Benchmarking Schedules for Major Defense Acquisition Programs

Thomas Light, Robert S. Leonard, Meagan L. Smith, Akilah Wallace, Mark V. Arena

For more information on this publication, visit www.rand.org/t/RR2144

Library of Congress Cataloging-in-Publication Data is available for this publication.
ISBN: 978-0-8330-9903-7

Published by the RAND Corporation, Santa Monica, Calif.

Preface

RAND Project AIR FORCE (PAF) was engaged in a multiyear project—"Weapon System Acquisition and Cost Analysis Umbrella Project"—to conduct analyses of interest to the Deputy Assistant Secretary for Acquisition Integration, Office of the Assistant Secretary of the Air Force for Acquisition (SAF/AQX), to improve weapon system acquisition outcomes and develop better cost- and schedule-estimating tools for use by the acquisition community. Major defense acquisition programs (MDAPs) are required to report programmatic information to Congress on an annual basis in the form of selected acquisition reports (SARs). PAF has developed and maintains a comprehensive database of program cost and schedule information obtained by analyzing and summarizing the contents of the SARs from the inception of each program through the latest out-of-cycle and annual SARs submitted as part of each year's President's Budget. This database supports ongoing analyses of interest to U.S. Air Force leadership.

One part of PAF's SAR analyses during fiscal year 2016 was the development and application of methodologies to assess and benchmark MDAP schedule estimates. This report describes an approach developed by PAF to support the evaluation of schedule plans for MDAPs that recently entered the Air Force portfolio. In this report, we apply the approach to five Air Force MDAPs currently undergoing development: the Global Positioning System Next-Generation Operational Control System, KC-46, F-22 Increment 3.2B Modernization, B61 Mod 12 Life Extension Program Tailkit Assembly, and Combat Rescue Helicopter programs.

This research was conducted as part of a broader research effort focused on providing the Air Force with implementation guidance for schedule related analyses. This report should be of interest to analysts and decisionmakers concerned with MDAP schedule planning and outcomes. The research was conducted within PAF's Resource Management Program.

RAND Project AIR FORCE

RAND Project AIR FORCE (PAF), a division of the RAND Corporation, is the U.S. Air Force's federally funded research and development center for studies and analyses. PAF provides the Air Force with independent analyses of policy alternatives affecting the development, employment, combat readiness, and support of current and future air, space, and cyber forces.

Research is conducted in four programs: Force Modernization and Employment; Manpower, Personnel, and Training; Resource Management; and Strategy and Doctrine. The research reported here was prepared under contract FA7014-16-D-1000.

Additional information about PAF is available on our website:

www.rand.org/paf/

This report documents work originally shared with the U.S. Air Force on September 30, 2016. The draft report, issued on February 16, 2017, was reviewed by formal peer reviewers and U.S. Air Force subject-matter experts.

Contents

Preface iii
Lists of Figures and Tables..vii
Acknowledgments ix

CHAPTER ONE
Introduction 1
Structure of the Report.. 2

CHAPTER TWO
Approach for Developing Schedule-Estimating Relationships 3
Methodology for Establishing Schedule-Estimating Relationships and
S-Curves.. 7
Benchmarking Program Schedule Plans Using S-Curves Derived from
Schedule-Estimating Relationships 11

CHAPTER THREE
Application of Schedule-Estimating Relationships to Five MDAPs
Currently Under Development... 15
Estimates of Schedule S-Curves for Five Air Force MDAPs................. 18

CHAPTER FOUR
Concluding Remarks..29

APPENDIX
Steps Performed to Conduct Benchmarking 31

Abbreviations..35
References 37

Lists of Figures and Tables

Figures

2.1. Example of S-Curve for F-22 Inc. 3.2B Program First LRIP Contract Award Schedule 13
3.1. Illustration of Schedule Benchmarking for GPS OCX Program 21
3.2. Illustration of Schedule Benchmarking for KC-46 Program 23
3.3. Illustration of Schedule Benchmarking for F-22 Inc. 3.2B Program 24
3.4. Illustration of Schedule Benchmarking for B61-12 TKA Program 25
3.5. Illustration of Schedule Benchmarking for CRH Program 27

Tables

2.1. Schedule-Estimating Relationship Equation for Time from MS B to First LRIP Contract Award (Dependent Variable = Log[Time from MS B to First LRIP Contract Award]) 9
2.2. Schedule-Estimating Relationship Equation for Time from MS B to IOC/IOD/RAA (Dependent Variable = Log[Time from MS B to IOC/IOD/RAA]) 10
3.1. Program Characteristics for Select Air Force MDAPs as Planned at MS B 16

3.2. Information on Planned and Current Schedules to First LRIP Contract Award. 16
3.3. Information on Planned and Current Schedules to IOC, IOD, or RAA 17
3.4. GPS OCX Key Delivery Dates 20
A.1. Program Characteristics at MS B for F-22 Increment 3.2B Program 33
A.2. Construction of S-Curve for F-22 Increment 3.2B First LRIP Contract Award Schedule 34

Acknowledgments

This work would not have been possible without the sustained support of the Office of the Deputy Assistant Secretary of the Air Force for Acquisition Integration, including John M. Miller, Bobby W. Smart, Richard W. Lombardi, and Blaise J. Durante. We give thanks to our colleagues, especially Bill Shelton, who manages RAND Project AIR FORCE's Acquisition and Cost Analysis Umbrella Project, and Mark Lorell, Caroline Baxter, Leslie Payne, and Obaid Younossi, for their feedback and suggestions that contributed greatly to this analysis. We appreciate the reviews of an earlier version of this report that we received from our RAND colleagues Lionel Galway and Thomas Goughnour.

Acknowledgment of these individuals does not imply their endorsement of the views expressed in this report.

CHAPTER ONE

Introduction

With the Secretary of the Air Force outlining new schedule initiatives in 2015, the Air Force formally recognized the importance of managing schedules and reducing schedule slippage.[1] Unrealistic program schedules are problematic for a variety of reasons. First, stretching development or production activities over longer periods than planned may add significantly to acquisition costs. When schedules slip, program funds may also need to be reprogrammed, contributing to budget turbulence and uncertainty. Finally, delays during acquisition can result in later delivery of critical capabilities to the warfighter, forcing deployed forces to use aging, less capable, and potentially more-expensive-to-maintain assets longer than planned, while reducing overall force capabilities and effectiveness (Tyson, Harmon, and Utech, 1994; Riposo, McKernan, and Kaihoi, 2014).

It would be useful to have a framework for comparing proposed or planned program schedules against the schedules of similar historical programs. This would provide program staff, acquisition analysts, and decisionmakers with additional information from which to gauge the degree by which schedules may be aggressive or conservative. It could also help with the formulation of schedule targets or goals, for incorporation into schedule incentives.

---

1 The Secretary of the Air Force and other Air Force officials have discussed efforts to improve schedule outcomes as part of the "should schedule" initiative in recent years (James, 2015; Haux, 2015). Staff at SAF/AQX (Air Force Acquisition, Acquisition Integration Leadership) indicated that in 2017 the "should schedule" initiative was renamed to the "schedule assurance" initiative.

In this report, we present an approach developed by RAND Project AIR FORCE (PAF) to support the evaluation of schedule plans for major defense acquisition programs (MDAPs) that recently entered the Air Force portfolio. The method relies on standard statistical techniques to relate the distribution of historical schedule outcomes with observable program characteristics at Milestone (MS) B.[2] After estimating these relationships from data assembled from past programs, the statistical model can be applied to new programs entering the development phase.

To illustrate the approach, we apply it to five MDAPs that are currently being developed:

- Global Positioning System Next-Generation Operational Control System (GPS OCX)
- KC-46
- F-22 Increment 3.2B Modernization (F-22 Inc. 3.2B)
- B61 Mod 12 Life Extension Program Tailkit Assembly (B61-12 TKA)
- Combat Rescue Helicopter (CRH) programs.

Structure of the Report

The remainder of this report is structured as follows: Chapter Two describes the data and methodology we relied on to develop MDAP schedule-estimating relationships. Chapter Three applies the SERs we developed to five programs that recently entered the Air Force's MDAP portfolio. Chapter Four provides concluding remarks. The appendix provides a summary of the steps performed to conduct the benchmarking analysis presented in this report.

---

[2] Following MS B, programs enter the Engineering and Manufacturing Development (EMD) acquisition phase, where a system is developed and designed before going into production. MS B is considered the official start of an MDAP. We include in our analysis MDAPs that have a documented MS B that coincides with EMD contract award and an acquisition program baseline. For an overview on the current MS review process, see Department of Defense Instruction 5000.02, January 7, 2015.

CHAPTER TWO

Approach for Developing Schedule-Estimating Relationships

The acquisition process governing MDAPs has been largely standardized over the past several decades. As part of the acquisition process, MDAPs are required to report cost and schedule information annually in selected acquisition reports (SARs) and other documents. RAND has developed a database containing SAR cost, schedule, and other programmatic data spanning the past 40+ years. Using this database, we have developed *schedule-estimating relationships* (SERs) for programs that have completed an MS B review.

The data utilized here include MDAPs managed by all three military services. We exclude from our dataset canceled programs. In this analysis, we focus on two critical schedule durations:

- *Duration from MS B to first low-rate initial production (LRIP) contract award.* The time between MS B and the first LRIP contract award is when the majority of development activities tend to occur. More complex or sophisticated weapon systems will often require more time and resources to complete this acquisition phase. In general, we observe that the date of first LRIP contract award correlates closely with a program's MS C date, although there are some exceptions.[1]

[1] An important exception is the F-35 program, which awarded its first LRIP contract in July 2007 but is not scheduled to complete MS C until April 2019. The F-35 program is also somewhat unique in that it is scheduled to complete IOC prior to an MS C decision.

- *Duration from MS B to Initial Operational Capability (IOC), Initial Operational Date (IOD), or Required Assets Available (RAA).* This schedule duration represents the amount of time it takes to proceed from MS B to IOC, IOD, RAA, or other similar schedule milestones (e.g., ready to transition to operation [RTO]). A program's IOD represents the delivery of the first production configuration article to the service. Often, IOC or RAA dates are recorded instead of IOD, as these events tend to fall around the same time. There is some flexibility in how these dates are defined, as will become apparent in the next chapter.

As part of our schedule data-collection effort, we captured both the planned schedule at MS B and the actual schedules that were observed at program completion. For the purposes of the analysis shown here, we relate the actual schedules (rather than the planned schedules) of historical programs to program characteristics and use those relationships to project schedule outcomes for programs that recently entered the Air Force's portfolio. Other research has used similar quantitative methods to relate schedule growth (e.g., the degree by which actual schedules slip from those planned at MS B) with program characteristics (Tyson et al., 1989; Monaco and White, 2005; and Light et al., 2017).

We considered a variety of program characteristics that might influence schedule durations:[2]

- *Completion of MS A review.* Some programs complete an MS A review as part of the acquisition process, although many programs proceed without a formal MS A decision. To capture this, we created a binary variable in our dataset that equals 1 if the MDAP completed an MS A review and 0 otherwise.
- *Share of Research, Development, Test, and Evaluation (RDT&E) budget planned to be expended prior to MS B*. We calculate this share from the program funding plan presented in the MS B SAR.

---

2 The variables considered here overlap largely with those considered in prior RAND research. See Light et al. (2017) for summary statistics and additional details on many of the variables used in this analysis.

- *Share of RDT&E budget planned to be expended concurrently with production (i.e., "concurrency").* We created a variable that measures the share of the project's RDT&E budget expended concurrently with the production phase (after the first LRIP contract award) in the program plan presented in the MS B SAR.
- *Joint versus single-service programs.* We developed a binary variable equal to 1 if the MDAP is a joint program and 0 if the program is a single-service program.
- *Total development cost estimate at MS B.* We considered a variable representing the total program RDT&E cost estimate at MS B measured in millions of fiscal year (FY) 2012 dollars. This variable has the potential to capture schedule requirements that are systematically related to the overall size of the development program for MDAPs.
- *Procuring service.* While there is general U.S. Department of Defense (DoD) acquisition guidance and policy, the services have some leeway in their approach to managing MDAPs. We use indicator variables to capture the procuring service. For joint programs, we associate the program with the lead service.
- *Acquisition era.* McNicol (2014) and McNicol and Wu (2014) have found that there are meaningful differences in Program Acquisition Unit Cost (PAUC) growth observed over different budget climates, with more growth experienced in periods associated with a tight or contracting DoD budget environment.[3] We categorize each MDAP into an "acquisition era" based on the program's MS B date. This variable is intended to capture changes in acquisition policy and approaches over time. We place each program into one of the following eras, which represent breaks in the budget and defense acquisition policy environment: pre-1986; 1986 to 1994; 1995 to 2003; and post-2003. For a discussion of defense acquisition policy changes over time, see Fox (2011).
- *Weapon system type.* We categorize each MDAP into a weapon system category to capture differences in risk that may vary sys-

3 This is in contrast to Younossi et al. (2007), who found that development cost growth over the previous three decades remained high and without any significant improvement.

tematically with the type of weapon system being procured. The program portion that dominates by value designates the weapon system type. The weapon system categories we consider are (1) aircraft; (2) electronic; (3) space; (4) torpedoes, munitions, and missiles; and (5) other.[4] Because of their unique nature, we excluded submarine and ship programs from our analysis.[5]

- *Type of procurement program.* We create indicator variables to capture whether the weapon system program is funding new units of a new design; new units of a modified design; the modification of existing units; or the integration of existing design components.

The program characteristics listed above are readily available from data RAND has been compiling from SARs over the past two decades. In many respects, these factors are considered fundamental to an MDAP and difficult to change without significantly altering a program. Past analyses of cost and schedule outcomes have considered and controlled for many of these factors.

Other program features that have been considered in the literature (see Monaco and White [2005] for a review) but which are not captured in the data we utilize include contract type, number of test articles, and measures of competition, funding stability, and program complexity. Integrating measures of these factors is left for future research.

4 Examples of MDAPs that fall in the "other" category include the Army's Future Combat Systems, the Navy's Expeditionary Fighting Vehicle, and the Air Force's Peacekeeper Rail Garrison program.

5 Submarine and ship programs are excluded because they are not weapon systems procured by the Air Force and they are approached somewhat differently in the acquisition process. For a discussion of the differences in acquisition processes applied to submarines and ships versus other types of weapon systems, see Drezner et al. (2011).

Methodology for Establishing Schedule-Estimating Relationships and S-Curves

We develop regression models that correlate the factors noted above with the two schedule durations.[6] The resulting regression equations represent a SER that can be used to develop schedule point estimates and s-curves. As we illustrate in the next chapter, the SERs can also be used to benchmark the schedule plans of programs currently undergoing development activities. The regression models we develop relate program characteristics at MS B with the natural logarithm of schedule durations.[7] We assume that schedules can be related to observable program characteristics at MS B through the following multivariate regression equation:

$$\log(y_i) = \beta X_i + \varepsilon_i \tag{1}$$

where y_i is one of the two actual schedule durations considered for MDAP i, β is a vector of coefficients to be estimated, X_i is a vector of program characteristics as reported at MS B, and ε_i is a normally distributed error term.[8] The error term, ε_i, has mean zero and variance that differs for each MDAP based on its weapon system type. This type of regression model is commonly referred to as a heterogeneous variance model (Snedecor and Cochran, 1976, p. 256). We estimate the above regression model using maximum likelihood techniques.

While all of the program characteristics noted above could conceivably be correlated with schedule duration, many turn out to be statistically insignificant predictors of schedule durations when tested.

---

6 Our regression analysis is very similar to that of Jimenez et al. (2016), who developed a model that can be used to predict a program's schedule from MS B to IOC as a function of program characteristics derived prior to MS B.

7 By taking the natural logarithm, we ensure that schedule predictions are strictly positive. This is a common transformation used when modeling cost or schedules outcomes using regression analysis (Naval Center for Cost Analysis, 2014).

8 In applying this framework, we estimated separate equations for each schedule duration we considered. The separate equations will have different dependent (y_i) and independent (Xi) variables, as well as different coefficients (β) and residual terms (ε_i).

Variables that were deemed not statistically significant predictors were excluded from the refined regression models applied later in the report. As part of the model refinement and validation process, we examined regression statistics and residual terms to assess our distributional assumptions, identify outliers and influential cases, and refine the regression specification.[9] We also considered the interrelationship of covariates by looking at correlations among independent variables and conducting sensitivity analysis to identify possible collinearity issues.

Schedule-Estimating Relationship Coefficient Estimates

Tables 2.1 and 2.2 provide the coefficient estimates that make up the SERs applied in the next chapter to Air Force programs currently under development.

The coefficient estimates are interesting in that they provide insight into factors that are associated with longer or shorter schedules. We find that the size of the planned RDT&E budget at MS B, how the development budgets are phased (as captured by the share of the planned RDT&E budget expended prior to MS B and concurrent with production), and the weapon system type are good predictors of both schedule metrics. For example, all else equal, a program with a 10 percent greater planned development budget will have, on average, a 1.0 percent longer schedule to first LRIP contract award and a 0.7 percent longer schedule to IOC, IOD, or RAA. Also, as one might expect, programs that plan to spend a greater share of their development budget prior to MS B or concurrently with production activities tend to have shorter schedules. This finding is consistent with those of Drezner and Smith (1990), who found that concurrency led to shorter schedules from a statistical analysis conducted of ten programs. In testing this relationship, we found that concurrency has less of an effect on the schedule to first LRIP contract award for electronic programs, and

[9] We relied on SAS's "proc mixed" estimation procedure (see SAS Institute Inc., 2008) to estimate the regression. We reviewed regression statistics and other diagnostics available within this procedure.

Table 2.1
Schedule-Estimating Relationship Equation for Time from MS B to First LRIP Contract Award (Dependent Variable = Log[Time from MS B to First LRIP Contract Award])

	Coefficient	Standard Error	*p*-value
Intercept	1.434	0.324	<0.0001
Log of RDT&E estimate	0.106	0.035	0.003
Share of RDT&E expended pre–MS B	–1.084	0.305	0.001
Share of RDT&E expended concurrent with production	–1.310	0.212	<0.0001
Share of RDT&E expended concurrent with production × electronic program dummy variable	1.060	0.456	0.023
Acquisition era[a]			
Pre-1986	–0.154	0.125	0.221
1986 to 1994	0.104	0.136	0.449
1995 to 2003	–0.103	0.129	0.427
Weapon system type[b]			.
Electronic	–0.396	0.209	0.061
Other	–0.758	0.237	0.002
Space	–0.340	0.308	0.274
Torpedo, munitions, and missile	0.029	0.100	0.775
Error term variance estimates			
Electronic	0.1759		
Other	0.0559		
Space	0.6392		
Torpedo, munitions, and missile	0.1791		
Aircraft	0.0992		

[a] The post-2003 category is excluded.

[b] The aircraft category is excluded.

NOTES: Regression includes data for 116 MDAPs. Regressions estimated using maximum likelihood techniques (–2 Residual Log Likelihood = 107.1).

Table 2.2
Schedule-Estimating Relationship Equation for Time from MS B to IOC/IOD/RAA (Dependent Variable = Log[Time from MS B to IOC/IOD/RAA])

	Coefficient	Standard Error	*p*-value
Intercept	1.744	(0.248)	<0.0001
Log of RDT&E estimate	0.072	(0.029)	0.016
Share of RDT&E expended pre–MS B	–0.667	(0.239)	0.006
Share of RDT&E expended concurrent with production	–0.424	(0.157)	0.008
Weapon system type[a]			
Electronic	–0.148	(0.107)	0.169
Other	–0.246	(0.259)	0.344
Space	0.140	(0.142)	0.326
Torpedo, munitions, and missile	–0.034	(0.084)	0.687
Error Term variance estimates			
Electronic	0.1847		
Other	0.3794		
Space	0.1845		
Torpedo, munitions, and missile	0.0957		
Aircraft	0.1326		

[a] The aircraft category is excluded.

NOTES: Regression includes data for 94 MDAPs. Regressions estimated using maximum likelihood techniques (–2 Residual Log Likelihood = 117.3).

we allow for that in our regression.[10] We also found that the acquisition era was a statistically significant predictor of the first LRIP contract award schedule.[11] We include these factors as explanatory variables in the SERs applied in the next chapter.

Program characteristics that were not generally found to be correlated with longer or shorter schedules (after controlling for other factors) include completion of an MS A review, joint versus single-service programs, the procuring service, and the type of procurement program being pursued (i.e., new units of a new design, new units of a modified design, the modification of existing units, or the integration of existing design components).

Benchmarking Program Schedule Plans Using S-Curves Derived from Schedule-Estimating Relationships

The regression models and associated SERs presented above can be used to generate schedule point estimates. Two point estimates of interest are the median and mean schedule estimate, which can be calculated as $\exp(BX_i)$ and

$$\exp\left(BX_i + \frac{\sigma_i^2}{2}\right),$$

respectively, where σ_i represents the standard deviation associated with the logged observation i around the logged predicted value, BX_i.[12] The

[10] Electronic programs tend to be more developmentally intensive when compared with other types of weapon systems programs. This may explain why concurrency has less of an impact on electronic programs.

[11] This is based on a F-test conducted on the set of acquisition era variables, which showed statistical significance at the 10 percent significance level.

[12] Calculation of σ_i incorporates two sources of variation: (1) the variation around the mean of the prediction (which is calculated at the bottom of Tables 2.1 and 2.2 and varies by weapon system type) and (2) the variation in the prediction, which will depend on the total number of cases and on the location of the covariate pattern for observation i in the configuration of the covariates used to estimate the regression. The second source of uncertainty will

median will lie below the mean schedule estimate because the regression model shown in Equation 1 implies that the uncertainty in schedule outcomes takes on a log-normal distribution, which has a longer right hand-side tail.

The regression models can also be used to construct the distribution of schedule outcomes that can be expected based on the outcomes observed for other historical programs with similar characteristics. The distribution of expected schedule outcomes can be represented as an "s-curve," where the s-curve can be interpreted as the cumulative proportion of programs with similar characteristics that have schedule durations less than (or greater than) certain levels.[13]

Under our regression assumptions, that s-curve for program *i* will take the form of a cumulative log-normal distribution characterized by the following equations:

$$F_i(z) = \Phi\left(\frac{\log(z) - BX_i}{\sqrt{\sigma_i^2}}\right) \tag{2}$$

where $F_i(z)$ can be interpreted as the share of programs similar to program *i* that have a schedule less than *z* years long, and Φ is the cumulative distribution function for the standard normal distribution. To display the s-curve, an analyst can plot $F_i(z)$ for alternative values of *z*. For discussion of how to derive an s-curve from a regression model, see the *Joint Agency Cost Schedule Risk and Uncertainty Handbook* (Naval Center for Cost Analysis, 2014).

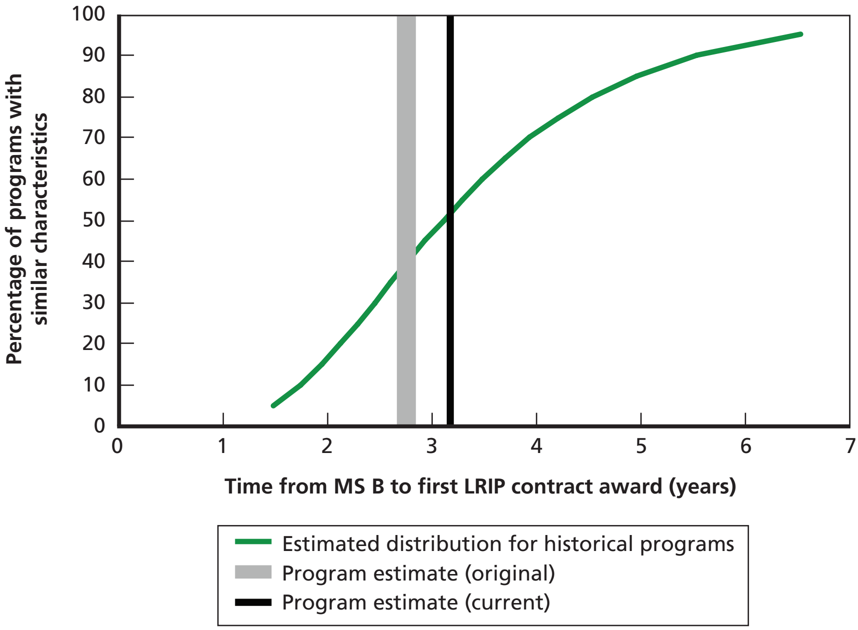
As an example, Figure 2.1 shows in green the s-curve derived for the F-22 Inc. 3.2B program's schedule from MS B to first LRIP con-

---

vary across prediction cases. We use the computational capability that is part of SAS's "proc mixed" procedure to generate estimates of this variation for each prediction case (e.g., each of the five programs) generated from each regression. See Naval Center for Cost Analysis (2014, pp. 19–20) for a discussion of how to combine these two sources of variation in the case of a univariate ordinary least squares regression model.

[13] A number of studies report the development and use of s-curves in cost risk assessments (see, for example, Technomics, 2012). Application of these approaches to schedule risk assessments is less common in practice according to Air Force cost analysts we spoke with.

Figure 2.1
Example of S-Curve for F-22 Inc. 3.2B Program First LRIP Contract Award Schedule



RAND *RR2144-2.1*

tract award.[14] The green curve represents the distribution of schedule outcomes based on the regression coefficient shown in Table 2.1 and the program's characteristics. The gray vertical line reflects the original schedule duration estimated at MS B of 2.8 years.

---

[14] The value of BX_i equals 1.1316 for the F-22 Inc. 3.2B program's first LRIP contract award schedule based on the program's characteristics and the coefficient estimates shown in Table 2.1. Based on the work content of the program, the F-22 Inc. 3.2B program is classified as an electronic program, so we use a value of σ_i^2 equal to 0.1759. This implies that the program has a median and mean schedule point estimate of approximately 3.1 [= exp(1.1316)] and 3.4 [= exp(1.1316 + 0.1759 / 2)] years, respectively. The s-curve for the program is calculated from the following function:

$$F(z) = \Phi\left(\frac{\log(z) - 1.1316}{\sqrt{0.1759}}\right).$$

The green curve and gray line intersect at roughly the 40 percent mark on the y-axis. This indicates that we would expect the F-22 Inc. 3.2B program to make its planned schedule to first LRIP contract award at MS B 40 percent of the time and be longer 60 percent of the time, based on schedule outcomes for historical programs with similar characteristics.

The black vertical line represents the actual schedule of 3.2 years.[15] We see that the black line and green curve intersect at roughly the 50 percent level on the y-axis. This indicates that, historically, similar programs would have schedules that are equal or less than the program's current schedule 50 percent of the time, and equal or exceed the program's current schedule 50 percent of the time. As a result, one might conclude that the program's current first LRIP contract award schedule seems quite reasonable, based on the schedules of similar historical programs.

---

[15] The program completed MS C and was authorized to make its first LRIP contract award on August 2, 2016.

CHAPTER THREE

Application of Schedule-Estimating Relationships to Five MDAPs Currently Under Development

We illustrate how the regression model and resulting SERs described in the previous chapter can be applied to programs that recently completed MS B to inform assessments of their schedules. Specifically, we apply the program schedule estimate model to five MDAPs:

- GPS OCX
- KC-46
- F-22 Inc. 3.2B
- B61-12 TKA
- CRH.

We apply the model against the schedule duration based on each program's MS B date and the schedule "current estimate" reported for each relevant milestone.[1] We calculate the schedule duration to each milestone as reported in a program's MS B SAR and the latest available SAR.

A summary of the program characteristics of each of these programs is shown in Table 3.1.

Information on the date of each program's MS B decision and its planned (at MS B) and current first LRIP contract award is shown in Table 3.2, and information on each program's planned and current IOC, IOD, or RAA date is shown in Table 3.3. All the programs except

1 SARs also present "objective" and "threshold" schedule estimates. The s-curves developed here can be used to evaluate the reasonableness of these alternative schedule estimates.

Table 3.1
Program Characteristics for Select Air Force MDAPs as Planned at MS B

	GPS OCX	KC-46	F-22 Inc. 3.2B	B61-12 TKA	CRH
RDT&E Cost Estimate at MS B (millions of FY12 dollars)	3,204.0	6,933.5	1,125.1	964.5	1,800.0
Share of RDT&E expended pre–MS B	53%	6%	53%	9%	6%
Share of RDT&E expended concurrent with production	0%	28%	33%	21%	27%
Weapon system type	Electronic	Aircraft	Electronic	Electronic	Helicopter

NOTES: Values derived by RAND from MS B program SARs. RDT&E cost estimates at MS B converted to FY12 dollars using RDT&E inflation index published by the Office of the Secretary of Defense. Weapon system type classified by RAND based on the primary work content of the program by value.

Table 3.2
Information on Planned and Current Schedules to First LRIP Contract Award

	MS B Date	First LRIP Contract Award Date		Duration from MS B to First LRIP Contract Award (years)	
	Actual	At MS B	Current Plan	At MS B	Current Plan
GPS OCX	Nov-12	Oct-15	Jul-20	2.9	7.7
KC-46	Feb-11	Aug-15	Aug-16	4.5	5.4
F-22 Inc. 3.2B	Jun-13	Mar-16	Aug-16	2.8	3.2
B-61 TKA	Nov-12	Apr-18	Oct-18	5.4	5.9
CRH	Jun-14	Oct-19	Oct-19	5.3	5.3

NOTES: All dates derived from SARs with the exception of the "Current Plan" dates for the KC-46 and F-22 Inc. 3.2B programs, which have occurred and were taken from the last available Defense Acquisition Executive Summary report for each program.

Table 3.3
Information on Planned and Current Schedules to IOC, IOD, or RAA

	MS B Date	IOC, IOD, or RAA Date		Duration from MS B to IOC, IOD, or RAA (years)	
	Actual	At MS B	Current Plan	At MS B	Current Plan
GPS OCX	Nov-12	Oct-16	Jul-21	3.9	8.7
KC-46	Feb-11	Aug-17	Aug-17	6.5	6.5
F-22 Inc. 3.2B	Jun-13	Mar-19	Sep-19	5.8	6.3
B-61 TKA	Nov-12	Jun-19	Dec-19	6.6	7.1
CRH	Jun-14	Sep-20	Sep-20	6.3	6.3

NOTE: All dates derived from SARs.

the CRH program have experienced some degree of schedule slip. The GPS OCX program stands out as originally having a relatively short planned schedule to first LRIP contract award and IOC/IOD/RAA compared with the other programs. However, since the program's MS B decision, the GPS OCX schedule has been updated and extended considerably, resulting in the longest schedule among the five programs considered.

Programs can experience schedule slip for a variety of reasons. Riposo, McKernan, and Kaihoi (2014) reviewed the literature on the causes of schedule slip and found that the three most prominent causes are (1) difficulty of managing technical risk (e.g., program complexity, immature technology, and unanticipated technical issues); (2) optimistic or ambitious initial assumptions or expectations that were difficult to fulfill (e.g., schedule estimates, risk control, requirements, and performance assumptions); and (3) funding instability that complicates management and can directly stretch production schedules.

Schedule benchmarking approaches like the one presented in this report can provide information that can help one assess the degree by which a program's schedule plan may be ambitious or conservative, as well as the level of schedule risk and uncertainty that can be expected. The approach can also inform the setting of contractor schedule incentives by identifying for leadership which schedule times are likely to be challenging to achieve and which should be easily obtainable based on the historical experience for similar programs.

Estimates of Schedule S-Curves for Five Air Force MDAPs

Not all program schedules line up as well as the example shown at the end of the previous chapter (in Figure 2.1). The following sections describe the application of the model to the five programs and two schedule metrics discussed above.

Global Positioning System Next-Generation Operational Control System Schedule Assessment

The GPS OCX aims to provide enhancements to the legacy Global Positioning System (GPS) control network software. It is intended to support the latest generation of GPS satellite being developed as part of the Global Positioning System Third Generation (GPS III) program, as well as legacy GPS satellites. The GPS OCX program is highly software-intensive, with a single set of hardware delivered on which it operates.

The GPS OCX program plan evolved through several iterations, with different blocks and subblocks over the years. The GPS OCX plan, as of early 2016, consists of the following blocks:

- Block 0, a subset of Block 1, will allow GPS OCX to support the launch and checkout of GPS III satellites.
- Block 1 will replace the legacy GPS command-and-control system and fields the operational capability to control legacy (GPS IIR, IIR-M, and IIF) and new (GPS III) GPS satellites.
- Block 2 will add operational control of the new international open, civil, and military signals.

The GPS OCX program received its MS B approval in November 2012, allowing for EMD to formally begin. With the MS B came an updated Acquisition Program Baseline (APB). The program was designated an MDAP at this time, and its first SAR followed shortly thereafter. Prior to November 2012, the program was housed under the GPS program and therefore did not receive its own acquisition category designation.

While GPS OCX funding has been relatively stable since its MS B, the program has experienced chronic execution problems since that milestone. According to President's Budget justification documents and SARs, there have been fundamental flaws in the program's execution, including a lack of rigorous system engineering prior to code development, and challenges implementing the complete set of information assurance requirements. In addition, increases in scope, Requests for Equitable Adjustment for GPS III system and satellite simulators, engineering studies, and Engineering Change Proposals (offset by affordability efforts) have resulted in increases in the program's cost estimate. These issues led to schedule breaches and a program re-baseline in 2014. In July 2015 an Acquisition Incident Review board identified five root causes for the program's execution challenges: an unrealistic program schedule was set at contract award; appropriate system engineering and system integration practices were not implemented by Raytheon at the start-up of the program; cyber security requirements were not clearly understood; a complex incentive structure; and high government personnel turnover.

A new APB was established in October 2015, but the schedule for that had been breached by early 2016. The causes included a lack of appropriate system engineering and configuration management practices, information assurance requirement complexity, and an approximate 40 percent software code growth. As a result, another program re-plan was ongoing as of March 2016.

In an Air Force press release dated June 30, 2016, Air Force Secretary Deborah Lee James declared a Nunn-McCurdy cost breach in the GPS OCX program. The development cost breach occurred because estimated costs now exceeded the 25 percent cost overrun threshold from the November 2012 APB. Consistent with prior reports, the latest cost increases were attributed to inadequate system engineering at program inception, Block 0 software having high defect rates, and Block 1 designs requiring rework.

Program execution problems identified since 2012 have manifested themselves in multiple ways, including three- to five-year schedule slips in anticipated key delivery dates from those established at the MS B in November 2012. The schedule slips are shown in Table 3.4. It is highly likely that the minor under-execution problems observed in 2014 and 2015 resulted from the multiple program reviews, re-plans, and re-baselines.

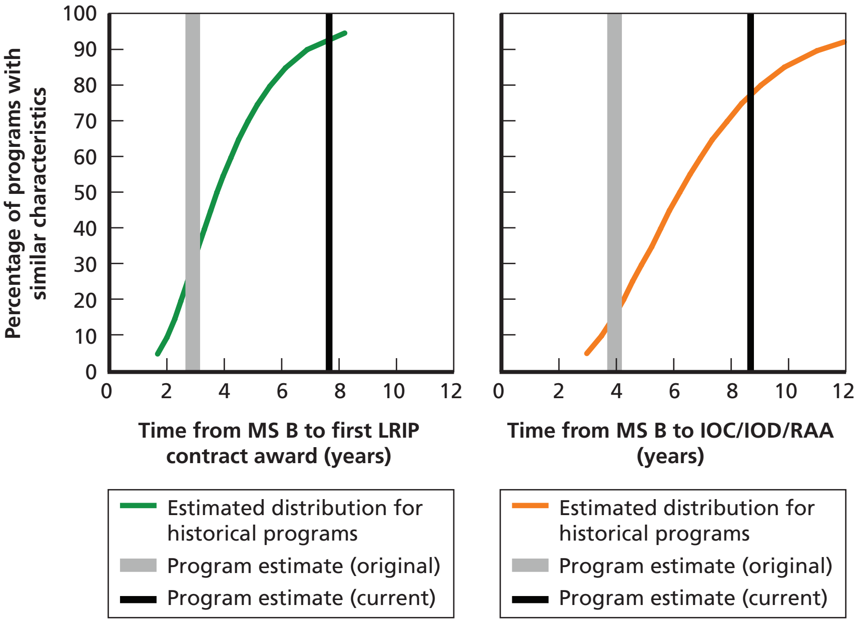
For the purposes of this analysis, we associate the program's MS C with the award of the program's first LRIP contract and the RTO of Block 1 with our definition of an IOC, IOD, or RAA date. Figure 3.1 suggests that the original GPS OCX schedule was somewhat aggressive. If this type of assessment was available when the program schedule was being developed around MS B, one might start to question the reasonableness and assumptions underlying the original schedule.

Having seen how far to the right the program's original schedule has shifted in relation to the s-curves raises other issues—particularly for the program's MS C (which we associate with the first LRIP contract award schedule). There may be lessons learned from this program regarding factors that should be more closely considered or anticipated when developing schedules.

Table 3.4
GPS OCX Key Delivery Dates

	Date of Estimate				
Event	**November 2012**	**Early 2014**	**June 2014**	**Early 2015**	**Early 2016**
Block 0: Launch and Checkout System Delivery	Nov-14	Apr-15	Nov-15	Feb-16	Sep-17
First LRIP Contract Award/MS C	Oct-15	Apr-16	Jan-17	Jul-18	Jul-20
Block 1: RTO	Oct-16	Sep-17	Nov-18	Jul-19	Jul-21
Block 2: RTO	Jun-17	Apr-18	Nov-19	Jul-20	Jul-22

Figure 3.1
Illustration of Schedule Benchmarking for GPS OCX Program



RAND *RR2144-3.1*

KC-46 Tanker Modernization Schedule Assessment

The KC-46 Tanker Modernization program will replace the Air Force's aging fleet of KC-10 and KC-135 tanker aircraft. Relative to existing tanker aircraft, the KC-46 will have enhanced refueling, cargo, and aeromedical capabilities. It will be equipped with a modernized KC-10 refueling boom integrated with a fly-by-wire control system, and a hose and drogue system will add additional mission capability.

The Office of the Under Secretary of Defense for Acquisition, Technology and Logistics approved MS B on February 24, 2011, and entered into a fixed-price incentive (firm target) development contract with Boeing. Under the design put forward by Boeing, it would integrate military refueling and other technologies onto a 767 aircraft designed for commercial use. The contract includes firm fixed-price contract options for the first and second production lots and options with not-to-exceed prices for lots 3 through 13.

The KC-46 schedule at MS B called for the initial LRIP contract award to occur in August 2015, with RAA occurring in August 2017 and representing the delivery of 18 operational aircraft meeting final production configuration with all required training equipment, support equipment, and sustainment support in place to support IOC. The program's initial LRIP contract award slipped to August 18, 2016. According to the U.S. Government Accountability Office (GAO, 2016), the program office has delayed the LRIP decision because Boeing has had problems developing the first four aircraft.

The schedule s-curves for the KC-46 program are shown in Figure 3.2. Based on our modeling, both of the KC-46 schedules appear somewhat short relative to what we would have expected. It is not clear at this point whether the KC-46 program was simply aggressive in its scheduling assumptions or whether factors not captured by the model explain the program's shorter schedule (or, as is likely the case, some combination of both are at play). That said, GAO (2016) has stated that "[t]est officials believe Boeing's test schedule is optimistic and it may not have all aircraft available when needed to complete planned testing."

F-22 Increment 3.2B Modernization Schedule Assessment

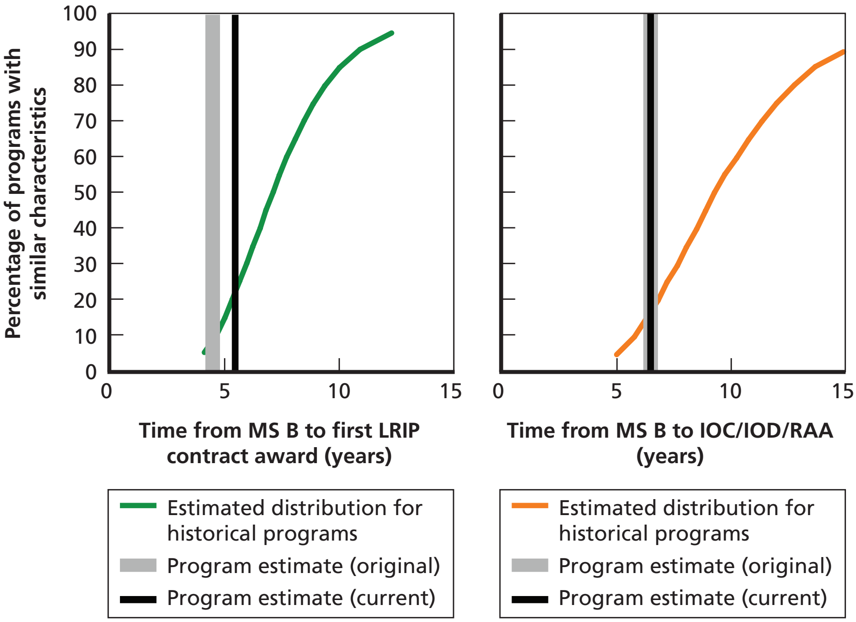
The F-22 weapon system continues to be updated and improved via a series of modification programs. The largest of those to date, the F-22 Inc. 3.2B program, integrates the Air Intercept Missiles AIM-9X and AIM-120D, adds Electronic Protection techniques, incorporates new hardware, enhances Geolocate capability, and expands Intra/Inter-Flight Data Link functionality. The F-22 Inc. 3.2B program officially started in FY 2013 with approval of MS B.[2]

The program's planned first LRIP contract award, which coincides with the program's MS C date, was initially scheduled to occur in March 2016 but was later pushed to August 2016. The program's RAA

---

[2] Prior to FY 2011, the F-22 modification plan included an Increment 3.2. That effort was broken into the 3.2A and 3.2B programs in FY 2011. This breakup allowed for adjusting to financial constraints, facilitated improved baseline control/management, and helped meet capability delivery needs. The Materiel Development Decision (MDD) providing the foundation for the F-22 Inc. 3.2B program occurred in December 2011.

Figure 3.2
Illustration of Schedule Benchmarking for KC-46 Program



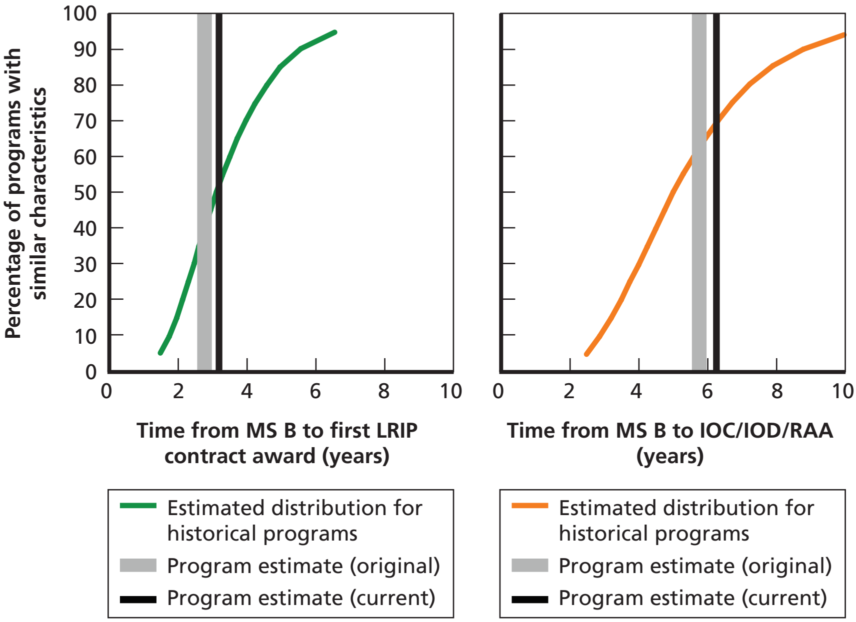
RAND *RR2144-3.2*

date, which is defined as the delivery of six aircraft and their associated support equipment, coincided at MS B with the planned end of the development effort in March 2019, but has slipped six months to September 2019.

The FY 2017 President's Budget SAR states that the EMD effort is progressing as planned; full hardware qualification is complete; and final software Critical Design Review was completed on October 29, 2015. Developmental software coding is ongoing, and five developmental test aircraft were modified and delivered. Laboratory and flight tests are proceeding on production-representative hardware. Full-rate production is planned to commence in July 2018, and the RAA date remains September 2019.

The F-22 Inc. 3.2B program's current first LRIP contract award schedule falls close to the 50 percent level, according to our s-curve estimate for the program shown in Figure 3.3. The program's current

Figure 3.3
Illustration of Schedule Benchmarking for F-22 Inc. 3.2B Program



RAND *RR2144-3.3*

schedule to IOC/IOD/RAA is modestly longer than we would expect, falling at the 70 percent level.

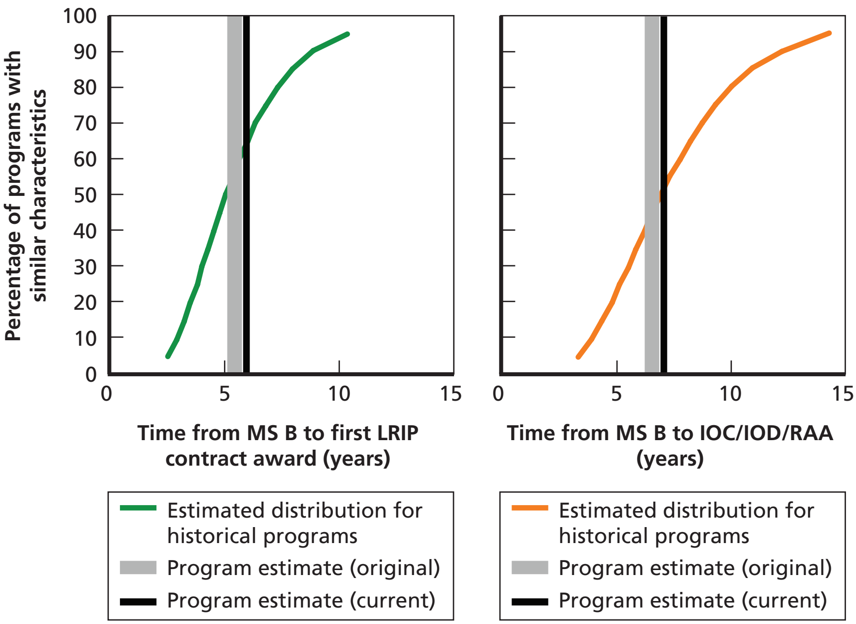
B61 Mod 12 Life Extension Program Tailkit Assembly Schedule Assessment

The B61-12 TKA program combines a series of modifications and service life extension activities into a single program for the B61 nuclear bomb. The Under Secretary of Defense for Acquisition, Technology and Logistics directed the B61-12 TKA program office to proceed to a MS B decision in April 2012, and on November 19, 2012, the USAF was granted approval of MS B and authorization to enter the EMD phase. Shortly after, on November 27, 2012, the B61-12 TKA program office awarded a cost plus incentive fee contract to Boeing for EMD Phase 1 with priced options for EMD Phase 2 and a technical data package.

At MS B, the program was scheduled to complete its MS C review and first LRIP contract award in April 2018, but that has been pushed to October 2018. The first tailkit assembly (TKA) production delivery (which we equate with the an IOC, IOD, or RAA date) was originally scheduled to occur in June 2019, but that date has been pushed to December 2019. The latest program SAR notes that certain system qualification tests originally planned for use in the program are no longer feasible and that other system qualification flight testing processes are being pursued prior to MS C. This has led to a six-month increase in the program's planned MS C and first TKA production delivery schedule.

Figure 3.4 shows the B61-12 TKA program's projected s-curves and schedules. The program's current first LRIP contract award schedule intersects the s-curve at approximately the 65 percent level, while the IOC/IOD/RAA schedule falls close to the 50 percent level.

Figure 3.4
Illustration of Schedule Benchmarking for B61-12 TKA Program



RAND *RR2144-3.4*

Combat Rescue Helicopter Schedule Assessment

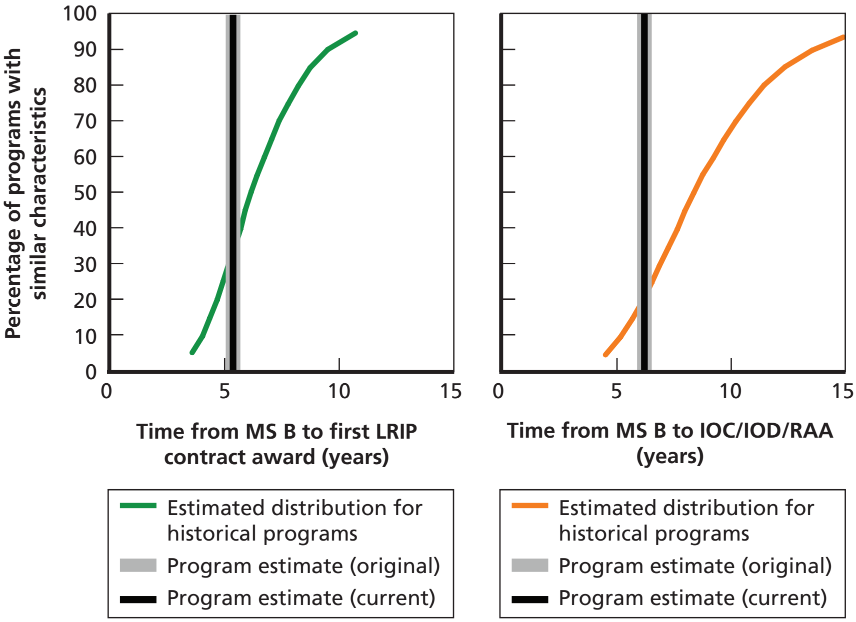
The CRH program seeks to recapitalize the aging HH-60G Pave Hawk medium-lift combat-search-and-rescue helicopter. The CRH system will provide personnel recovery forces with a vertical-takeoff-and-landing aircraft for worldwide missions. The CRH will be capable of employment day or night, in adverse weather, and in a variety of threat spectrums, from terrorist attacks to chemical, biological, radiological, and nuclear threats. The CRH system may also conduct other missions, such as nonconventional assisted recovery, national emergency operations, civil search and rescue, international aid, emergency aeromedical evacuation, disaster/humanitarian relief, counterdrug activities, support for National Aeronautics and Space Administration flight operations, and insertion or extraction of combat forces.

The CRH program initiation was approved on March 2, 2012, but, due to funding uncertainty during FY 2015 budget deliberations, the future of the CRH program was in doubt throughout early 2014. This caused the MS B decision to slip to June 2014, at which point the Air Force awarded a $1.28 billion fixed-price incentive fee contract to Sikorsky Aircraft for the CRH EMD program, with options for development, integration, production, and initial sustainment.

The program office has thus far published two comprehensive acquisition estimates, reflected in the program's December 2014 and December 2015 SARs. Both CRH SARs project a MS C decision and associated initial LRIP contract award occurring in October 2019, with an RAA for IOC in September 2020.

Figure 3.5 shows the CRH program schedule. Like the KC-46 program, the CRH program's schedules appear somewhat short relative to what we would expect. As a result, it may be useful to explore scheduling assumptions for this program and the extent by which factors not captured by the statistical model may explain the CRH program's shorter schedule.

Figure 3.5
Illustration of Schedule Benchmarking for CRH Program



RAND *RR2144-3.5*

CHAPTER FOUR

Concluding Remarks

S-curves have been extensively applied in the context of cost estimates (Air Force Cost Analysis Agency, 2008; Technomics, 2012; Naval Center for Cost Analysis, 2014), although they can prove to be an equally useful tool for conducting schedule assessments and risk analysis. The s-curves shown in the previous chapter provide information on how program schedules line up in relation to similar historical programs. For programs with established schedules, this information can help inform assessments of schedule risk and reasonableness. For programs earlier in the development phase, benchmarking methods such as the one presented here can be particularly useful for informing the development of schedules and schedule goals and incentives.

To develop and apply the schedule benchmarking method presented here, one needs to assemble schedule and other information for historical programs. This can be quite time-consuming. Luckily, for this effort we have been able to leverage information from SARs that has been systematically collected by RAND over the past two decades. To facilitate the application and updating of schedule benchmarking assessments such as the one described in this report, we recommend that a repository of schedule data be developed and made available to defense analysts and program office staff.

It is important to emphasize that the approach for benchmarking schedules presented here is meant to complement, but not replace, other approaches for assessing schedules. For example, to support development of program cost estimates, a detailed integrated master schedule with timelines for specific tasks is often constructed. The approach presented here can be used to check the reasonableness of the proposed master schedule and characterize the degree of uncertainty in time required to achieve major milestones that might be expected. But it cannot replace development of an integrated master schedule.

It is also important to note that using historical program schedules to statistically model schedules for new programs has some limitations. First, statistical modeling can include only program characteristics that can be reasonably quantified and applied consistently across programs. "Complexity" and "technology maturity," for example, are known to drive development schedules, but we lack good measures of these factors that can be consistently derived for MDAPs. Second, if there are few historical programs that resemble a program of interest, model based estimates are likely to be less accurate. As a result, other approaches for assessing schedules, such as subject-matter expert assessment, can be important to conduct in conjunction with quantitative approaches, such as the one presented here.

APPENDIX

Steps Performed to Conduct Benchmarking

This appendix reviews the basic analytical steps used to perform the benchmarking assessment shown in this report. It is intended to provide guidance for cost and other analysts tasked with benchmarking MDAP schedule estimates. A familiarity with analytical methods and principles presented in the Naval Center for Cost Analysis's *Joint Agency Cost and Schedule Risk and Uncertainty Handbook* (2014) is assumed.

- **Step 1: Assemble schedule and other data for historical programs to be included in the benchmarking analysis.** In this assessment, we utilized previously compiled data derived from SARs. The data include information on program cost and schedule estimates at MS B and in each program's last available SAR. We also captured information as of each program's MS B date on whether the program completed an MS A review, the share of RDT&E budget planned to be expended prior to MS B, the share of RDT&E budget planned to be expended concurrently with production, whether the program is a joint or single-service program, the program's total development cost estimates at MS B, the program's lead procuring service, the program's MS B date (which allowed us to group programs into acquisition era), the weapon system type, and the type of procurement program. See Chapter Two for details on how we calculated each of these variables. The data used in this analysis were provided to the Air Force Cost Analysis Agency for updating and use in other studies.
- **Step 2: Adjust data if necessary so that information is comparable across programs.** This entails putting costs in the same

base year dollars using inflation indices published by the Office of the Secretary of Defense or others and adjusting schedule milestones if necessary so that they are consistently defined across programs.

- **Step 3: Relate historical schedule outcomes to program characteristics using regression techniques.** In this analysis, we used a heterogeneous variance model, which allowed us to relate both the mean and variance of schedule outcomes to program characteristics (see Chapter Two). We estimated the regression model using SAS's "proc mixed" procedure. We refined the regression specifications used here so that only those variables that show strong predictive power are included in the equations used for benchmarking.[1]
- **Step 4: Assemble schedule and other data for programs to be compared against benchmarked schedules.** Information on all the explanatory variables used in the regressions described in Step 3 must be assembled for programs that are to be benchmarked. Data for explanatory variables should be adjusted if necessary so that they are comparable with the historical program data used in the regressions (e.g., adjust dollars amounts so they are in the same base year). As an example, the Table A.1 shows the program characteristics for the F-22 Increment 3.2B program.
- **Step 5: Apply the regressions developed in Step 3 to the data assembled in Step 4.** From the applied regression projections, we developed s-curves for each program covered by the data assembled in Step 4 (see Chapter Two). We developed the s-curves shown in this report using Microsoft Excel.

As an example, consider the F-22 Inc. 3.2B program. The value of BX_i described in Chapter Two equals 1.1316 for the F-22 Inc. 3.2B program's first LRIP contract award schedule, based on the program's characteristics shown in Table A.1 and the coefficient estimates shown in Table 2.1. Specifically, it is calculated as 1.1316 = 1.434 + 0.106 × log(RDT&E Estimate = 1,125.14 mil-

[1] See pp. 115 and 116 of Jimenez et al. (2016) for a detailed discussion of one model refinement approach applied in the same context as ours.

Table A.1
Program Characteristics at MS B for F-22 Increment 3.2B Program

Program Characteristic	Value
Weapon system type	Electronics
Acquisition era	Post-2003
RDT&E estimate	$1,125.14 million
Share of RDT&E expended pre–MS B	53%
Share of RDT&E expended concurrent with production	33%

lion dollars) − 1.084 × (Share of RDT&E Expended pre-MS B = 0.53) − 1.310 × (Share of RDT&E Expended Concurrent w. Prod. = 0.33) + 1.060 × (Share of RDT&E Expended Concurrent w. Prod. × Electronic Program Dummy Variable = 0.33) − 0.396 × (Dummy Variable for Electronics Programs = 1). Based on the work content of the program, the F-22 Inc. 3.2B program is classified as an electronic program so we use a value of σ_i^2 equal to 0.1759. This implies that the program has a median and mean schedule point estimate of approximately 3.1 [= exp(1.1316)] and 3.4 [= exp(1.1316 + 0.1759 / 2)] years, respectively. The s-curve for the program is calculated from the following function:

$$F(z) = \Phi\left(\frac{\log(z) - 1.1316}{\sqrt{0.1759}}\right).$$

Table A.2 shows the values of $F(z)$ obtained for different values of z.

- **Step 6: Overlay proposed or planned program schedules on s-curves derived in Step 5.** As an example, Figure 2.1 plots the information shown in Table A.2 and overlays the program's planned and current schedule. See Chapter Three for an illustration of how we performed this step to facilitate benchmarking for other programs.

Table A.2
Construction of S-Curve for F-22 Increment 3.2B First LRIP Contract Award Schedule

Years from MS B to First LRIP Award (*z*)	Share of Programs with Similar Characteristics (*F*(*z*))
1.6	5%
1.8	10%
2.0	15%
2.2	20%
2.3	25%
2.5	30%
2.6	35%
2.8	40%
2.9	45%
3.1	50%
3.3	55%
3.4	60%
3.6	65%
3.9	70%
4.1	75%
4.4	80%
4.8	85%
5.3	90%
6.2	95%

Abbreviations

APB	Acquisition Program Baseline
B61-12 TKA	B61 Mod 12 Life Extension Program Tailkit Assembly
CRH	Combat Rescue Helicopter
DoD	U.S. Department of Defense
EMD	Engineering and Manufacturing Development
F-22 Inc. 3.2B	F-22 Increment 3.2B Modification
FY	fiscal year
GAO	U.S. Government Accountability Office
GPS	Global Positioning System
GPS III	Global Positioning System–Third-Generation
GPS OCX	Global Positioning System Next-Generation Operational Control System
IOC	Initial Operational Capability
IOD	Initial Operational Date
LRIP	low-rate initial production
MDAP	major defense acquisition program
MS	milestone
PAF	RAND Project AIR FORCE
RAA	Required Assets Available
RDT&E	research, development, test, and evaluation
RTO	ready to transition to operation

SAR	selected acquisition report
SER	schedule-estimating relationship
TKA	tailkit assembly

References

Air Force Cost Analysis Agency, *Air Force Cost Analysis Handbook*, February 2008.

Department of Defense Instruction 5000.02, *Operation of the Defense Acquisition System*, Washington, D.C.: U.S. Department of Defense, January 7, 2015.

Drezner, Jeffrey A., Mark V. Arena, Megan P. McKernan, Robert E. Murphy, and Jessie Riposo, *Are Ships Different? Policies and Procedures for the Acquisition of Ship Programs*, Santa Monica, Calif.: RAND Corporation, MG-991-OSD/NAVY, 2011. As of September 7, 2017:
https://www.rand.org/pubs/monographs/MG991.html

Drezner, Jeffrey A., and Giles K. Smith, *An Analysis of Weapon System Acquisition Schedules*, Santa Monica, Calif.: RAND Corporation, R-3937-ACQ, 1990. As of September 7, 2017:
https://www.rand.org/pubs/reports/R3937.html

Fox, J. Ronald, *Defense Acquisition Reform, 1960 to 2009: An Elusive Goal*, Washington, DC: U.S. Army Center of Military History, 2011.

Haux, Hailey, "Acquisition General Speaks on Priorities, Should Schedule," U.S. Air Force, October 1, 2015. As of September 18, 2017:
http://www.af.mil/DesktopModules/ArticleCS/Print.aspx?PortalId=1&ModuleId=850&Article=621421

James, Deborah Lee, "Reinventing the Aerospace Nation," keynote speech at the Air and Space Conference, September 14, 2015. As of September 18, 2017:
https://spacepolicyonline.com/pages/images/stories/AFSec%20James%20to%20AFA%20conf%20Sept%2014%202015.pdf

Jimenez, Christopher, Edward White, Gregory Brown, Jonathan Ritschel, Brandon Lucas, and Michael Seibel, "Using Pre-Milestone B Data to Predict Schedule Durations for Defense Acquisition Programs," *Journal of Cost Analysis and Parameters*, Vol. 9, No. 2, 2016, pp. 112–126.

Light, Thomas, Robert S. Leonard, Julia Pollak, Meagan Smith, and Akilah Wallace, *Quantifying Cost and Schedule Uncertainty for Major Defense Acquisition Programs (MDAPs)*, Santa Monica, Calif.: RAND Corporation, RR-1723-AF, 2017. As of September 7, 2017:
https://www.rand.org/pubs/research_reports/RR1723.html

McNicol, David, *Cost Growth, Acquisition Policy, and Budget Climate*, Alexandria, Va.: Institute for Defense Analyses, IDA Document NS D-5180, May 2014.

McNicol, David, and Linda Wu, *Evidence on the Effect of DoD Acquisition Policy and Process on Cost Growth of Major Defense Acquisition Programs*, Alexandria, Va.: Institute for Defense Analyses, IDA Paper P-5126, September 2014.

Monaco, James, and Edward White III, "Investigating Schedule Slippage," *Defense Acquisition Review Journal*, 2005, pp. 176–193. As of September 7, 2017:
http://www.dtic.mil/dtic/tr/fulltext/u2/a441770.pdf

Naval Center for Cost Analysis, *Joint Agency Cost and Schedule Risk and Uncertainty Handbook*, Washington, D.C., March 2014. As of September 19, 2016:
http://cade.osd.mil/Files/CADE/JA%20CSRUH%20Final%2012Mar2014%20With%20Signatures%2011May2015.pdf

Riposo, Jessie, Megan McKernan, and Chelsea Kaihoi, *Prolonged Cycle Times and Schedule Growth in Defense Acquisition: A Literature Review*, Santa Monica, Calif.: RAND Corporation, RR-455-OSD, 2014. As of September 21, 2016:
http://www.rand.org/pubs/research_reports/RR455.html

SAS Institute Inc., *SAS/STAT® 9.2 User's Guide*, Cary, N.C., 2008. As of May 3, 2017:
https://support.sas.com/documentation/cdl/en/statugmixed/61807/PDF/default/statugmixed.pdf

Snedecor, G. W. and C. Cochran, *Statistical Methods*, Ames, Iowa: Iowa State University Press, 1976.

Technomics, *User Guide for S-Curve Tool Version 1.0*, Washington, D.C.: Naval Center for Cost Analysis, September 12, 2012. As of September 19, 2016:
https://www.ncca.navy.mil/tools/User_Guide_S_Curve_Tool_v1_0.pdf

Tyson, K. W., B. R. Harmon, and D. M. Utech, *Understanding Cost and Schedule Growth in Acquisition Programs*, Alexandria, Va.: Institute for Defense Analyses, P-2967, 1994.

Tyson, K. W., J. R. Nelson, N. I. Om, and P. R. Palmer, *Acquiring Major Systems: Cost and Schedule Trends and Acquisition Initiative Effectiveness*, Alexandria, Va.: Institute for Defense Analyses, P-2201, March 1989.

U.S. Government Accountability Office, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, Washington, D.C., March 2009. As of September 22, 2016:
http://www.gao.gov/new.items/d093sp.pdf

———, *KC-46 Tanker Aircraft: Challenging Testing and Delivery Schedules Lie Ahead*, Washington, D.C., GAO-16-346, April 2016.

Younossi, Obaid, Mark V. Arena, Robert S. Leonard, Charles Robert Roll, Arvind Jain, and Jerry M. Sollinger, *Is Weapon System Cost Growth Increasing? A Quantitative Assessment of Completed and Ongoing Programs*, Santa Monica, Calif.: RAND Corporation, MG-588-AF, 2007. As of September 7, 2017: http://www.rand.org/pubs/monographs/MG588.html

With the Secretary of the Air Force outlining new scheduling initiatives in 2015, the Air Force formally recognized the importance of managing schedules and reducing schedule slip. This report provides a framework for benchmarking major defense acquisition program (MDAP) proposed or planned schedules against the actual schedules of similar historical programs. The framework is applied to five Air Force MDAPs currently undergoing development: the Global Positioning System Next Generation Operational Control System, KC-46, F-22 Increment 3.2B Modernization, B61 Mod 12 Life Extension Program Tailkit Assembly, and Combat Rescue Helicopter programs. Schedule benchmarking approaches such as the one developed in this report can provide program staff, acquisition analysts, and decisionmakers with additional information from which to gauge the degree by which schedule estimates may be aggressive or conservative. They can also inform the formulation of schedule targets or goals for incorporation into schedule incentives.

RAND PROJECT AIR FORCE

www.rand.org

$13.50

ISBN-10 0-8330-9903-5
ISBN-13 978-0-8330-9903-7

51350

9 780833 099037

RR-2144-AF