification, and commercialization demands. This is consistent with the findings of Hsiao et al. (2017) on better new product performance when firms exploit core capabilities (competencies) and first-mover strategies.

Jaifer et al. (2020) developed an aerospace new product development case study, grouping schedule-related factors into *complexity* and *proficiency* categories, with uncertainty a subset of complexity. Bearden et al. (2012) developed a system complexity index for space systems[9] that showed a strong association between cost growth and the complexity index. Jaifer et al. (2020) decomposed complexity into technological complexity,[10] organizational complexity,[11] and environmental complexity.[12] The acquisition process itself exhibits inherent complexity. Wirthlin (2009) developed a discrete event simulation model of the DoD acquisition process reflecting systemic complexity by including process interdependencies as programs competed for finite resources.[13] In large scale systems-of-systems, the interdependencies may manifest as interoperability or integration issues, with discovery and correction needing exquisite engineering discipline (Garrett et al., 2011). Prescriptions include increasing system resiliency (Roberts et al., 2016), increasing inherent reliability, and reducing system complexity by increasing system commonality, modularity, and use of standards (Jovel & Jain, 2009).

A significant source of program uncertainty is the DoD preference for technical superiority, and the system technical maturity reflected in the *technical debt* that the program must retire (Boehm & Behnamghader, 2019). Patil and Bhaduri (2020) argued for incremental requirements, constrained (“frugal”) developments, and frequent interaction with users (“fast”) to reduce development uncertainty and improve product innovation, Williams’s (2005) program uncertainty is related to technical uncertainty and may be addressed by reusing existing technologies (Eiband et al., 2013). Peters et al. (2017) showed that new technology development challenges reduce technology maturity, increasing program uncertainty. Program schedule uncertainty is also related to program complexity, so organizational factors such as contract types and intentional schedule overlaps matter (Jaifer et al., 2020).

In prior research, we developed regressions showing that Major Defense Acquisition Program[14] (MDAP) schedules were related to the research and development budget size, whether the program depended on another MDAP, the reuse of existing or commercial

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[8] Battaglia et al. (2021) included external funding as part of the network.

[9] Named the Complexity-Based Risk Assessment (CoBRA).

[10] Technological complexity includes factors such as technical maturity, number of requirements, components, and functions.

[11] Organizational complexity includes factors such as contract types, program phase overlaps, team size, and number of technical disciplines.

[12] Environmental complexity includes factors such as legal constraints, numbers of stakeholders and suppliers, and competition levels.

[13] In Wirthlin’s (2009) model, most programs never progressed to production.

[14] These are traditional large defense acquisition programs. They are now called Major Capability Acquisitions.

technology, the type of software development, and whether or not the program is joint with another service (Etemadi & Kamp, 2021b). There are other policy-related decisions associated with schedules and schedule growth such as percent research and development budget remaining at program start (Jimenez et al., 2016), using incremental development (Mortlock, 2019), and contract type selection (General Services Administration, 2019).

Schedule risk definitions differ 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 (1998) used causal loop representations to identify likely sources and consequences of schedule delays, and showed how uncertainty drives risk. Earned-value methods are used to estimate schedule performance risk within a known project scope and budget (Swartz, 2008). Such simulations require detailed work project schedules and duration uncertainty distributions as inputs.

The existing literature describes organizational factors related to and qualitative attributes of rapid new product development. The military services, led by the Department of the Air Force, are discovering how to rapidly deliver new capabilities to the field to employ these new authorities. This paper is based on research we conducted for the Acquisition Research Program under Grant No. 12936478. Our research focused on rapid acquisitions, including MTAs, their program structures and products, and what acquisition strategy decisions were made to achieve schedule performance. In this paper we discuss use of simulations to understand schedule-related issues associated with constrained duration programs.

Material and Methods

While some MTA programs are delivering products now, most are not yet reporting sufficient data for analysis. Given the relative newness of MTAs, we used publicly reported event dates to characterize schedule variances for MTA and MDAPs,[15] and developed Monte Carlo simulations seeded with these recent program data. The simulations help develop insights into MTA performance relative to MDAPs.

We used publicly available data sources including GAO annual weapon system assessments (Oakley, 2020) and released Selected Acquisition Reports (SARs).[16] We started with the 2020 GAO annual weapon system assessment (Oakley, 2020; n = 63), eliminating entries with insufficient data (n = 3) and programs changing structures (n = 2). As each commodity type has unique development issues, we further reduced this to consider only air and missile commodity types,[17] leaving 27 entries, shown in Table 1.

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[15] Formerly Major Defense Acquisition Programs, now called Major Capability Acquisitions (Lord, 2020).

[16] See Washington Headquarters Services (2022).

[17] A commodity type represents the product, in this case an aircraft system or a missile system.

Table 1. 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	** Indicates MTA*		

The DoD has specific acquisition pathways (Lord, 2020). We defined a generic schedule consisting of a program start, a decision gate to start development,[18] a critical design review (CDR), a decision gate to start production,[19] a declaration of initial operational capability (IOC), and intervals between these events, as shown in Figure 1.

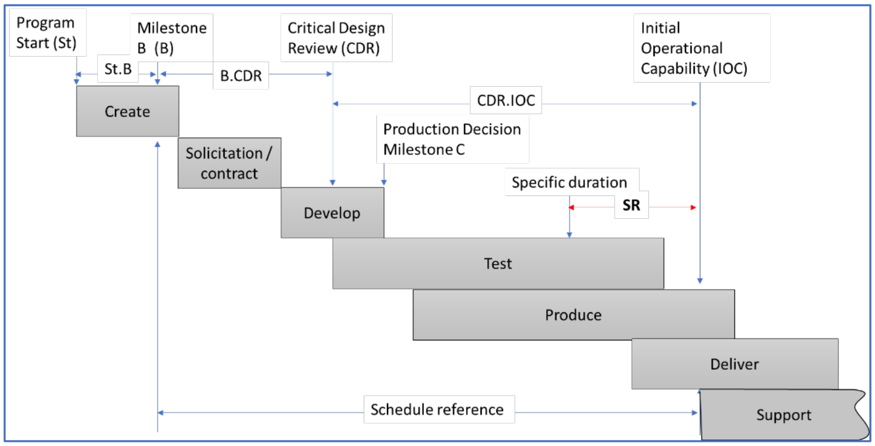

Figure 1. Notional Schedule and Schedule Reference

In Figure 1, the interval labels identify the starting and ending events, such as St.B being the interval in months between program start and the development start decisions. Table 2 summarizes the intervals used in this paper.

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[18] Called Milestone B in the Major Capability Acquisition pathway, it is also development contract award, formally the start of development.

[19] Called Milestone C in the Major Capability Acquisition pathway, it is marked by award of an initial or low-rate production contract.

Table 2. Interval Definitions

Interval	Description
St.B	Interval between initiation (St) and development decision (start of Engineering and Manufacturing Development phase, or Milestone B)
B.CDR	Interval between development decision (Milestone B) and Critical Design Review (CDR)
CDR.IOC	Interval between Critical Design Review (CDR) and Initial Operational Capability (IOC)
B.IOC	Interval between development decision (Milestone B) and Initial Operational Capability (IOC)

MTA programs are structured as either a Rapid Prototyping or Rapid Fielding program, as shown in Figure 2.

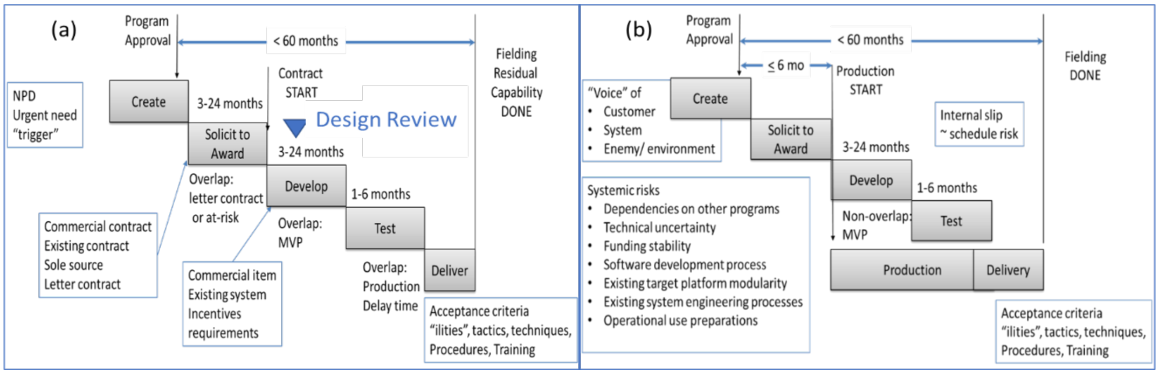

Figure 2. MTA Schedule Models[20]

While the overall sequencing is like Figure 2, there is an explicit schedule constraint of 60 months between program start and completion forcing early decisions to achieve this constraint as shown in the text blocks.[21] The Rapid Prototyping MTA (Figure 2a) is the most common model. The product is a prototype or residual capability. In this model, program approval is the equivalent of development start (Milestone B), and fielding is IOC. There is no explicit CDR requirement; typically, a design review occurs early in development. Unlike the Rapid Prototyping model, the Rapid Fielding MTA (Figure 2b) is intended for delivery of operational products and forces an early product start within 6 months of program approval.

The program *schedule* is the interval between development start (Milestone B) and IOC.[22] We define the program schedule as

$$schedule = B.CDR + CDR.IOC \qquad (1)$$

Schedule will generally equal the interval between Milestone B and IOC (B.IOC), unless a program has no reported CDR. We do not include the time prior to the development decision (St.B) in the overall schedule as this is prior to a formal development commitment, and includes planning and precontract activities. We modeled schedule as both a sum and as an interval

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[20] NPD = New Product Development, MVP = Minimum Viable Product.

[21] Schedule speed results from use of commercial-type contracts or Other Transaction Agreements, and adaptation of commercial or near-commercial products.

[22] This interval is also known as the program cycle time (the variable names Cycle.Mo in the data set).

(B.IOC), and compared results. Additionally, we did not decompose the interval after CDR to IOC (CDR.IOC) further as real programs differ in both sequences and events during this interval, with parallel[23] execution of various development, testing, production, and deployment activities. We defined *schedule risk* (SR in Figure 2) as a measure of the remaining schedule to IOC, equivalently the likelihood of exceeding a specified schedule duration:

$$schedule\ risk\ (SR) = 1 - p(schedule\ \leq specific\ duration) \tag{2}$$

The right-hand-side probability is the cumulative distribution function for the overall or reference schedule.

We performed Monte Carlo simulations for each interval and for the overall schedule for the Table 1 subset, simulating normal and Weibull distributions for both MDAP and MTA program types. The MTA schedule risk simulation depends on two assumptions: the model distribution and the likelihood of exceeding the schedule constraint. For the first assumption, if MTAs are *equally likely* to experience schedule contraction or growth, then assuming schedules are normally distributed is reasonable. In practice, few programs deliver early, and many programs complete later than initially planned, so skewed distributions[24] were used to simulate reference schedule and interval distributions. The second assumption is the likelihood of MTA schedule duration exceeding 60 months. In this case, we assumed that acquisition executives (decision authorities) may restructure struggling programs, so we did not explicitly restrict MTA schedule durations from exceeding 60 months. Instead, we used schedule variance estimates from the GAO data to seed Monte Carlo simulation models created in Excel. Figure 3 shows an example set of normal cumulative distribution functions for MTA programs where the expected (planned) durations vary from 60 months (schedule.MTA) to 24 months (24.MTA) with an overlaid set of hypothetical intervals.

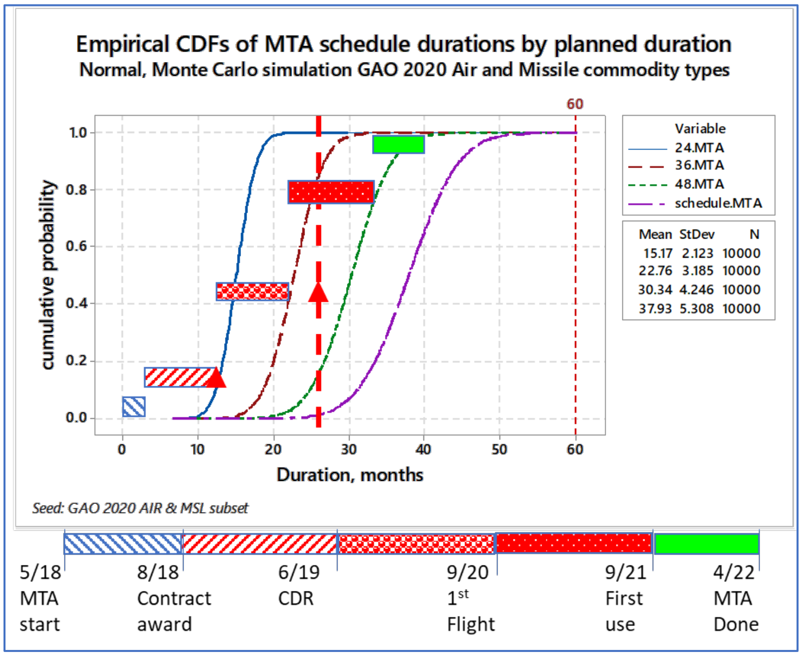

Figure 3. Example Mapping of Key Events to MTA Simulation Model

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[23] Often called concurrency; a similar concept is fast-tracking.

[24] We used Weibull distributions (McCool, 2012) to simulate skewed distributions. Minitab 18 was used to calculate scale, shape, and threshold parameters from empirical data fits.

In Figure 3, intervals are *head-to-tail*, where the end of the final event corresponds to the overall planned duration. The red triangles are when an event occurred relative to program start (duration, months) *at the cumulative probability of the interval*. We see that the latest event occurred later than planned and can visually estimate how late a program might be without corrective actions. The green bar is a margin set by the program office, making the example MTA duration 40 months. The vertical dotted line is the duration at which first flight occurred (10 months late), and the red triangle on the red dotted line indicates the actual event completion date.

In Figure 3, first use corresponds to IOC and occurs at about 34 months, showing a planned schedule of nearly 36 months (36.MTA). In this example, the schedule risk is 0.6, meaning that the program has a 0.6 chance of *not* making the 40-month schedule without corrective action, but is likely to complete in the next 2 years (42–48 months total duration, or 2–8 months late), close to the original plan plus margin. There is little chance of the schedule exceeding 60 months, unless it crosses the 60-month (schedule.MTA) curve.

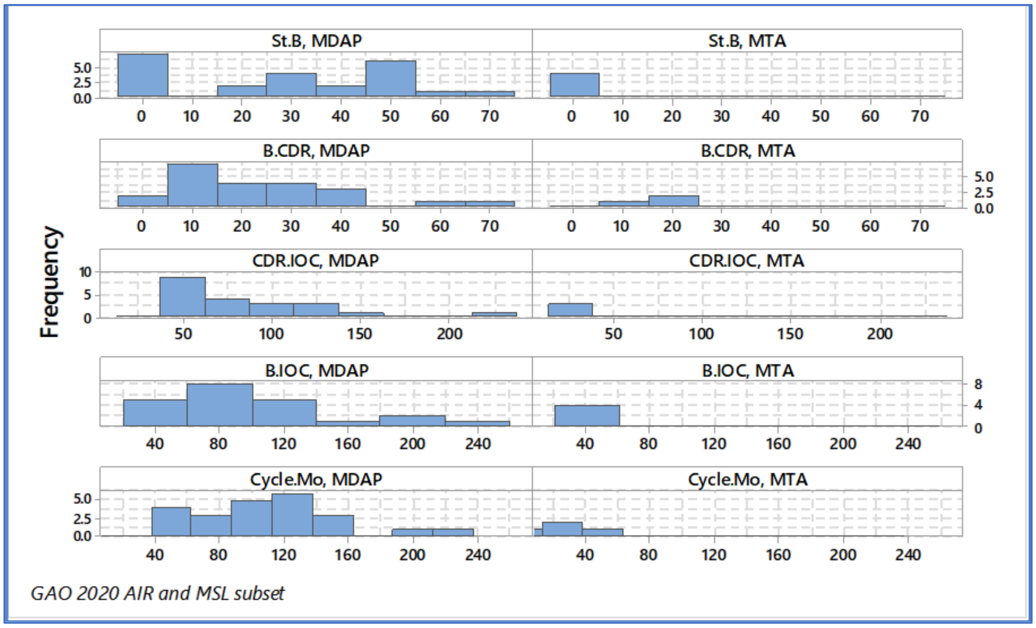
Results and Discussion

We sorted the Table 1 programs by MDAP and MTA and calculated descriptive statistics sorted by acquisition type (MDAP or MTA). Table 3 summarizes data set interval statistics.

Table 3. Interval Simulation Descriptive Statistics

Interval	Type	Mean	StDev	Scale	Shape	Threshold
St.B	MDAP	28.48	22.46	0.6683	24.04	-0.2923
	MTA	2.00	1.826	20.14	28.19	-25.62
B.CDR	MDAP	22.41	17.28	1.252	22.81	1.2
	MTA	17.67	4.51	51.59	162.4	-144.3
CDR.IOC	MDAP	83.33	43.88	1.91	52.34	34.17
	MTA	23.00	8.54	59.63	347.9	-3243
B.IOC	MDAP	102.50	56.3	1.495	89.37	21.67
	MTA	39.25	10.14	1962	13909	-13865
Cycle.Mo	MDAP	110.22	45.12	1.616	79.08	39.14
	MTA	25.25	18.98	2.093	36.12	-6.494

The distribution statistics reflect the small number of MTA programs (4) in the data set. We tested these intervals for goodness of fit against both normal and Weibull distributions, and were acceptable at a significance of 0.01. Figure 4 shows the histograms for these intervals.



GAO 2020 AIR and MSL subset

Figure 4. Empirical Interval Histograms

We developed Monte Carlo simulations of interval durations in Excel using interval data from the Table 1 programs. We ran 10,000 normal and Weibull simulations for each Table 3 interval and present selected Weibull simulation results in Figure 5.

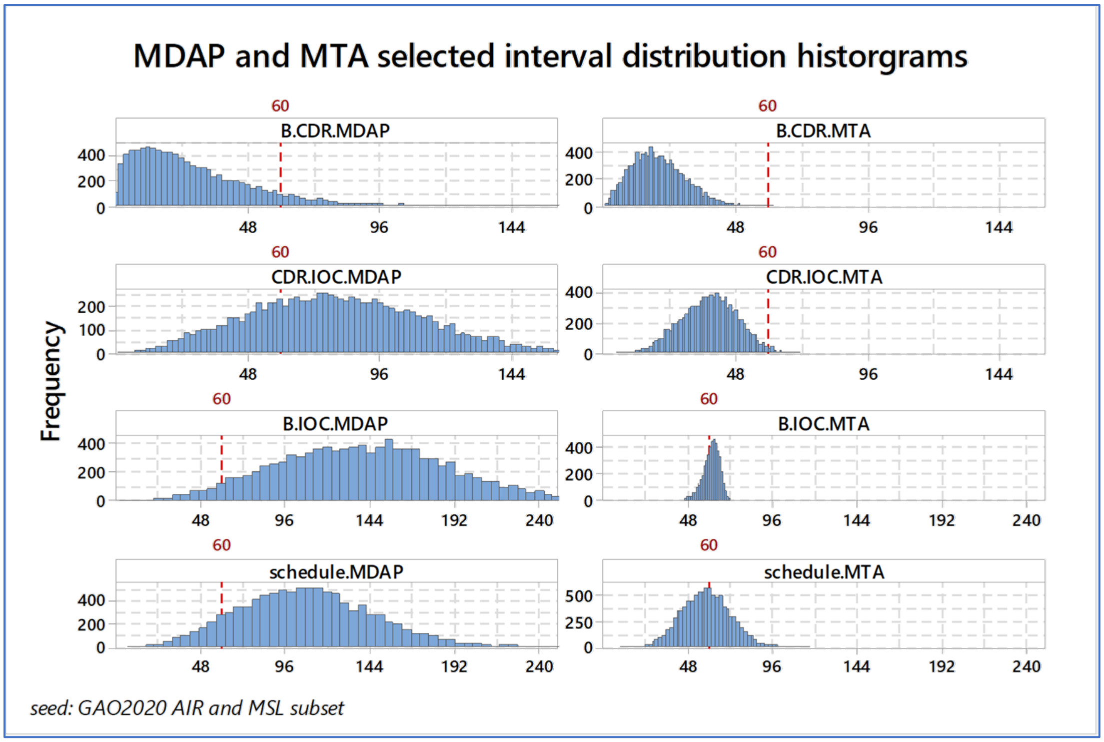


Figure 5. Weibull MDAP and MTA Interval Simulation Results

The Figure 5 simulations show the compression of MTA intervals and schedules relative to traditional MDAP programs. The right-skew of development and design (B.CDR) is more pronounced than that of the production to delivery (CDR.IOC) phase, meaning MDAP and MTA schedule durations are largely due to CDR.IOC. In all simulations, the MTA variance is much smaller than traditional MDAP programs. Figure 6 shows cumulative distribution functions for selected intervals and schedules for MDAPs and MTAs.

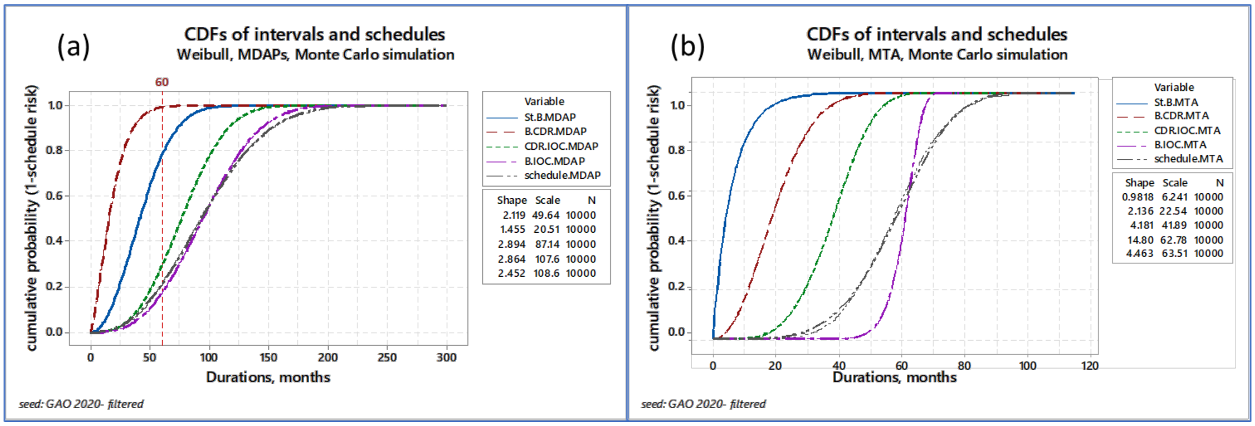


Figure 6. Cumulative Distribution Function Simulation Results

The time from program start to development start (St.B) is quite fast for MTAs, meaning that rapid contracting and award approaches are essential for an MTA.[25] Figure 6a shows that the B.CDR is similar in shape to the interval between program start and Milestone B (St.B, blue

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[25] In principle, average MTA might be finished before the average MDAP is under contract.

curve). In Figure 6b, the MTA B.CDR curve is quite steep compared to Figure 6a, meaning MTA programs should prefer technologies closer to actual use (less technical uncertainty) than normally used by a MDAP.

The steepness of the CDR.IOC curve for MTA (red curve) emphasizes the inability of an MTA to accommodate system complexity within duration constraints. The program must complete integration and demonstration in about 2 years, while a MDAP will take about four times as long to proceed from CDR to initial fielding. This may reflect the different testing and initial production issues related with MDAPs. The MTA CDR.IOC curve is also steeper, meaning the system must be much less complex to produce and field than a MDAP system. We compare MDAP and MTA schedule performance in Figure 7.

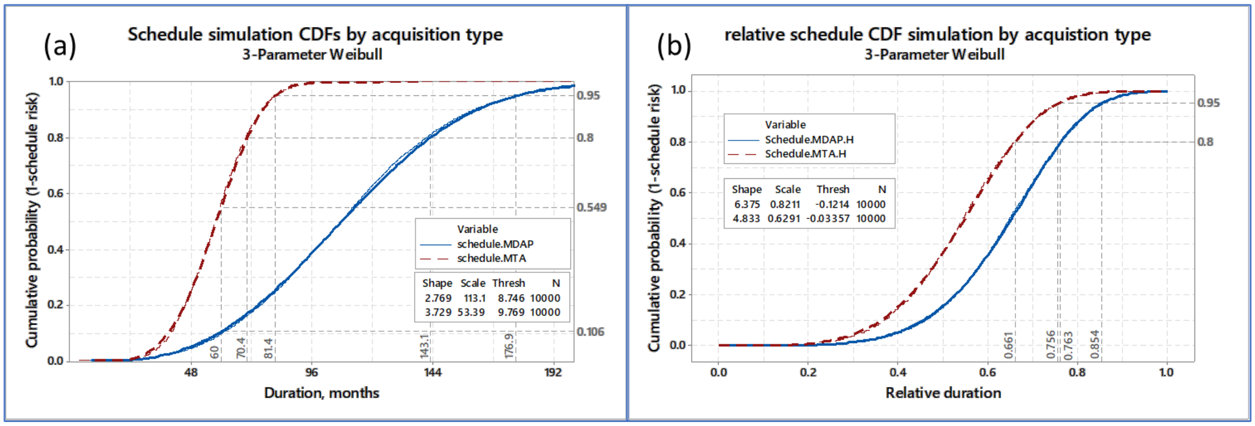

Figure 7. MDAP and MTA Schedule Duration Simulations

By inspection, Figure 7a shows MTAs have less schedule risk than MDAPs at the same *absolute* schedule duration. In Figure 7b, both schedule curves are scaled by the maximum duration for each distribution, resulting in duration fractions between 0 and 1. Figure 7a shows neither MDAPs nor MTAs are likely to take less than 2 years to complete. The MTA model was allowed to exceed 60 months due to random variation. The simulation suggests that MTAs are likely to exceed 60 months by less than 10 months without additional controls, but unlikely to exceed 84 months. Additionally, both Figures 7a and 7b show that MTAs have lower absolute (7a) or relative (7b) schedule risk than MDAPs. We conclude that the MTA schedule risk is less than an MDAP.

Conclusions

The simulation results show that DoD MTAs are unlikely to complete in less than 2 years, but can deliver within the 60-month limit. Program offices can adjust planning and execution to meet an explicit schedule constraint. The key program attributes that help achieve these results are short times to contract award (development start), and intentionally reducing program complexity and technical uncertainty. The short time to contract award can include both using commercial-type contracting methods and reducing contractual requirements. The MTA product design should not require extensive technical risk reduction and should complete in less than 12–18 months (B.CDR). The interval after design complete (CDR.IOC) has the most effect on schedule duration, meaning that program offices should simplify production, test, and certification gates, and plan additional schedule margin during this phase. The simulations show that adding schedule margin *at the end* of a program is prudent.

The simulations provide a way to assess program performance without requiring in-depth understanding of program plans. The ability to compare an overall duration and plan against an expected distribution and schedule risk allows discussions about why a schedule is faster or slower than expectations.

The development and application of schedule risk simulations to assess likely MTA performance is an original contribution of the paper. The research highlights the importance of reducing program complexity and uncertainty to reduce program schedules. The indirect quantification of program complexity and uncertainty in terms of program schedule allow discussions and trades to reduce the schedule risk associated with a particular program plan.

This research is applicable to DoD air and missile commodity type MDAP and MTA acquisition programs. The results are based on publicly released data. Different conclusions may result if these methods are applied to more complete data sets, other commodity types, or to programs with unstable requirements and resources. Future research opportunities include applying these methods to restricted data sets and comparing internal program assessments to these refined models, validation with future programs, and association of department, program office, and commodity type cultural factors to MTA schedule performance.

Credit Author Statement

Amir Etemadi: Funding acquisition, Supervision, Project administration, Writing - Review & Editing. John Kamp: Funding acquisition, Conceptualization, Methodology, Investigation, Data Curation, Formal analysis, Validation, Visualization, Writing - Original Draft.

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Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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