Naval Aviation Maintenance System

ANALYSIS OF ALTERNATIVES

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Preface

The U.S. Navy's aviation maintenance capability suffers from supportability issues because of its antiquated software architecture and codebase. As a result, the Navy is seeking to modernize its afloat and ashore maintenance capabilities, better integrating them with the future Naval Operational Supply System and maximizing value from sustainment costs.

The Navy asked RAND Corporation researchers to assist with the analysis of alternatives for fielding the Naval Aviation Maintenance System. This report presents the results of that analysis, which was conducted from September 2017 to April 2018. This report should be of interest to those who conduct naval aviation maintenance and analysts and managers of defense business systems.

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Summary

The business of managing the U.S. Department of the Navy's operational force includes a broad set of activities, such as personnel management, ship maintenance, aviation maintenance, spare parts oversight, and expeditionary force support. To help manage its aviation maintenance activity, the Navy established the Naval Aviation Maintenance Program (NAMP), which sets the Navy's policy for achieving materiel readiness and safety standards. Naval aviation has a three-level division of maintenance—organizational (O-level), intermediate (I-level), and depot (D-level)—and each level has associated software and hardware systems to support the program. D-level maintenance is supported by the Naval Depot Maintenance System (NDMS), and the current program of record for O-level and I-level maintenance is the Naval Tactical Command Support System (NTCSS). The primary NTCSS subsystem that supports aviation logistics is the Naval Aviation Logistics Command Management Information System (NALCOMIS).

NTCSS was developed in the 1990s as a family of systems to consolidate stovepiped management across a variety of sponsors and interests, and it is operated at more than 700 sites and has more than 150,000 users.

Some concerns have been raised about NTCSS, including the following:

- Its technical architecture has failed to mature adequately, thus creating supportability issues.
- It has multiple fielded versions.
- It has static business processes.
- These problems contribute to the Navy not meeting its aircraft readiness goals.

The baseline is currently being consolidated to address some of the supportability and version-control issues; however, open supportability, architectural, and business process reengineering challenges remain.

To address these problems—and broader issues within its logistics enterprise—the Navy has begun modernizing its family of logistics systems by replacing them with the Navy Operational Business Logistics Enterprise (NOBLE). A key set of objectives is to provide centralized acquisition management and realize information tech-

nology (IT) and Navy logistics operational cost savings through efficiencies. *NOBLE* is an umbrella term for three new subprograms: the Naval Operational Supply System (NOSS), the Naval Aviation Maintenance System (NAMS), and the Naval Operational Maintenance Environment (NOME). The focus of this study is on NAMS.

NAMS is intended to address the concerns and challenges with NTCSS by augmenting and enhancing (through integration) several existing and planned systems, including the Aviation Logistics Enterprise and NDMS. NAMS will be required to work closely with NOSS.

Table S.1 shows the key attributes the Navy identified for NAMS. To satisfy these attributes and meet the demands of the current and future aviation logistics enterprise, the Navy identified 269 high-level requirements. It asked RAND researchers to assist in an analysis of alternatives (AoA) under the guidance of study director Kevin Geist of Naval Supply Systems Command Business Systems Center. Additional team members included subject-matter experts from Client Solutions Architects and cost specialists from Space and Naval Warfare Systems Command Cost Estimating and Analysis Division (SPAWAR 1.6). The AoA was conducted in accordance with the study guidance and the following standard practice for AoAs. We assessed both the costs and risks of the designated alternatives using best practices for these types of analyses. We assessed capability by comparing vendor and existing government capabilities with the Navy's high-level requirements. The primary sources of data used for these analyses were industry and government responses to a request for information (RFI), follow-up discussions with selected industry and government experts, interviews with stakehold-

Table S.1
Navy-Identified Key NAMS Attributes

Attribute	Description
Enterprise capability	• Connected and operational across the globe • Integrated data environment
Product-centric	• Ready to integrate into a product life-cycle management–centric ecosystem
Streamlined and usable	• Enables warfighters to accomplish tasks as efficiently as possible • Open to new ways of doing business
Supportable and maintainable	• Allows easy corrections and updates to business processes and data models without coding or software deployments; configuration not customization • Cyber-secure and cyber-insulated (to decrease exposure to IT controls at the network and server levels)
Integrated	• Interoperable with other deployed logistics IT systems

SOURCE: U.S. Department of the Navy NAMS problem statement provided by the Command and Control Systems Program Office (PMW 150).

ers, a literature review, and study guidance and the study problem statement provided by the research sponsor.

Analysis of Alternatives Results

We first identified and refined the alternatives for evaluation, drawn from the study guidance. We then evaluated those refined alternatives in terms of effectiveness (capability and quality), cost, risk, and schedule.

Identified and Refined Alternatives for Evaluation

The Navy identified four alternative areas that were refined in the AoA (see Table S.2). We consolidated and cleaned (reduced duplication and improved semantics) the 269 high-level requirements that the Navy identified down to 56 to facilitate better engagement with commercial and government software providers and integrators. We also developed and released an RFI to assess the market to support the requirements. More than 50 COTS and GOTS vendors were alerted to the RFI release, and we received 28 responses. The respondents represented a wide range of systems, integrators, cloud vendors, and other entities.

Table S.2
Alternatives for Evaluation

Alternative Area	Alternative Name	Description
Status quo	1. Status Quo—NALCOMIS No Modernization	Baseline (current NALCOMIS)
	2. Status Quo—NALCOMIS New Development	NALCOMIS reconstructed with a modern software architecture
Commercial off-the-shelf (COTS)	3. COTS—Enterprise Systems Active in Defense Aviation	Enterprise systems that are primarily offered as enterprise resource planning systems
	4. COTS—Enterprise Asset and Service Management Systems	Systems that do not necessarily perform aviation maintenance but whose processes align with maintenance concepts
	5. COTS—Niche Aviation Maintenance, Repair, and Overhaul (MRO) Systems	Systems that specialize in aviation maintenance
Government off-the-shelf (GOTS)	6. GOTS—Autonomic Logistics Information System (ALIS)	System that leverages existing Navy and U.S. Department of Defense (DoD) investments in F-35 maintenance
Hybrid	7. Hybrid—COTS and NDMS	NDMS at the I- and D-level maintenance, with COTS at the O-level

From the 28 responses, we selected a sample of 12 responses (nine COTS and three GOTS) for follow-up meetings, during which the vendors had an opportunity to clarify their RFI responses and demonstrate their products. These 12 vendors were selected because they could best meet the 56 requirements outlined in the questionnaire and were a representative sample of RFI respondents overall.

After the follow-up meetings, we refined the four alternative areas into seven alternatives, as shown in Table S.2.

Effectiveness Analysis (Capability and Quality Analyses)

We conducted an effectiveness analysis by analyzing the ability of the alternatives to meet the set of 56 consolidated requirements and an additional set of software quality attributes. We summarized the analysis with a combined capability factor to represent the combination of requirements and quality, as shown in Table S.3. Alternatives 3 and 4 were the strongest overall (indicated by the bolded rows). New development in Alternative 2 is likely to be strong as well; however, nothing exists today, creating substantial risk.

Cost Analysis

All costs in this report are presented in base year (BY), or constant year, 2016 dollars. We normalized costs to BY 2016 dollars using the latest inflation indexes published by

Table S.3
Summary of Capability Scores, by Alternative

Alternative Name	% of Requirements Fully Met (n = 56)	Quality Score (out of 200)	Capability Factor
1. Status Quo—NALCOMIS No Modernization	54	30	48
2. Status Quo—NALCOMIS New Development	100	70	93
3. COTS—Enterprise Systems Active in Defense Aviation	**93**	**75**	**89**
4. COTS—Enterprise Asset and Service Management Systems	**97**	**68**	**90**
5. COTS—Niche Aviation MRO Systems	85	68	81
6. GOTS—ALIS	86	60	80
7. Hybrid—COTS and NDMS	68	75	70

NOTE: The quality scores use the validated, top-performing responses. Alternative 2 was assessed based on its expectation of capability.

the Naval Center for Cost Analysis. When labor rates were used, our conversions were based on SPAWAR 1.6–approved labor rates and PMW 150 spend plan rates.

Alternatives 4 and 6 had the lowest average risk-adjusted cost, as shown in Table S.4. The Navy can save money in NAMS with COTS if it can keep recurring license fees in check. If it does not do so, it is unlikely that there would be any cost savings compared with the status quo. Alternatives 3 and 5 had higher overall license costs.

The average life-cycle cost (LCC) of NAMS is roughly 2.3–2.8 F/A-18F aircraft (based on the F/A-18 LCC). Considering that the Navy alone operates more than 500 F/A-18 Super Hornets, the cost of operating NAMS for 16 years is a very small percentage of the cost of buying and sustaining its Super Hornet fleet.[1] Furthermore, NAMS will support another 2,100 aircraft of varying types, models, and series across the Navy and Marine Corps, making the system's cost relative to the cost of procuring and sustaining 2,700 aircraft negligible. This cost is important to have in perspective when considering the cost of the alternatives and the differences between them.

Risk Analysis

To determine the relative risk posture among the seven identified NAMS alternatives, we developed and scored risk factors and areas of cost, schedule, and operational

Table S.4
Risk-Adjusted Cost Summary (Relative Values)

	Total LCC FYs 2019–2034 (BY 2016 $millions)		NAMS FYDP Total FYs 2019–2023 (BY 2016 $millions)	
Alternative	**Low**	**High**	**Low**	**High**
1. Status Quo—NALCOMIS No Modernization	—	—	—	—
2. Status Quo—NALCOMIS New Development	41	66	26	118
3. COTS—Enterprise Systems Active in Defense Aviation	–53	66	–20	47
4. COTS—Enterprise Asset and Service Management Systems	**–138**	**110**	**–28**	**76**
5. COTS—Niche Aviation MRO Systems	–91	117	–26	75
6. GOTS—ALIS	**–124**	**—**	**–39**	**18**
7. Hybrid—COTS and NDMS	162	311	55	137

NOTE: FY = fiscal year; FYDP = Future Years Defense Program.

[1] The estimate uses a conservative $50 million flyaway and $70 million sustainment for 531 Super Hornets, totaling $63.7 billion.

performance using a nominal group technique. The technique was applied in three rounds and was intended to reduce bias in qualitative scoring. To generate the overall risk posture, we multiplied risk likelihoods by each consequence score and summed for each alternative. This was followed by a calculation for the mean and standard deviation of totals across alternatives. Table S.5 shows the results.

The table shows risk roll-ups in two ways: one for high-impact risks only and one combining both high and moderate risks. High-risk designations are shown in red (alternatives above half of a standard deviation from the average), moderate designations are shown in yellow (alternatives within half of a standard deviation from the average), and low designations are shown in green (alternatives below half of a standard deviation from the average). As mentioned, Alternative 1 has fewer risks than other alternatives; however, among those risks, the high-impact ones are highly likely and highly consequential. In contrast, Alternatives 2–7, collectively, have a reduced risk posture. Even though there are more risks, they are, generally, moderately likely and of moderate consequence.

COTS Alternatives 3 and 5 have the lowest overall exposure to high risks. The biggest **risk to operations** is that NAMS is insufficiently backward compatible with NALCOMIS. The biggest **risks to cost** are overspecification of requirements, infeasible solutions, excessive configuration or customization, and a lack of authority to authorize business process changes. The biggest **risks to schedule** are overspecification of requirements, infeasible solutions, excessive configuration or customization, inaccuracy in as-maintained aircraft configurations, and limited ship availability.

Table S.5
Exposure to Risk, by Alternative

Alternative	Exposure to High-Scoring Risks	Exposure to High- and Moderate-Scoring Risks
1. Status Quo—NALCOMIS No Modernization	High	Low
2. Status Quo—NALCOMIS New Development	High	Moderate
3. COTS—Enterprise Systems Active in Defense Aviation	**Low**	**Low**
4. COTS—Enterprise Asset and Service Management Systems	Moderate	High
5. COTS—Niche Aviation MRO Systems	**Low**	**Moderate**
6. GOTS—ALIS	Moderate	Low
7. Hybrid—COTS and NDMS	Moderate	High

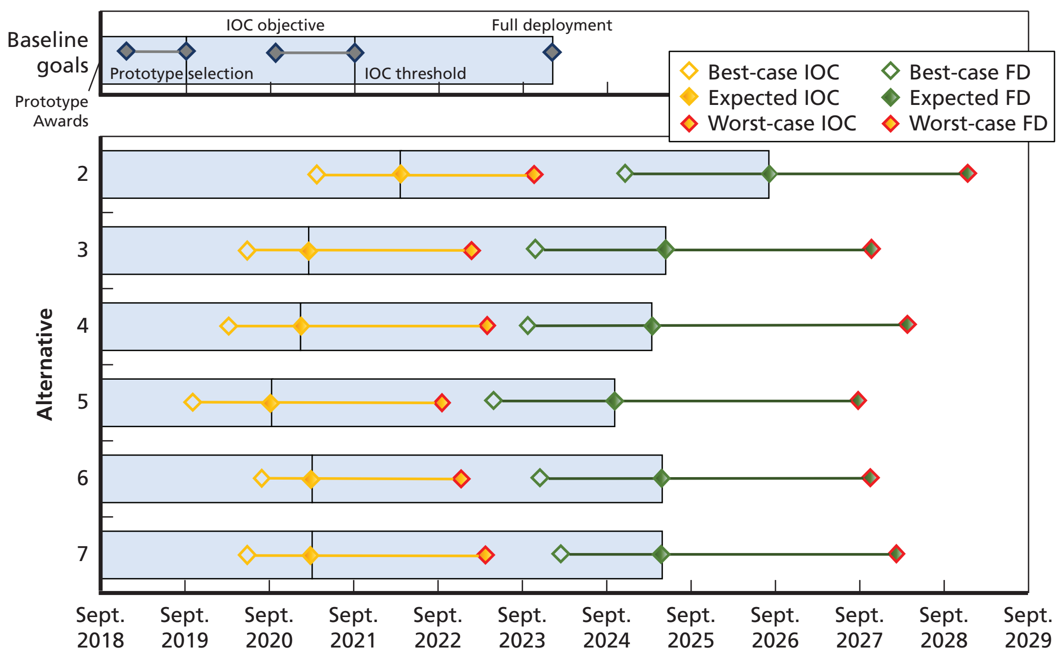
NOTE: We include high risks in both analysis columns to present an overall picture of risk.

All of the alternatives suffer from risk related to the uncertainty of future interface requirements and the complexity needed in meeting those requirements, representing a moderate degree of risk to NAMS acquisition.

Schedule Analysis

We made schedule projections using a model developed for the study. We calculated schedules with an expected start date of September 1, 2018. We calculated initial operational capability (IOC) and full deployment (FD) completion dates from the results of a Monte Carlo analysis for each alternative. Alternative 1 was omitted from the schedule analysis with the rationale that it represents a program that is already in place and complete. We assumed that Alternative 2 did not proceed with an other transaction authority (OTA) approach and instead involved the Navy engaging in an in-house development. We assumed that Alternatives 3–7 proceeded with an OTA approach. In these cases, we also assumed that work would begin on September 1, 2018, with awards to a few vendors for the creation of prototype NAMS solutions. Before September 2019, one of the prototypes would be selected as the NAMS solution, and the selected vendor would then proceed with development of its prototype product to achieve IOC. Figure S.1 shows the best-case, worst-case, and expected IOC and FD completion dates for each alternative.

Figure S.1
Calculated Schedule for Each Alternative



After completing the modeling for each alternative, we conducted a logistic regression analysis on the schedule model results to identify the relative impact of acquisition stages and risk factors. The model predicts the number of days to complete the process, controlling for the following:

- time per site to extract and cleanse aircraft configuration data
- time per site to extract and cleanse historical work action data
- quality of the data
- total number of sites migrated at IOC
- number of data migration teams for IOC
- reusability of the extract and cleanse process configuration
- number of teams for full operational capability (FOC) data migration
- time per site for IOC implementation
- number of install teams for IOC
- number of install teams for FOC
- increasing requirements over time
- ship availability.

Table S.6 highlights the factors that significantly affect schedule outcomes. Other factors in the model had little or no relative impact.

Drawing on the results of the Monte Carlo modeling and the sensitivity analysis, we reached several key conclusions about the overall schedule analysis:

Table S.6
Schedule Factors with Greatest Impact on Ability to Meet Schedule Objectives

Factor	Value	Impact (odds ratio)
Ship availability for installations	5 years vs. 4 years 4 years vs. 3 years	72x more likely to miss FD goal 6x more likely to miss FD goal
Requirements creep	High vs. expected	12x more likely to miss FD goal
Total activities migrated at IOC	77 activities vs. 14 activities	6x more likely to miss FD goal
Quality and cleanliness of current and historical aircraft configurations and work actions	Twice the time to extract and cleanse	5x more likely to miss FD goal
Time to extract and cleanse aircraft configuration, per activity	30 days vs. 10 days	3x more likely to miss FD goal
Number of concurrent FD data migration teams	4 teams vs. 8 teams	3x more likely to miss FD goal
Time to extract and cleanse work action data, per activity	30 days vs. 10 days	3x more likely to miss FD goal

- *None of the alternatives is expected to meet the goal for FD*. Although some of the alternatives have best-case scenario results ahead of the recommended FD deadline, none of the alternatives has expected completion dates within the range.
- *All the alternatives exhibit a large degree of schedule uncertainty.* Although Alternative 5 is most likely to finish within expectations for the program, all the alternatives have wide ranges for expected completion dates for IOC and FD. Alternatives range from approximately three years between the best- and worst-case results for IOC to approximately four years between the best- and worst-case results for FD.
- *All the alternatives are expected to meet IOC within the threshold range*. Increasing the number of sites required for implementation at IOC may push the schedule beyond the threshold dates for IOC, but all alternatives should be able to reach IOC within the deadline.

Overall Conclusions

Table S.7 shows the summary roll-up of results.

There is no question that COTS Alternatives 3 and 4 provide more-configurable capability and quality than the current NALCOMIS, as would a more hypothetical Alternative 2. A more supportable, configurable, usable, and interoperable system would improve the fleet's ability to respond to security requirements and future needs.

Alternatives 3 and 5 have less exposure to critical risks. Alternative 4 is riskier because these systems do not operate in the defense realm or aviation maintenance.

All alternatives have challenges in meeting schedule goals. If the Navy wants to meet schedule objectives, it will likely have to give up goals to make near-term gains in readiness derived from analytics. Beneficial analytics depend on clean and accurate historical data on maintenance actions and aircraft configurations. It is unclear to what extent current data are accurate. However, one 2017 Center for Naval Analyses and Digital Warfare Office study of Super Hornet radars showed that only 25 percent of the available data set was usable because of missing serial numbers, inconsistent timelines, and aircraft mismatch (Zolotov and Palmieri, 2017). If it takes the Navy two months per activity to extract, transform, and load historical data on maintenance actions and configurations, the Navy will be five times more likely to miss the FD goal. Furthermore, ship availability is, by far, the largest driver of the ability of any NAMS alternative to meet the FD goal.

Alternatives 4 and 6 have the best cost profiles. Alternative 3 options have higher recurring license fees. In general, the cost of NAMS pales in comparison with the cost of fleet procurement and sustainment. By one estimate, the cost of operating a COTS version of NAMS for 16 years is a very small percentage of the cost of buying and sus-

Table S.7
Roll-Up of Summary Analysis Factors

Alternative	Capability Factor (out of 100)	Exposure to High-Scoring Risks	LCC, Relative Values ($millions)			Scheduled FD Date		
			Low	Mid	High	Best Case	Most Likely	Worst Case
1. Status Quo—NALCOMIS No Modernization	48	High	—	—	—	In use	In use	In use
2. Status Quo—NALCOMIS New Development	93	High	41	104	169	Dec. 2024	Aug. 2026	Dec. 2028
3. COTS—Enterprise Systems Active in Defense Aviation	**89**	**Low**	**–53**	**6**	**66**	**Nov. 2023**	**June 2025**	**Nov. 2027**
4. COTS—Enterprise Asset and Service Management Systems	90	Moderate	–138	–14	110	Oct. 2023	June 2025	April 2028
5. COTS—Niche Aviation MRO Systems	81	Low	–91	12	117	April 2023	Dec. 2024	Sept. 2027
6. GOTS—ALIS	80	Moderate	–124	–62	—	Dec. 2023	July 2025	Oct. 2027
7. Hybrid—COTS and NDMS	70	Moderate	162	236	311	Jan. 2024	Sept. 2025	Feb. 2028

NOTE: Color codes for capability, risk, and cost are based on relative values above or below one-half of the standard deviation from the mean value. Color coding for schedule is based on the time beyond the threshold.

taining the Super Hornet fleet, and NAMS will support 2,100 additional non–Super Hornet aircraft.

Therefore, there is no silver bullet, but COTS Alternatives 3 and 4 offer the best chance for capability gain, the best potential to meet schedule demands, modest cost savings with the right recurring license contract, and limited scope of migration. Alternative 3 poses less overall risk than Alternative 4.

The Navy should consider increasing the budget to improve the odds that NAMS can improve readiness more quickly. The cost of NAMS is negligible compared with the cost of procuring and sustaining the aircraft fleet. The added cost to extract and clean historical data is a reasonable trade-off for a system that supports so many aircraft. Increasing efforts to clean data will get more aircraft into the new system faster with better-quality data, thereby increasing the ability of analysis software to conduct analytics useful for improved maintenance execution and, ultimately, aircraft readiness.

If the Navy does not increase its efforts to clean historical data up front, its ability to improve readiness and reduce demands on its workforce will be hindered. It can try to forgo migrating historical maintenance action data, but it must migrate current as-is aircraft configuration data at some level. If it loads inadequate configuration data, then it merely shifts the problem of cleaning to NAMS sustainment, resulting in misleading analytics along the way. Many vendors stressed the need to get the data problem corrected as much as possible up front.

Fully verifying an aircraft's as-is configuration can require deconstructing the aircraft, which further confounds the data problem. This verification is an arduous task, to say the least—and is not practical. All these challenges point to the reason the Navy needs a pragmatic yet aggressive approach to handling its existing aircraft maintenance data, understanding that not doing so will minimize the ability of NAMS to positively affect readiness across the fleet. Addressing data cleanliness, whether before, during, or following the rollout of NAMS, is a key success factor for the systems integrator.

Another area where the Navy must focus is in how it manages its contract for the new software. It makes sense to separate out control of the interfaces for NOSS, NOME, and other key systems rather than including the solution as part of the overall NAMS contract. If the Navy retains control of those interfaces, it will be better able to change the software vendor in the future as technology changes. Additionally, the primary area to control cost is through recurring software maintenance fees.

Recommendations

Our analysis led us to the following recommendations as the Navy considers its options for modernizing its logistics systems:

- Pursue a COTS migration with a focus on prototyping Alternatives 3 and 4. Alternative 3 options are preferred because they pose less risk to unclear business process definitions and have lower overall risk.
- Study data quality and implement improvement plans, where necessary, for targeted type, model, or series to improve future analytical outcomes. This approach includes increasing spending to clean historical data to better enable analytics that improve aircraft availability.
- Acquire a separate interface layer through commercial application programming interface management, GOTS enterprise service bus, domestic technology transfer plan, or NOSS acquisition; make vendors work through this layer.
- Actively negotiate terms for recurring software maintenance fees before the downselect (particularly if an Alternative 3 type is the choice).
- Make sufficient numbers of knowledgeable personnel available for OTA participation.

- Ensure that authorized personnel are available after the post-OTA down-select to authorize changes to the NAMP or execute other policies and processes as required.
- Reach out to the Global Combat Support System–Army's Army Enterprise Systems Integration Program for information on Army aviation tactical maintenance modernization and aviation notebook lessons learned.
- Simplify maintenance processes as much as possible to increase the rate of adoption into COTS business processes.
- Analyze requirements of the Virtual Fleet Support Cartridge-Actuated Device/Propellant-Actuated Device, All Weapons Information System, Buffer Management Tool, and Aircraft Material Supply and Readiness Reporting to NAMS and consider consolidating the maintenance function as much as possible into NAMS and the supply function into NOSS.
- Closely manage the interface between NOSS and NAMS to ensure forward-compatibility.
- Study and quantify the potential gain from an improved maintenance process in terms of aircraft readiness.
- Make every possible effort to adjust to ship availability, which poses a large schedule risk.

Some Perspective on the Challenges Ahead

Moving forward, the Navy needs to maintain some perspective on the challenges it faces. The major North American commercial airlines tend to mirror the current NTCSS arrangement: an in-house custom solution with multiple, separate systems providing financial, supply, and planning data and maintenance management. The reasons for this approach are primarily the cost and time to migrate and the perceived lack of readily tailorable software to meet the airlines' stringent operational requirements. Put succinctly, most airlines think they can still do it better themselves or are so invested in their current solutions that it is impractical to change. Modernization is continuously explored. Southwest Airlines is in the midst of a three-year migration to a COTS solution. The airline is not expecting significant cost savings; rather, it is focused on improved compliance with Federal Aviation Administration regulations.

These facts should concern the Navy, as our analysis shows. If the Navy does not control its implementation scope, there could be serious delays well beyond the 2024 FD goal out to 2028 and potentially beyond. A single cutover, similar to Southwest's plan, seems impossible for the Navy, but the alternative, phased approach is equally challenging.[2] It forces the Navy to have a strong interface to NALCOMIS because of how aircraft can move from activity to activity. If this approach is a nonstarter, then the Navy will have to change some of its core business processes for using aircraft and exchanging parts.

Although the Navy has challenges with the proposed approach, it also has legitimate challenges with the current system, with software problems affecting supportability and the ability to provide mission-capable aircraft, among other tasks. Gains in supportability will come quickly with the new system; however, improving readiness will not.

[2] A single cutover event is one that transfers all users to the new system overnight.

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Abbreviations

AoA	analysis of alternatives
ALE	Aviation Logistics Enterprise
ALIS	Autonomic Logistics Information System
AMSRR	Aircraft Material Supply and Readiness Reporting
ASM	Automated Skills Management
ATO	authority to operate
AWIS	All Weapons Information System
BMT	Buffer Management Tool
BPR	business process reengineering
BY	base year
CAD/PAD	Cartridge-Actuated Device/Propellant-Actuated Device
CANES	Consolidated Afloat Networks and Enterprise
CASS	Consolidated Automated Support System
COMNAVAIRFORINST	Commander, Naval Forces Instruction
CONOPS	concept of operations
COTS	commercial off-the-shelf
DoD	U.S. Department of Defense

EAM	enterprise asset management
ELA	enterprise license agreement
ERP	enterprise resource planning
ETL	extract, transform, and load
FD	full deployment
FIAR	Navy Financial Improvement and Audit Readiness
FOC	full operational capability
FY	fiscal year
FYDP	Future Years Defense Program
GAO	U.S. Government Accountability Office
GCSS-A	Global Combat Support System–Army
GCSS-MC	Global Combat Support System–Marine Corps
GFE	government-furnished equipment
GOTS	government off-the-shelf
IDE	integrated development environment
IOC	initial operational capability
IQR	interquartile range
IT	information technology
LCC	life-cycle cost
LMP	Logistics Modernization Program
MRO	maintenance, repair, and overhaul
NALCOMIS	Naval Aviation Logistics Command Management Information System
NAMP	Naval Aviation Maintenance Program

NAMS	Naval Aviation Maintenance System
NAVAIR	Naval Air Systems Command
NDMS	Naval Depot Maintenance System
NOBLE	Navy Operational Business Logistics Enterprise
NOME	Naval Operational Maintenance Environment
NOSS	Naval Operational Supply System
NTCSS	Naval Tactical Command Support System
O&MN	operations and maintenance, Navy
O&S	operation and sustainment
OIMA	optimized intermediate maintenance activity
OOMA	optimized organizational maintenance activity
OPN	other procurement, Navy
OTA	other transaction authority
PMW 150	Command and Control Systems Program Office
RDT&E	research, development, test, and evaluation
RFI	request for information
RFP	request for proposals
RIO	risk, issue, opportunity
ROM	rough order of magnitude
SME	subject-matter expert
SPAWAR	Space and Naval Warfare Systems Command
SPAWAR 1.6	Space and Naval Warfare Systems Command Cost Estimating and Analysis Division
VFS	Virtual Fleet Support
WBS	work breakdown structure

CHAPTER ONE

Introduction

The business of managing the U.S. Navy and U.S. Marine Corps's operational force includes a broad set of activities, such as personnel management, ship maintenance, aviation maintenance, spare parts oversight, and expeditionary force support. To help manage its aviation maintenance activity, the U.S. Department of the Navy established the Naval Aviation Maintenance Program (NAMP). The NAMP sets the Navy's policy for achieving materiel readiness and safety standards. The program is sponsored and directed by the Chief of Naval Operations and administered and managed by the Commander, Naval Air Forces, who set standards for its operation in coordination with the Commandant of the Marine Corps. The program's core principles include

- ensuring strict adherence to quality and safety
- maximizing efficient repair of aeronautical equipment and materiel
- minimizing the degradation of materiel through planned maintenance
- conducting data collection and analytics to improve efficiency, effectiveness, quality, and safety.

Today's naval aviation force consists of more than 70 types, models, and series and approximately 2,400 Navy and 1,400 Marine Corps aircraft—a total number that is almost equivalent to all the aircraft operated by commercial airlines American, Delta, United, Southwest, and NetJets combined (approximately 3,900).

Commander, Naval Air Forces Instruction (COMNAVAIRFORINST) 4790.2C states that naval aviation maintenance

> is divided into three levels—organizational (O-level), intermediate (I-level), and depot (D-level). O-level maintenance is performed by operating units, such as a squadron, on a day-to-day basis. This work consists of inspecting, servicing, lubricating, adjusting, and replacing parts, minor assemblies, and subassemblies. I-level maintenance is performed at centrally located facilities, such as a Fleet Readiness Center (FRC), in support of operating units. This work consists of calibration, repair, or replacement of damaged or unserviceable parts, components, or assemblies; limited manufacture of parts; and technical assistance. D-level maintenance is performed at large industrial-type facilities, such as a Naval Aviation

Depot (NADEP), and includes major overhaul and major repair or modifications of aircraft, components, and equipment, and the manufacture of parts. Each level of aviation maintenance is supported by various hardware and software systems (COMNAVAIRFORINST 4790.2C, 2017).

D-level maintenance is performed by the Naval Depot Maintenance System (NDMS), while the current program of record for O-level and I-level maintenance is the Naval Tactical Command Support System (NTCSS). The primary NTCSS subsystem that supports aviation logistics is the Naval Aviation Logistics Command Management Information System (NALCOMIS), as shown in Figure 1.1.

NALCOMIS consists of optimized organizational maintenance activity (OOMA) for O-level and optimized intermediate maintenance activity (OIMA) for I-level. The NTCSS family of systems was developed in the 1990s to consolidate stovepiped management across a variety of sponsors and interests. NTCSS is operated at more than 700 sites and has more than 150,000 users (Harder, 2015). Some of the concerns that have been raised about NTCSS are as follows:

- Its technical architecture has failed to mature adequately, thus creating supportability issues.
- It has multiple fielded versions.

Figure 1.1
NAMP Three-Level Maintenance System

SOURCES: (From top) U.S. Navy photo by Petty Officer Second Class Adrian Ostolski, U.S. Navy photo by Photographer's Mate Airman Jhi L. Scott, and U.S. Navy photo by Jim Markle.

- It has static business processes.
- These problems contribute to the Navy not meeting its aircraft readiness goals.

The NALCOMIS baseline is currently being consolidated to address some of the supportability and version control issues; however, open supportability, architectural, and business process reengineering (BPR) challenges remain.

Supportability Issues

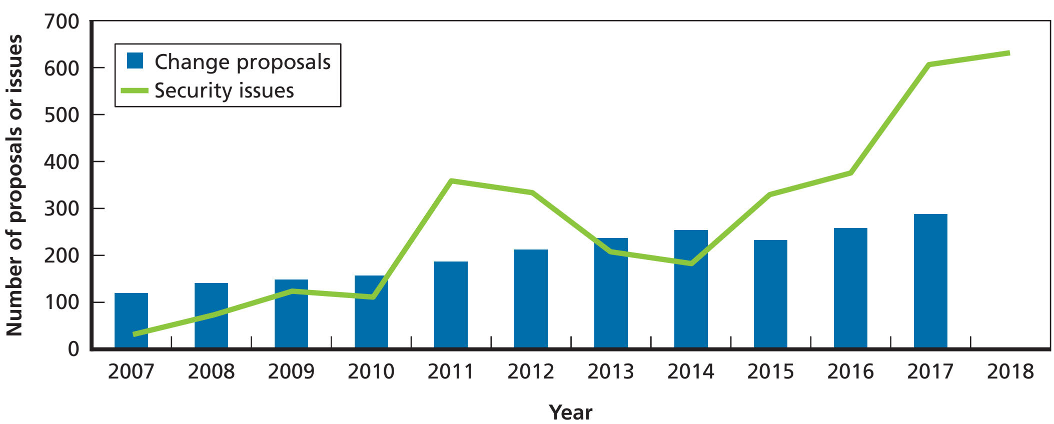
Research for the analysis of alternatives (AoA) confirmed that NALCOMIS is unable to keep up with supportability demands, such as software function change proposals and information assurance vulnerability alerts. As shown in Figure 1.2, a perpetual backlog of security issues is increasing along with the backlog of change proposals.

The two are positively correlated, with a correlation coefficient of 0.83; however, correlation does not mean causation. Potential reasons for the supportability challenges that emerged during the study included

- an antiquated NALCOMIS software architecture
- increased demand for functional changes related to changing aircraft maintenance action procedures
- increased awareness and focus on software security issues
- challenges in managing the life-cycle sustainment of NALCOMIS.

The study was unable to confirm the primary reason for these issues becoming more common; regardless, they are. Putting more resources into the program to

Figure 1.2
Backlog of Change Proposals and Security Issues



SOURCES: Based on data provided to RAND by Space and Naval Warfare Systems Command (SPAWAR) (change proposals) and Defense Information Systems Agency (information assurance vulnerability alerts).
NOTES: For OOMA only, change proposals also include technical refresh changes and number of change proposals opened. As of writing, the data on change proposals for 2018 were not available.

address such issues more quickly may be stymied by the challenge of implementation, and it is likely that only a more modern architecture and software sustainment process can alleviate security concerns such that issues can be addressed and deployed to the fleet in a timely manner.

Aircraft Readiness Below Goals

The readiness challenge is reflected in the growing gap between the total inventory of F/A-18 Super Hornets and those that are mission capable. In November 2017 congressional testimony on naval readiness, VADM Troy M. Shoemaker indicated that only 31 percent of F/A-18 Super Hornets were mission capable (Shoemaker, 2017). The Naval Aviation Maintenance System (NAMS) problem statement noted that the objective is 56 percent.

The shortfall has been blamed on sequestration, which led to parts shortages, maintainer reductions, and cuts in depot operations, as well as increases in the pace of operations over the past decade. How much NALCOMIS (and related systems) contribute to or help mitigate problems exemplified by the shortfall remains unquantified. The Navy believes that reengineering its business processes in maintenance (and supply) will mitigate problems with better predictive maintenance and make it more agile to address emerging problems, such as funding limitations. How much a new system will affect readiness also remains unquantified.

Congress has acted to address the shortfall by buying new aircraft. In the 2018 Consolidated Appropriations Act, Congress provided $739 million for ten new F/A-18 Super Hornets (U.S. Senate Appropriations Committee, 2018). Part of the reason for the procurement was to address the shortfall in available aircraft (Office of the Under Secretary of Defense [Comptroller]/Chief Financial Officer, 2018). The F/A-18 has a flyaway cost of approximately $73 million and a sustainment cost of $63 million to $94 million.[1]

The Navy's Proposed Solution

To address these problems and broader issues across its logistics enterprise, the Navy in 2017 began modernizing its family of logistics systems and replacing them with the Navy Operational Business Logistics Enterprise (NOBLE) (see Wilson et al., 2018). The objective is to provide more-centralized acquisition management and realize information technology (IT) and Navy logistics operational cost savings through efficiencies. NOBLE is an umbrella term for three subprograms: the Naval Operational Supply System (NOSS), NAMS, and the Naval Operational Maintenance Environment (NOME). Figure 1.3 shows all three systems and their approximate fielding objectives. The focus of our study was on NAMS, as highlighted by the oval in the figure. NAMS has been designated a category II defense business system.

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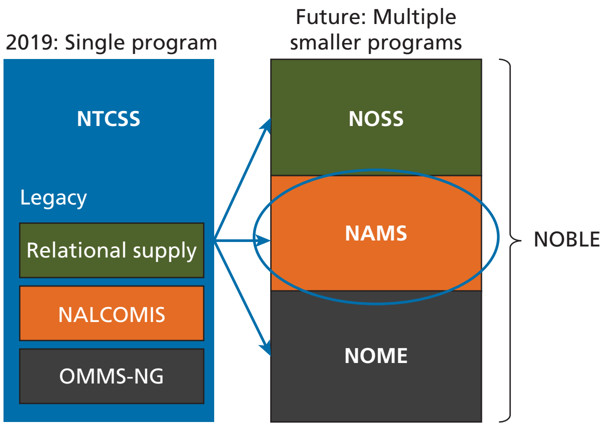
1 Sustainment cost assumes a $10,500-per-hour cost and 6,000–9,000 lifetime hours (McCarthy, 2016).

Figure 1.3
NOBLE Modernization Objective



Program	Objective initial capability	Objective full capability to fleet
NOSS	October 1, 2020	July 1, 2023
NAMS	4th quarter, 2021	January 1, 2024
NOME	4th quarter, FY 2022	4th quarter, FY 2025

NOTES: OMMS-NG = Organizational Maintenance Management System Next Generation; FY = fiscal year.

NAMS is intended to address the concerns and challenges with NTCSS by augmenting and enhancing several existing and planned systems, including the Aviation Logistics Enterprise (ALE) and NDMS. NAMS will be required to work closely with NOSS.

NAMS is intended to support approximately 94,000 users (85,000 shoreside) and more than 335 activities: 315 shoreside and 20 afloat on nuclear-powered aircraft carriers and on landing helicopter assault and landing helicopter dock ships. NAMS will support about 2,700 of the 3,800 aircraft across the Navy, with notable exceptions being the F-35 and contractor-operated training aircraft. The Navy identified key attributes of NAMS, shown in Table 1.1.

To ensure that NAMS aligns with these attributes and meets the demands of the current and future aviation logistics enterprise, the Navy identified 269 high-level requirements, discussed in greater detail in Chapters Two and Three.

Objectives

The objective of this study was to assist the Navy's PMW 150 by conducting an AoA to assess technical solutions, as defined by the program office for NAMS. The goals of the analysis were (1) to help inform decisionmakers of viable alternatives by identifying potential solutions, analyzing market research, and assessing a solution's ability to satisfy functional, technical, and life-cycle support requirements and (2) to provide data to assess cost analysis, overall risk, and delivery schedule impacts (U.S. Department of Defense [DoD] Instruction 5000.75, 2015, p. 17).

Table 1.1
Navy-Identified Key NAMS Attributes

Attribute	Description
Enterprise capability	• Connected and operational across the globe • Integrated data environment
Product-centric	• Ready to integrate into a product life-cycle management–centric ecosystem
Streamlined and usable	• Enables warfighters to accomplish tasks as efficiently as possible • Open to new ways of doing business
Supportable and maintainable	• Allows easy corrections and updates to business processes and data models without coding or software deployments; configuration not customization • Cyber-secure and cyber-insulated (to decrease exposure to IT controls at the network and server levels)
Integrated	• Interoperable with other deployed logistics IT systems

SOURCE: U.S. Department of the Navy NAMS problem statement provided by the Command and Control Systems Program Office (PMW 150).

The AoA was conducted in accordance with study guidance and the NAMS problem statement provided by the research sponsor. The study guidance provided four broad classes of alternatives:

- **Status quo (baseline, no modernization).** Explore maintaining NALCOMIS capabilities, including costs to upgrade the system to meet NAMS requirements.
- **Commercial off-the-shelf (COTS).** Examine hardware and software associated with a commercial solution and associated configuration to meet the Navy's needs. There may be variants of this alternative.
- **Government off-the-shelf (GOTS).** Examine product suites owned by the U.S. government. There may be several variants associated with this alternative, including leveraging the Navy's investments in F-35 maintenance.
- **Hybrid.** This is essentially a catch-all option that could have several variants that are combinations of previous alternatives.

Approach

In this section, we describe the tasks that supported the AoA.

Supporting Market Research Through Request for Information Development

The AoA team leveraged responses to the NOSS request for information (RFI) and provided analytic support to the Navy as it developed the RFI for NAMS.[2] This sup-

[2] For background, see Wilson et al., 2018.

port included developing questions and data collection methods, such as a survey website where respondents could answer a series of questions. Questions were based on the NAMS requirements and levels of configuration or customization required to meet those requirements. We also solicited additional information about the complexity of the requirements.

Developing an Analytic Method to Assess Performance Measures

We leveraged the results of other research studies, the perspectives of subject-matter experts (SMEs), NOSS AoA findings, and the Navy's evaluation criteria matrix to develop candidate measures of effectiveness traceable to the problem statement performance measures and BPR effort.[3] The NOSS study developed technical and life-cycle support measures related to enterprise capability, cybersecurity, auditability, supportability, disconnected operations, mobile solutions, and open architecture. We worked with the study director and government team to prioritize relevant measures, given the expected timeline.

Refining Alternatives

We also worked with the government team to refine the definitions of the alternatives by identifying their distinguishing characteristics. Some examples included descriptors of the architecture (e.g., levels of modifiability), hardware and software dependencies, numbers and types of interfaces, ease of integration, and change of business processes. We defined suitable subalternatives based on key discriminating factors among the four base alternatives and worked with the sponsor to identify prescreening criteria to eliminate less likely alternatives.

Performing Capability Analyses

Given the method and measures and the data collected by the government and the RAND AoA teams, we assessed the ability of each alternative to meet the performance measures. This process involved the RFI, live demonstrations with selected vendors, data cleaning, review, and compilation.

Acquiring Available Cost and Materiel Data and Estimating Costs for Each Alternative

The specific cost-estimating methodology for each alternative was based on vendor responses to the RFIs and follow-up interviews. We worked with Navy cost experts and leveraged previous work that explored the Program Budget Information System.

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[3] The Navy conducted a high-level BPR effort ahead of the AoA to determine high-level requirements and process changes. A more detailed BPR was conducted concurrent to the AoA.

Researching Operational, Schedule, and Cost-Risk Areas

We examined various management, architectural, and complexity factors that could affect technical, schedule, and programmatic risks, including possible management structures, software architectures, and programmatic linkages and interdependencies associated with each alternative. We also performed a risk assessment that identified the technical elements critical to each alternative. That process involved (1) scoring the probability that an element would have a negative impact and (2) scoring the severity of the consequence of such an event. We assessed the likelihood of completing development, integration, and operational testing activities in the time required to achieve initial operational capability (IOC). The collection and adjudication of the data relied on a modified Delphi approach through which team members were asked to score each probability and consequence in isolation, with responses aggregated and then finalized through multiple rounds of discussion of disparate scores that were adjusted as needed to achieve consensus.

Assessing the Ability of the Alternatives to Meet Schedule

The AoA team collected schedule data for development, acquisition, and implementation and developed a Monte Carlo model to project the ability for various alternatives to meet IOC and full operational capability (FOC) objectives.

Providing Conclusions

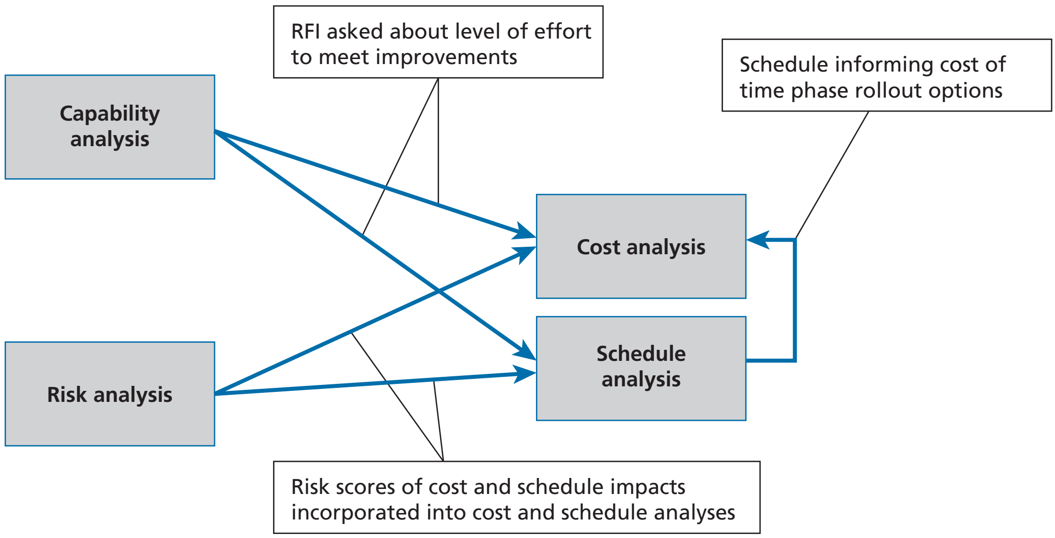
We compared the alternatives according to their cost, risk, schedule, and capability, then summarized the analyses and presented our findings and recommendations, including a preferred alternative.

The various aspects of the study were integrated as shown in Figure 1.4. The figure highlights how the capability and risk analyses informed findings on cost and schedule and how schedule informed cost in terms of rollout timing.

Organization of This Report

We discuss the effort to develop alternatives in Chapter Two. Chapter Three describes the analyses we used to evaluate capability: the RFI requirements response analysis and quality analysis. Chapter Four presents the results of our risk analyses, Chapter Five presents the results of our cost analyses, and Chapter Six presents the results of our schedule analyses. Chapter Seven offers conclusions and recommendations.

Figure 1.4
Analysis of Alternatives Sector Integration



CHAPTER TWO

Developing and Refining NAMS Alternatives

In this chapter, we discuss how we developed and refined the NAMS alternatives within the specified four classes of alternatives in the AoA guidance.

Developing the NAMS Alternatives

The NAMS AoA guidance specified four classes of alternatives that were further refined: status quo, COTS, GOTS, and hybrid (some combination of the other three). These four categories bounded the AoA, but there were many possible variants within each. Figure 2.1 shows the five-part process that we used to develop and refine the alternatives.

First, we took the 269 high-level requirements and consolidated them to 56 requirements that more broadly captured the high-level requirements. This was done to ease the burden of responding on vendors (with a secondary effect of potentially increasing the RFI response rate to the questionnaire) and to clean up semantic issues and redundancy within the requirements. We then developed a questionnaire asking vendors to assess—for each of the 56 requirements—their ability to meet the requirement, the level of effort required to meet it, and their confidence in both responses. In conjunction with the questionnaire, the RFI had a written response portion that asked the vendors to describe their recommended solution, with a specific focus on quality attributes, potential risks, and estimated cost and schedule. More than 50 COTS and

Figure 2.1
Five-Part Process for Alternative Development

GOTS vendors were alerted to the RFI release, and we received 28 responses. The responses represented a wide range of capabilities, including the following:

- field service management
- IT service management
- enterprise resource planning
- maintenance, repair, and overhaul (MRO)
- business process management
- computerized maintenance management systems
- enterprise asset management
- planning systems
- digital manuals
- integrators.

Of the 28 responses, we selected a sample of 12 (nine COTS and three GOTS) for follow-up meetings, during which the vendors had an opportunity to clarify their RFI responses and provide a demonstration of their products. These 12 vendors were selected because they could best meet the 56 requirements outlined in the questionnaire and were a representative sample of respondents overall.

Refining the NAMS Alternatives

After the follow-up meetings, we were able to refine the four alternative areas into the seven specific alternatives examined in this study, as shown in Table 2.1. The remainder of this section describes the alternatives and the refinement process in more detail.

Status Quo Refinement

Alternative 1 represents a baseline for comparison. It is an assessment of how well NALCOMIS can meet the NAMS requirements, as well as the potential costs, risks, and schedule for implementation.

The status quo alternative area includes a second alternative, whereby the Navy attempts to modernize NALCOMIS to meet the NAMS requirement set. This alternative captures ongoing efforts to modernize NALCOMIS and serves as an option for continued government ownership of the software that supports aviation maintenance.

COTS Refinement

COTS is defined in the Federal Acquisition Regulation as follows:

> (1) Means any item or supply (including construction material) that is—
> (i) A commercial item (as defined in paragraph (1) of the definition in this section);
> (ii) Sold in substantial quantities in the commercial marketplace; and

Table 2.1
Alternatives for Evaluation

Alternative Area	Alternative Name	Description
Status quo	1. Status Quo—NALCOMIS No Modernization	Baseline (current NALCOMIS)
	2. Status Quo—NALCOMIS New Development	NALCOMIS reconstructed with a modern software architecture
COTS	3. COTS—Enterprise Systems Active in Defense Aviation	Enterprise systems that are primarily offered as enterprise resource planning systems
	4. COTS—Enterprise Asset and Service Management Systems	Systems that do not necessarily perform aviation maintenance but whose processes align with maintenance concepts
	5. COTS—Niche Aviation Maintenance, Repair, and Overhaul (MRO) Systems	Systems that specialize in aviation maintenance
GOTS	6. GOTS—Autonomic Logistics Information System (ALIS)	System that leverages existing Navy and DoD investments in F-35 maintenance
Hybrid	7. Hybrid—COTS and NDMS	NDMS at the I- and D-level maintenance, with COTS at the O-level

> (iii) Offered to the Government, under a contract or subcontract at any tier, without modification, in the same form in which it is sold in the commercial marketplace. (Federal Acquisition Regulation, 2018, subpart 2.101)

From the RFI, the Navy received 23 responses from commercial companies. These responses varied widely in terms of product type, functionality, and scope. The responses fell into two categories:

- **software vendors**: companies that develop and build software to be purchased
- **software integrators**: companies that integrate the purchased software into the Navy's business processes. This category includes any configuration or customization needed for specific processes, any interfaces with other Navy systems, and any process-improvement or reengineering efforts to align the Navy with built-in system processes.

Within the software vendor category, there were three responses that offered an infrastructure solution, which would provide the backbone for other maintenance systems and therefore could not serve on their own as NAMS solutions. Otherwise, the software vendors aligned with at least one of the following four software categories:

- **Enterprise resource planning (ERP) systems** have "the ability to deliver an integrated suite of business applications. ERP tools share a common process and data model, covering broad and deep operational end-to-end processes, such as those found in finance, HR [human resources], distribution, manufacturing, service and the supply chain"(Gartner, undated-c).
- **Enterprise asset management (EAM) systems** "consist of asset register, work order management, inventory and procurement functions in an integrated business software package"(Gartner, undated-b).
- **Computerized maintenance management systems** are "application software used to provide for work and materials management of maintenance activities in a manufacturing organization" (Gartner, undated-a).
- **Field service management** "includes the detection of a field service need (through remote monitoring or other means, inspection or a customer detecting a fault), field technician scheduling and optimization, dispatching, parts information delivery to the field, and process support of field technician interactions" (Gartner, undated-d).

To refine the COTS alternative area, we focused on software vendors, specifically those that could provide more than an infrastructure solution. Although the above categorization captures the overall vendor responses well, individual vendor solutions did not cleanly fall into any one of the categories. Vendors often did not label their software in this way, and when they did, the combination of questionnaire response and product demo showed that functionality was similar across the board. It was therefore not meaningful to divide the COTS alternative by software type.

However, it was clear that not all COTS solutions were the same, and industry experience and product scope proved to be a better differentiator. Several of these companies also indicated that they could provide a single solution for NAMS, NOSS, and NOME. Therefore, the first divide was between the enterprisewide solutions that addressed these nonmaintenance capabilities and the aviation maintenance–specific solutions.

However, even among the large enterprise software vendors, there were notable differences. Several companies had already designed and implemented their software for a military aviation environment, while others had systems that were highly configurable and were used across a wide range of industries. Highly configurable systems allow more flexibility and changes after deployment, but initially defining business processes and workflows for these systems presents a higher risk than it does for the systems tailored to defense aviation. Therefore, these systems were treated as separate COTS alternatives to more accurately capture potential risks, estimated costs, and implementation schedule details. We therefore divided the COTS solutions into three categories:

- COTS enterprise systems (e.g., ERP) active in defense aviation
- COTS enterprise asset and service management systems offering a configurable solution
- COTS niche aviation MRO solutions.

Although the analysis focused on software systems and their capabilities, we engaged with software integrators to get their insights into integration and implementation risks and schedules and their experiences with some of the software vendors. Additionally, the integrators provided cost and risk data, which are presented later in this report.

GOTS Refinement

GOTS software products, as defined here, are those that are currently owned (through license or purchase) and used by the U.S. government. The software may have been developed by the U.S. government or a private company. Specifically, this alternative area focused on the viability of whether an extension or enhancement to existing DoD programs could meet NAMS requirements. All the GOTS products considered provided some form of maintenance management support to the current users.

We considered five GOTS systems. One system, NDMS, met only the I-level maintenance requirements of NAMS but is further discussed as a hybrid alternative in the next section. Of the remaining four systems, only one was considered a viable alternative, ALIS. The other three systems considered were the Logistics Modernization Program (LMP) and the Global Combat Support System's Army (GCSS-A) and Marine Corps (GCSS-MC) variants. We describe the four systems next and why each was or was not selected as a viable GOTS alternative.

Logistics Modernization Program

LMP is an ERP system produced by SAP that achieved IOC in 2003 and was fully deployed by 2016 (U.S. Army Program Executive Office, Enterprise Information Systems, 2018). LMP is one of the Army's four major ERP systems for managing major business functions. LMP specifically manages the national (or wholesale-level) logistics for the Army. In this role, LMP "supports the national-level logistics mission to develop, acquire, field and sustain the Army's equipment and services. It is an SAP commercial-off-the-shelf ERP program that manages and tracks orders and delivery of materiel to Soldier, where and when they need it" (U.S. Army Program Executive Office, Enterprise Information Systems, 2017, p. 12). NAMS is a retail-level system, so LMP's functionality is out of scope for NAMS.

GCSS-A and GCSS-MC

GCSS-A is another of the Army's four major ERP systems and manages tactical (or retail-level) logistics. It is a web-based SAP logistics and financial ERP system (Northrop Grumman, undated). It consists of two components, the first of which is the ERP that provides "a functional capability for deployable forces titled GCSS-A" (DoD, 2016a, p. 5). The second component, the Army Enterprise Systems Integration Program, functions as the technical enabler (DoD, 2016a). The system encompasses both supply and maintenance, unlike in the Navy, where those functions are part of the separate systems NOSS and NAMS. GCSS-A currently has 20,000 users, with full deployment (FD) of Increment 1 completed in March 2018 (Jane's, 2018). Northrop Grumman is the prime contractor responsible for the integration of GCSS-A (Northrop Grumman, undated). Although GCSS-A is a retail-level system like NAMS, its aviation maintenance capability will not come out until Increment 2, which is still under development; furthermore, extensive customization for the Army's operations make GCSS-A a nonviable option for NAMS (Jane's, 2018). Additionally, the Army has a separate system, Aviation Notebook, that is not a part of the ERP and was developed specifically for its aviation applications.

GCSS-MC is the Marine Corps program for managing logistics and supply operations. It is based on an Oracle web-based ERP system for logistics chain management (Oracle's 11i E-Business Suite) (GCSS-MC Program Management Office [PMW 230], 2017). GCSS-MC "is a portfolio of systems that supports logistics elements of command and control, joint logistics interoperability, and secure access to and visibility of logistics data" (DoD, 2016b, p. 5). GCSS-MC Increment 1 achieved FD in December 2015, with approximately 36,000 users (DoD, 2016b). Similar to GCSS-A, GCSS-MC has levels of customization and limited aviation maintenance capabilities. It is unclear how much customization has been done in both GCSS-A and GCSS-MC, how many processes require customization, or how much remediation is necessary to make the process work for NAMS. This AoA could not make these assessments without further analysis of the alignment of existing processes with those that are being proposed through the detailed BPR effort.

Autonomic Logistics Information System

ALIS is the "primary logistics tool to support F-35 operations, mission planning, and sustainment" (U.S. Government Accountability Office [GAO], 2016, p. 6). It was developed by the F-35 prime contractor, Lockheed Martin, and "helps maintainers manage tasks including aircraft health and diagnostics, supply-chain management, and necessary maintenance events" (GAO, 2016, p. 6). Being an O-level maintenance management system for one of the largest, most complex fleets in DoD makes ALIS a potential GOTS solution for NAMS.

Hybrid Refinement

The hybrid option emerged after meeting with representatives from NDMS. The way the Navy approaches maintenance is changing; therefore, the requirements for NAMS may not make sense in this new paradigm. Currently, as noted in Chapter One, the Navy divides maintenance into three broad categories: organizational (O-level), intermediate (I-level), and depot (D-level) maintenance. For naval aviation, specifically, NDMS is the system for D-level maintenance, OIMA is the system for I-level maintenance, and OOMA is the system for O-level maintenance. OOMA and OIMA are both part of NALCOMIS, which NAMS is supposed to replace. However, a recent Vision 2020 campaign led by Naval Air Systems Command (NAVAIR) and Commander, Fleet Readiness Centers, pushed for a transition from O-, I-, and D-level maintenance to "on-and-off equipment" maintenance. This approach loosely maps O maintenance to "on" equipment and I and D maintenance to "off" equipment.

The hybrid alternative makes NDMS the system of record for "off" aviation equipment, which includes aircraft and their subcomponents and engines. NAMS would then be the "on" equipment system. This designation would change the requirements for NAMS and, therefore, the acquisition strategy. With a smaller scope for NAMS, an MRO point solution could be used and other closely related systems, such as NOSS or ALE, could own the life-cycle management requirements. This alternative depends on the direction the Navy decides to take with its overall maintenance strategy.

CHAPTER THREE

Capability Analyses of the Alternatives

To assess the capabilities of the alternatives, we used two approaches: (1) a survey instrument issued through an RFI and (2) a quality analysis to cover items not specified in the requirements. This chapter describes these two analyses of the capabilities of the alternatives, starting with a discussion of the key requirements and quality attributes before turning to the two analyses and their results.

Requirements and Quality Attributes

Initial List of 269 High-Level Requirements

The Navy provided us with a list of 269 high-level requirements that were based on the Navy aviation maintenance business process structure.[1] Because the list of 269 requirements had been aggregated from various sources, there were redundancies in the content of individual requirements. In some cases, a requirement was listed more than four times with slightly different wording. There were also inconsistencies in the level of detail provided in the requirement descriptions; some requirements consisted of only a short phrase, while others were a paragraph long and full of detail. Because of the inconsistent and repetitive nature of the requirements, and because such a large number of requirements could impose a significant burden on survey respondents, we further aggregated the requirements.

Narrowing the List to 56 Consolidated Requirements

In conjunction with aviation maintenance SMEs from CSA Guidance Consulting, we reviewed and summarized each of the 269 high-level requirements and then grouped them into 56 consolidated requirements. We worked to remove jargon and rewrite or summarize the requirements so that they were consistent in the amount of detail provided. The 56 consolidated requirements also followed the business process structure and were further classified as functional requirements (40 requirements in eight groups), cross-functional requirements (five requirements in one group), and quality

[1] The requirements resulted from the BPR effort led by NAVAIR.

requirements (11 requirements in one group). Table 3.1 summarizes the requirements across the three groups.

A crosswalk between the original list of 269 requirements and the 56 consolidated requirements illustrated how each new requirement was constructed. Officials at NAVAIR reviewed and approved the list of 56 requirements. After the requirement consolidation effort, we further categorized the requirements into high-, medium-, and low-priority requirements and identified requirements that referenced analytics.

Table 3.1
Summary of 56 Consolidated High-Level Requirements

Area	Number of Requirements
Functional requirements	40
Maintenance	9
Maintenance preparation	1
Maintenance execution	12
Maintenance completion	4
Maintenance operations	3
Logistics product data	4
Supply chain management	4
Local supply chain management	3
Cross-functional requirements	5
Quality requirements	11
Usability	1
Security	2
Auditability	1
Availability	3
Integrity	1
Integration	1
Interoperability	1
Performance	1
Total	56

We also synthesized quality attributes from other sources, such as the study guidance and problem statement. In doing so, we identified other elements as important that had limited representation in the BPR requirements, such as forward compatibility, enterprise capability, and maturity.

Requirements Analysis

Overview of the Requirements Survey

We developed a survey data collection instrument for the RFI to obtain information about the capabilities of the organizations that proposed providing their software systems or integration services to support the Navy in its endeavor to modernize its naval aviation maintenance systems. The intent of the survey was to provide a high-level understanding of current capabilities with respect to the individual software requirements and to facilitate more in-depth conversations with software providers and integrators.

Survey Design

The survey fielded to software providers and integrators consisted of a Microsoft Word document that respondents filled out electronically and returned to the study team by email. The survey instrument included detailed instructions about the purpose and nature of the survey and an overview of the 56 consolidated software requirements. For each of the 56 consolidated requirements, we provided the full text of the requirement description and asked the following four questions:

1. Can your organization fulfill each requirement *today*? If yes, is some level of configuration, customization, or enhancement required?
2. On a scale from 1 to 5, how confident are you that your organization can fulfill each requirement? Pick a number from 1 to 5 where 1 is the lowest level of confidence and 5 is the highest level of confidence.
3. How much staff time would be required to fulfill each requirement (consider a midlevel engineer for average person-days)? Include time required to configure the system, create custom components, and accommodate any increase in testing beyond what would normally be required.
4. On a scale from 1 to 5, how confident are you in your assessment of the level of effort required to fulfill each requirement?

Provided responses to question 1 were as follows:

- Yes: Out of the box solution (no configuration or customization required)
- Yes: Solution available, configuration required
- Yes: Solution available, customization required

- No Capability Today: Enhancement needed and possible
- No Capability Today: Enhancement not possible.

Provided responses to question 3 were as follows:

- less than one person-week
- more than one person-week, but less than one person-month
- 1–2 person-months
- 3–5 person-months
- more than 5 person-months.

Figure 3.1 shows an example from the RFI survey for requirement 1.

Respondents were asked to provide one answer to each of the four questions for each of the 56 requirements. After respondents answered the four questions for each requirement in a business process section, they were asked the following questions about the previous group of requirements in that business process section:

- In your opinion, should the Navy consider this set of requirements as a low priority, medium priority, or high priority?

Figure 3.1
Requirement 1 from the RFI Survey

REQUIREMENT 1:
Support managing (documenting, distributing, and tracking) preventative maintenance requirements (PMRs), which pertain to the care and servicing needed to maintain aircraft equipment, support equipment (SE), facilities, and facilities equipment. PMRs are condition based and time based.

QUESTION 1					**QUESTION 2**				
Can your organization meet this requirement? Check (X) one category					**On a scale from 1 to 5, how confident are you that your organization can fulfill this requirement?** *Pick a number from 1 to 5 for each requirement where 1 is the lowest level of confidence and 5 is the highest level of confidence.*				
YES: Out-of-box solution *(no configuration or customization required)*	**YES:** Solution available; **configuration required**	**YES:** Solution available; **customization required**	**No Capability Today:** Enhancement needed and possible	**No Capability Today:** Enhancement not possible	Lowest confidence				Highest confidence
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

QUESTION 3					**QUESTION 4**				
How much staff time would be required to meet this requirement (consider mid-level engineer for average person-days)? *Check (X) the expected level of effort*					**On a scale from 1 to 5, how confident are you in your estimate of the level of staff effort required to fulfill this task?**				
Less than one person week	More than one person week, but less than one person month	1-2 person months	3-5 person months	More than 5 person-months	Lowest confidence				Highest confidence
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

- Do you have any comments about this group of requirements or individual requirements? IF YES, please use the text area for each question or expound on any issues in the RFI response document.

In the final portion of the survey, respondents were asked the following question to gather their opinion about the Navy's priorities overall:

- On a scale from 1 to 5, how important do you think each functional requirement area is relative to the others? Pick a number from 1 to 5 for each requirement, where 1 is the lowest level of importance and 5 is the highest level of importance.

Respondents answered this question for each of the eight groups of functional requirements (that contained 40 requirements), for the cross-functional group (that contained five requirements), and for the quality group (that contained 11 requirements).

Analysis of RFI Survey Responses

We compared responses to the four capability questions by the ten requirement groups, which are shown in Figure 3.2. The maintenance preparation requirement group had the greatest need for customization or enhancement. The maintenance requirements group had the highest rate of combined out-of-the-box and configuration capabilities. The distribution of responses to the amount of time required to meet each requirement by group is shown in Figure 3.3. The time estimate for implementing maintenance operations requirements was the highest across all of the areas.

The responses were combined with the alternatives identified earlier and discussed in Chapter Two. Table 3.2 shows how many responses related to each, as well as the total number of responses (17).

We combined the responses within each alternative and compared their overall capability and time required (Figure 3.4).

Alternatives 3, 4, and 6 had the highest overall capability. Figure 3.5 shows each of the alternatives broken out by the 17 individual responses.

The top Alternative 3 and 4 responses performed better overall. All but one of the 17 responses (response 4.1) required some amount of customization or enhancement. The one that did not was an IT service management system that was designed to be highly configurable. Although we could not definitively identify a requirement that might need customization or enhancement, this does not imply that the possibility does not exist. We then selected up to two of the best-performing responses per alternative (as defined by the maximization of out-of-the-box plus configuration capabilities). Figure 3.6 shows only those responses.

The alternatives with the most out-of-the-box and configuration capabilities combined were options 3.2, 4.1, and 4.2 for Alternatives 3 and 4.

Figure 3.2
Capability Responses, by Requirement Group

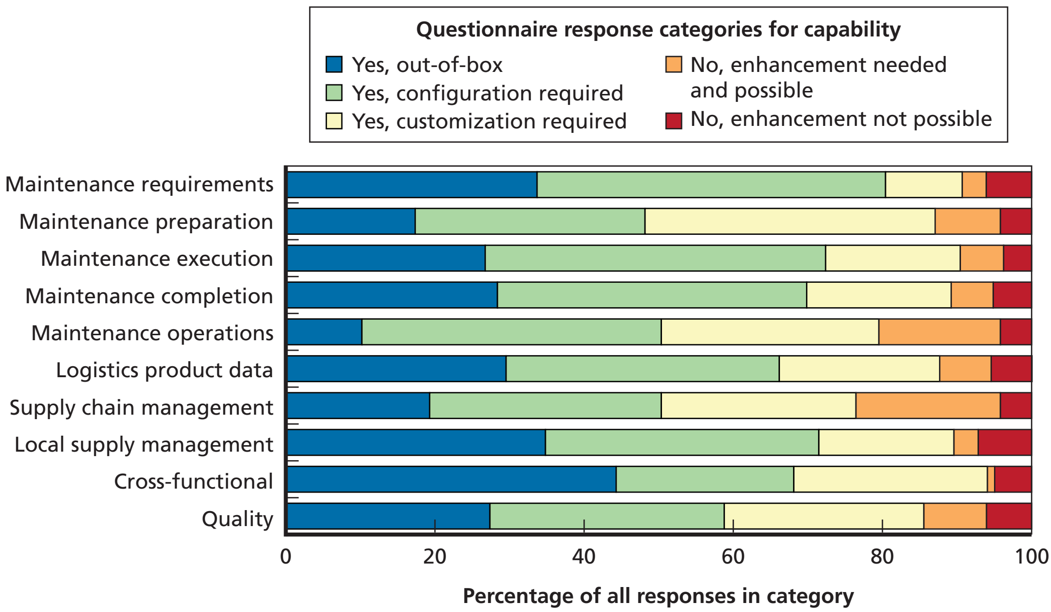


Figure 3.3
Amount of Time to Meet Requirements

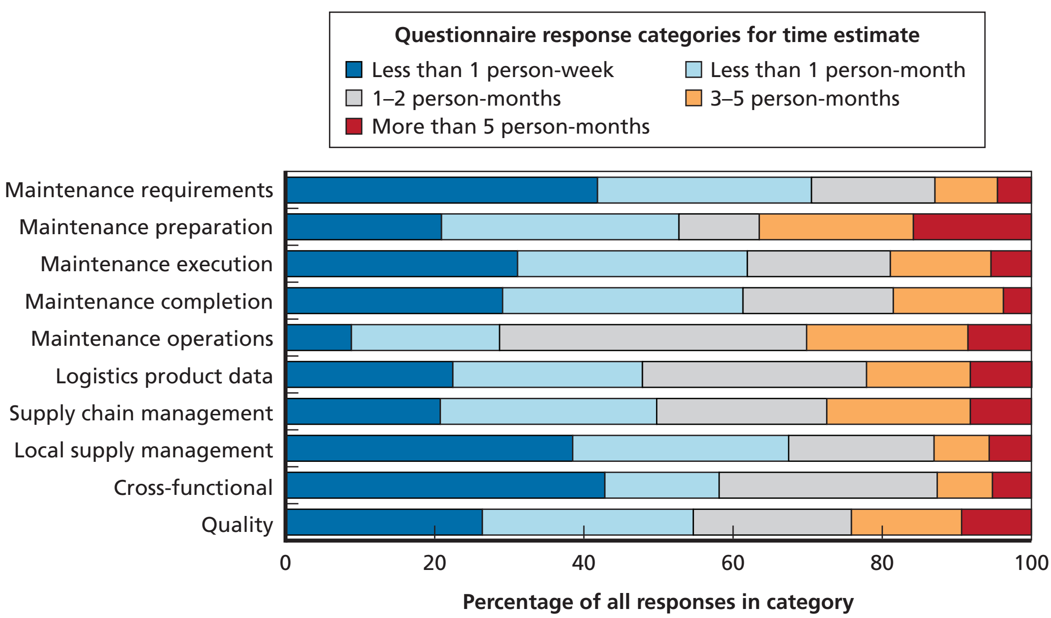
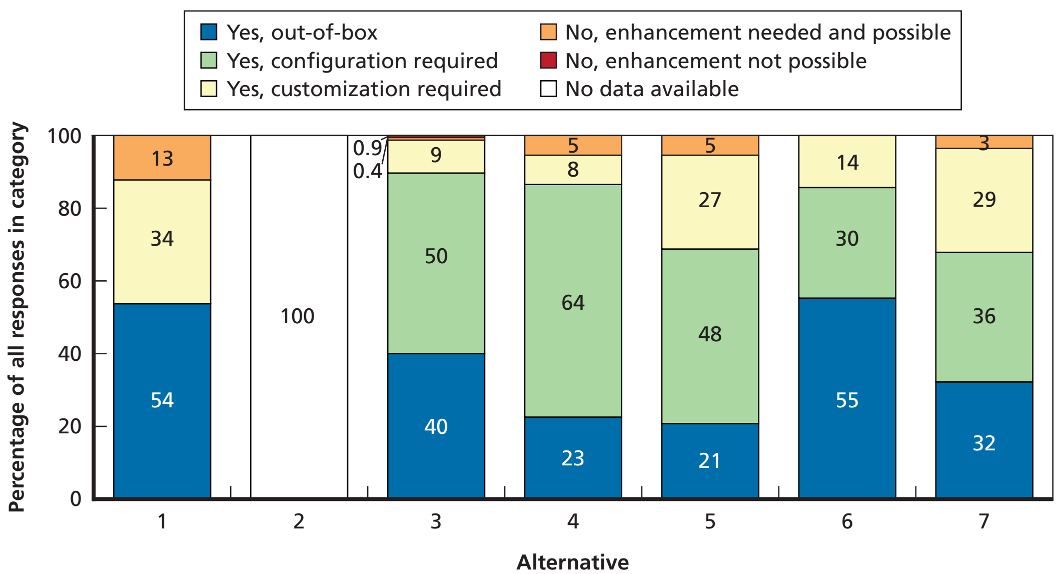


Table 3.2
Summary of High-Level Requirements

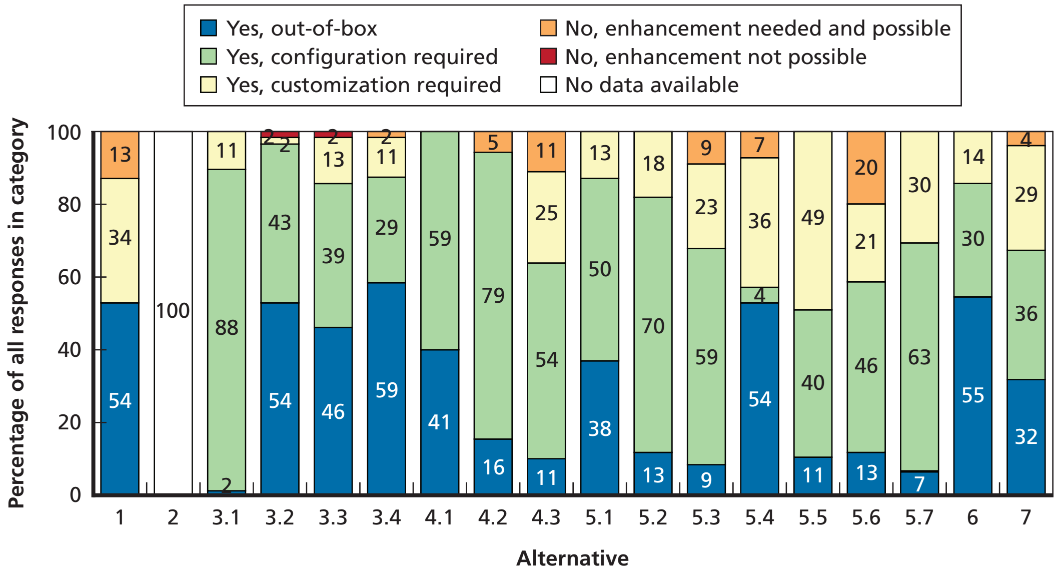
Alternative	Responses
1. Status quo—NALCOMIS (No Modernization)	1
2. Status quo—NALCOMIS New Development	0
3. COTS—Enterprise Systems Active in Defense Aviation	4
4. COTS—Enterprise Asset and Service Management Systems	3
5. COTS—Niche aviation MRO Systems	7
6. GOTS—ALIS	1
7. Hybrid—COTS and NDMS	1
Total	**17**

Figure 3.4
Combined Capability Responses, by Alternative



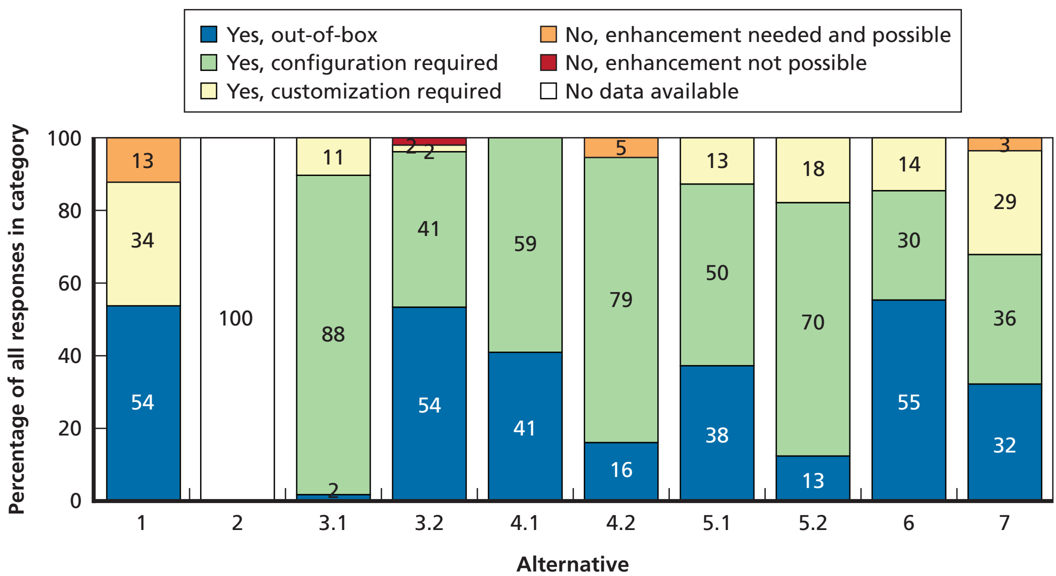
NOTE: Percentage totals may not sum to 100 because of rounding.

Figure 3.5
Capability Responses, by Individual Response



NOTE: Percentage totals may not sum to 100 because of rounding.

Figure 3.6
Capability Responses, by Alternative, Disaggregates, Top Two Performers



NOTE: Percentage totals may not sum to 100 because of rounding.

We also looked at the common requirements across the responses that were reported as customization, enhancement, or no enhancement possible. Table 3.3 presents the requirements that were in at least half of the responses.

Respondents believed that customization and enhancement are likely to be driven by implementation and interoperability unknowns; therefore, it is important for the Navy to try to refine these requirement areas as much as possible moving into the procurement phase.

Finally, we captured level-of-effort estimates from the respondents, as shown in Figure 3.7.

Looking at the results for the top two performers in each alternative, one conclusion is that the COTS alternatives (3, 4, and 5) have fewer requirements that need more effort. Furthermore, Alternative 4.1, which can meet all the requirements out-of-the-box or through configuration, also requires a higher level of effort than other alternatives requiring customization. Although the Navy wants its system to be configurable, optimizing on that objective may come with a higher up-front cost.

Requirements Analysis Summary

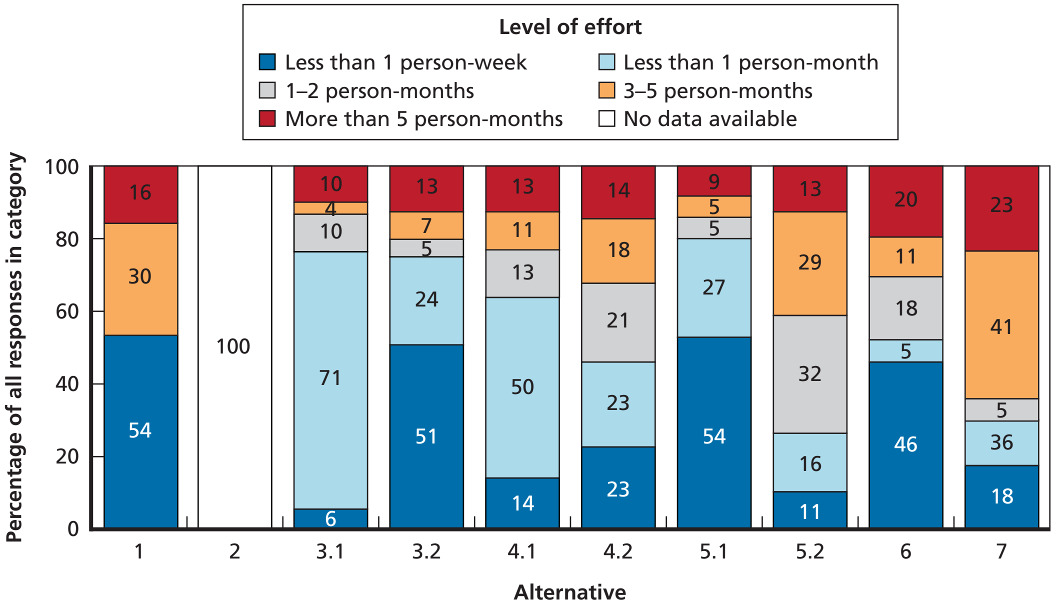
Table 3.4 shows the percentage of high-level requirements that each alternative was able to meet using the definition of out-of-the-box plus configuration.[2]

Table 3.3
Common Challenging Requirements

Requirement Text	Percentage of Top Performers Identifying the Requirement as Challenging
Implementation—Provide data migration services from current NALCOMIS data to NAMS	100
Interoperability—Interfaces to NOSS, Consolidated Automated Support System (CASS), ALE, Automated Skills Management (ASM), flight operations management systems	63
Provide additional analytics to look for premature or unusual failures or malfunctions encountered during equipment operation	50
Provide capability to respond to requests to optimize repair based on cost-benefit analysis functions and feed these data into readiness reporting capability	50
Provide ability to collect and view data both manually and automatically via portable devices and then store information in the system	50
Manage task scheduling, reports, forms, documentation, and notices for all maintenance levels and supply	50

[2] COTS options use an average of the top two software systems within the alternative.

Figure 3.7
Combined Time Estimates, by Alternative



NOTE: Percentage totals may not sum to 100 because of rounding.

Table 3.4
Summary of High-Level Requirements Each Alternative Could Meet

Alternative Name	Percentage of Requirements Fully Met (n = 56)
1. Status Quo—NALCOMIS (No Modernization)	54
2. Status Quo—NALCOMIS New Development	100
3. COTS—Enterprise Systems Active in Defense Aviation	93
4. COTS—Enterprise Asset and Service Management Systems	97
5. COTS—Niche Aviation MRO Systems	85
6. GOTS—ALIS	86
7. Hybrid—COTS and NDMS	68

NOTE: Score is the percentage of requirements met through out-of-the-box capabilities plus configuration using validated, top-performing responses.

Quality Attribute Analysis

As noted earlier in this chapter, quality measures were not fully captured in the high-level requirements, but quality was an important component of other guiding documents. The study guidance, study plan, interviews with stakeholders, and other program documentation revealed several important quality and performance attributes for NAMS, in addition to the functional requirements. We refined the qualities into a more meaningful set of quality attributes. Each alternative was assessed against each attribute to come up with an overall assessment of quality. Table 3.5 describes the quality areas and the set of measures for each evaluated area. It also shows the weight for all measures in the quality area, which is discussed next.

We developed a set of three criteria for each of the 25 measures shown in Table 3.5 and an associated score as follows:

- A zero indicated that the alternative did not meet the measure.
- A 1 indicated that it partially met the measure.
- A 2 meant that the alternative fully satisfied the condition.

Furthermore, each measure was assigned a weight from a total score of 100. The higher the weight, the more important the measure. The maximum weight for an individual measure is 10. Therefore, a perfect score is 200 (a total weight of 100 multiplied by a score of 2 for each measure). The weights were assigned based on our assessment of the relative importance of the individual factors, which was derived from interviews with stakeholders, interactions with stakeholders at the detailed BPR validation sessions, and assessment of the mapping between detailed BPR requirements and high-level BPR requirements.

The results are shown in Table 3.6. COTS Alternative 3 performed the best overall in terms of quality. Alternative 6 scored lower in supportability (software as a service cloud-capable) and usability (graphical business process configuration changes). Alternative 7 uses Alternative 5's quality score because a full demonstration of NDMS was not provided.

Combined Capability Factor Analysis

We created a capability factor to represent the combination of the requirements and quality score. The capability factors, which are discussed next, are shown in Table 3.7. The table combines the results from Tables 3.4 and 3.6 for the first two columns.

The capability factor is a simple weighting of the percentage of requirements fully met and the quality score. In Table 3.7, the capability factor is (percentage of requirements met × 0.75) + (percentage of quality score × 0.25). The weightings were applied in this manner to give the meeting of requirements more weight than the quality.

Table 3.5
Quality Areas and Measures of Capability

Quality Area	Number of Measures	Total Weight	Measures
Supportability	3	19	Thin client vs. thick client; monthly vs. annual releases; lightweight vs. heavyweight updates
Cybersecurity, supportability	3	17	FedRAMP approvals; approach to information assurance vulnerability alerts management; third-party software dependencies
Usability, configurability	2	10	Graphical user interface for configuration changes; user interface for business process changes
Availability	2	9	Disconnected operations and data authoritativeness strategies
Interoperability	2	9	Exemplar interfaces with external supply and analytics systems
Forward compatibility	3	8	Using S2000D standard; ability to replace modules and segregate data layers
Cybersecurity	2	7	Risk management framework authority to operate (ATO) today; DoD cyber penetration testing
Auditability	2	6	Separation of duties and logging; proven government audit readiness
Enterprise capability	1	4	Maximizing automated machine-to-machine interfaces in modular layer
Cybersecurity, enterprise capability	1	3	Number of accreditations
Scalability	1	2	Demonstrated support for more than 1,000 aircraft
Maturity	1	2	Large and diverse customer base
Modifiability	1	2	Will work with vendor in areas of customization to roll into future baselines
Mobility	1	2	Support for mobile maintenance devices (e.g., Navy program manager)
Total	**25**	**100**	

NOTES: Quality areas overlap for certain measures, and, in those instances, both are shown in the quality area description. FedRAMP = Federal Risk and Authorization Management Program.

Table 3.6
Summary of Quality Scores, by Alternative

Alternative Name	Quality Score (%)
1. Status Quo—NALCOMIS No Modernization	30
2. Status Quo—NALCOMIS New Development	70
3. COTS—Enterprise Systems Active in Defense Aviation	75
4. COTS—Enterprise Asset and Service Management Systems	68
5. COTS—Niche Aviation MRO Systems	68
6. GOTS—ALIS	60
7. COTS and NDMS	75

NOTE: The scores use the validated, top-performing responses. Alternative 2 was assessed based on its expectation of capability.

Table 3.7
Summary of Capability Factors, by Alternative

Alternative Name	Percentage of Requirements Fully Met (n = 56)	Quality Score (%)	Capability Factor
1. Status Quo— NALCOMIS No Modernization	54	30	48
2. Status Quo— NALCOMIS New Development	100	70	93
3. COTS—Enterprise Systems Active in Defense Aviation	93	75	89
4. COTS—Enterprise Asset and Service Management Systems	97	68	90
5. COTS—Niche Aviation MRO Systems	85	68	81
6. GOTS—ALIS	86	60	80
7. Hybrid—COTS and NDMS	68	75	70

NOTE: The scores use the validated, top-performing responses. Alternative 2 was assessed based on its expectation of capability.

However, as Figure 3.8 shows, changing the weighting does not change the overall conclusions about the most capable alternatives.

Alternatives 4 and 7 were the most sensitive to changing weights.

Alternative Capability Trade-Space Analysis

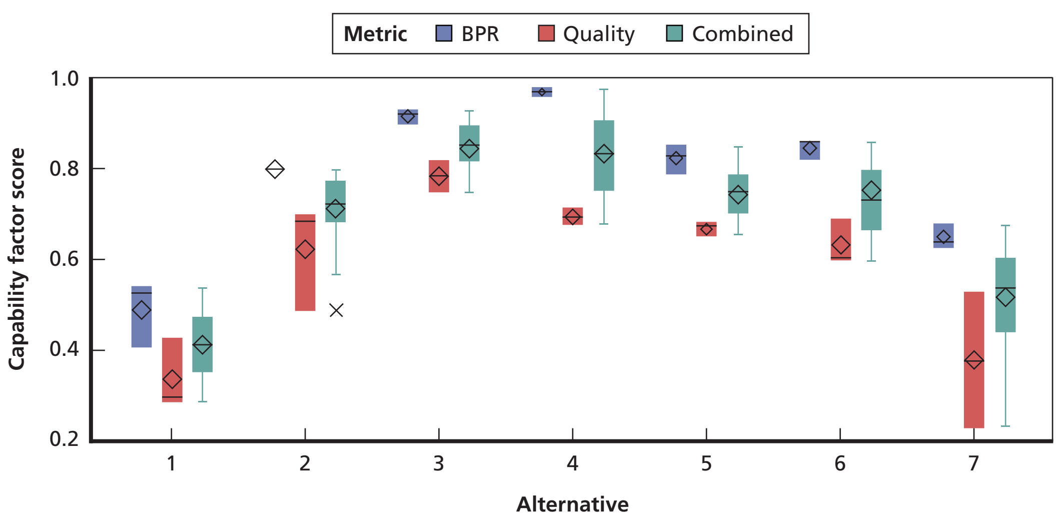
To compare the overall capability of the alternatives, we generated capability factors based on the responses from each of the software providers or integrators within a given alternative. We dichotomized the responses to the capability question into the following groups:

- ability to meet the requirement out of the box or with configuration
- ability to meet the requirement with customization or enhancement or no ability to meet the requirement.

We then calculated the effectiveness factor as the percentage of each requirement for all the respondents within each alternative who could meet the requirements out of the box or with configuration. We also calculated two weighted effectiveness factors using the same method above but weighting each capability response based on

- the Navy's prioritization of the requirements
- an attempt to balance readiness and function.

Figure 3.8
Sensitivity of Capability Factor to Changing Weights, by Alternative



NOTE: This box plot is a depiction of the data and consists of diamonds (mean value); blue, green, and red bars (representing data in the interquartile range [IQR] for BPR, quality, and combined capability factors, respectively); lines bisecting the bars (median value); "whiskers" (representing data outside of the IQR but within 1.5 × IQR); and "X" (representing outliers, defined as data points more than 1.5 × IQR).

Capability factors for each of the seven alternatives are shown in Table 3.8. Alternatives 3 and 4 consistently had the highest effectiveness scores, regardless of the weighting method used. Alternatives 1 and 7 consistently had the lowest effectiveness scores, regardless of the weighting method used.

Figure 3.9 summarizes where each of the alternatives ranked across all possible weights and capability scores. The frequency is the number of times an alternative achieved a particular rank. Alternatives 3 and 4 consistently ranked in the top two.

Summary of Findings from Capability Analyses

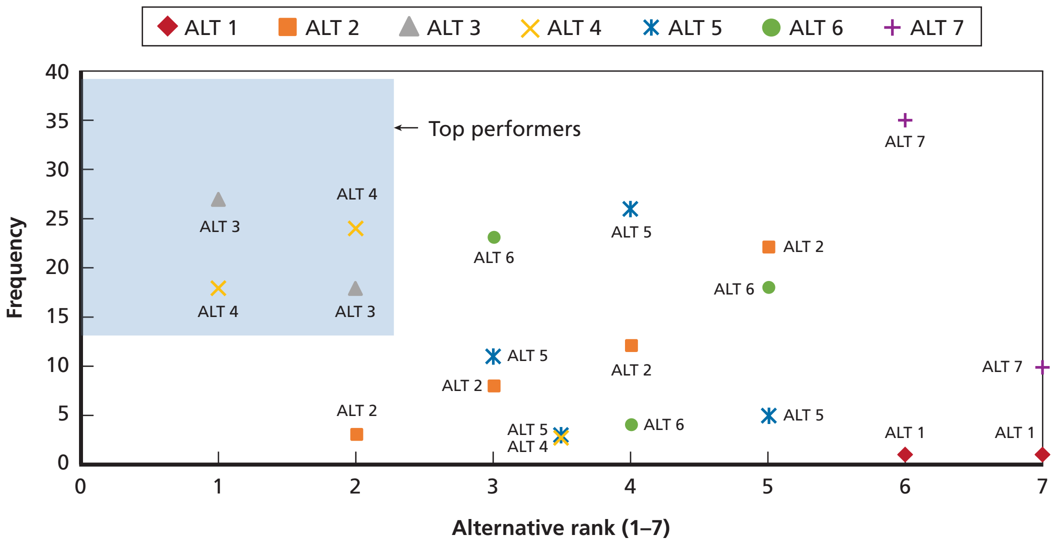
The analysis described in this chapter led us to the following conclusions:

- There is a seismic shift in the level of configurability and quality in nearly all modern alternatives compared with the status quo.
- No solutions meet the NAMS requirements entirely out of the box.
- Configuration may come with a higher up-front level of effort than customization does.
- All alternatives call for some level of customization and enhancement.
- The ability to manage requirements for maintenance was more likely than any other feature to be available out of the box or with configuration, whereas maintenance preparation had the most potential for customization.
- COTS Alternatives 3 and 4 are the most-capable systems, according to the survey responses and follow-up revisions.

Table 3.8
Capability Trade-Space Summary

Alternative Name	Unweighted Effectiveness Factor	Weighted Effectiveness Factor (Navy prioritization)	Weighted Effectiveness Factor (balanced)
1. Status Quo—NALCOMIS No Modernization	0.54	0.53	0.41
2. Status Quo—NALCOMIS New Development	0.80	0.80	0.80
3. COTS—Enterprise Systems Active in Defense Aviation	0.93	0.92	0.90
4. COTS—Enterprise Asset and Service Management Systems	0.97	0.98	0.96
5. COTS—Niche Aviation MRO Systems	0.85	0.83	0.79
6. GOTS—ALIS	0.86	0.86	0.82
7. Hybrid—COTS and NDMS	0.68	0.64	0.63

Figure 3.9
Summary of Alternative Rankings



- Implementation and interoperability unknowns are the top concerns when it comes to possible solutions, and it is likely valuable to clarify requirements in these areas.
- COTS Alternatives 3, 4, and 5 have fewer requirements that need more effort.
- COTS vendors believe their systems are more capable than GOTS systems are, and COTS vendors are more confident about these capabilities.
- COTS vendors believe they require less time to configure or customize their systems to meet a requirement than GOTS vendors do, and COTS vendors are more confident about this belief.
- Vendors that both sell software and perform their own integration believe there is nothing they cannot do through customization.

CHAPTER FOUR

Cost Analysis of the Alternatives

In addition to the capability results—which covered how well the alternatives met the functional requirements and quality attributes—we analyzed how well the alternatives met cost, schedule, and risk requirements.

In this chapter, we present cost analysis results for each alternative (starting with the cost-estimating ground rules and assumptions that underlie that analysis). We discuss the schedule and risk analysis results in subsequent chapters.

Cost-Estimating Ground Rules and Assumptions

This section describes some of the key ground rules and assumptions made by the RAND team in developing the rough-order-of-magnitude (ROM) cost estimates of the alternatives. We note that the resultant cost estimates are of sufficient quality to support acquisition and investment decisions, but they are not budget quality. These cost-estimating ground rules and assumptions are overarching in nature and applicable to all the alternatives estimated, unless otherwise noted.

All costs in the report are presented in base year (BY), or constant year, 2016 dollars. We normalized costs to BY 2016 dollars using the latest inflation indexes published by the Naval Center for Cost Analysis. In instances where labor rates were used, these data were based on SPAWAR 1.6–approved labor rates and PMW 150 spend plan rates.

The work breakdown structure (WBS) used for the estimates is loosely based on the top-down SPAWAR 1.6 cost estimate WBS template (of SPAWAR Global WBS Mod E). We used this template as a guide for identifying general cost elements to consider and as a template for presenting cost estimates. However, our cost estimates had a higher level of granularity than what is in SPAWAR Global WBS Mod E because of the fidelity of available data for the ROM cost estimates.

The life-cycle of the cost estimates was defined as ten years beyond the deployment of all Increment I builds or, alternatively, ten years beyond FOC. FOC has been defined as the deployment of NAMS Increment I to all sites by the end of FY 2024. Therefore, the life-cycle cost (LCC) estimate time frame is FY 2019 through FY 2034.

Additionally, the cost estimates include the costs of a hosting solution properly sized to handle all data requirements and support implementation during the development, production, and deployment phases.

We also assumed in the cost estimates that hardware costs were not included; such costs are assumed to be government-furnished equipment (GFE) from the perspective of the NAMS program of record. That is, hardware is assumed to be provided by the host organization.

In addition to the investment costs for the various alternatives, the sustainment cost estimates of the status quo legacy systems and applications were included until their capabilities had been fully replaced or until FOC was achieved.

As discussed in Chapter Three, each of the alternatives failed to fully meet all the specified requirements. Using that analysis, we estimated additional development costs to fill the capability gaps for each alternative.

ROM Cost Estimates for the Seven Alternatives

In this section, we provide specific ROM cost estimates for each of the seven alternatives discussed earlier. We start with Alternative 1, then discuss phase-out assumptions and methodology for legacy operation and sustainment (O&S) estimates for Alternatives 2–7, and end with the specific ROM cost estimates.

Alternative 1 ROM Cost Estimate

The status quo cost estimate captures the costs of maintaining the legacy systems that would retire under NAMS implementation. Put another way, if NAMS were not implemented, the status quo represents the costs to maintain all legacy systems that provide functionality to meet the NAMS requirements. The costs represent annual steady-state sustainment without any modernization.

NALCOMIS is the only legacy system to be directly replaced by the NAMS program and thus serves as the basis for the status quo estimate. The O&S cost estimates for NALCOMIS were provided by SPAWAR 1.6. The estimate range for O&S projections was based on differing methods of looking at the historical NALCOMIS costs. One method looked at the most recent FY actuals and assumed steady state based on that year alone. The second method looked at the five-year average of actuals from the past five years. These calculations were done separately for OPN and O&MN appropriations. For OPN, the low estimate is based only on FY 2016 data, while the high estimate is based on a five-year average from FYs 2012–2016 data. For O&MN, the opposite is true. The low estimate is based on a five-year average from FYs 2012–2016, and the high estimate is based only on FY 2016 data.

Potentially Subsumed Legacy Systems and Programs

During the analysis of Navy legacy systems that have some amount of functionality in NAMS, several systems were identified as having significant overlap with NAMS requirements. Although the immediate plan is not to retire these programs, these systems could possibly be subsumed by NAMS and therefore offer savings to the Navy at a future date with the implementation of NAMS.

Table 4.1 summarizes the list of systems or programs identified as candidates for possible retirement under the NAMS solution. We collected O&S costs from various sources, including program office requests and historical budget data.

Before turning to the specific cost estimates for Alternatives 2–7, we discuss some phase-out assumptions and methodology that cut across all of them.

Methodology for Legacy O&S Estimates in Alternatives 2–7

Phase-Out Assumptions

For Alternatives 2–7, we assumed that the sustainment costs of the status quo legacy systems and applications will continue until their capabilities have been fully replaced or until FOC is achieved. Beginning in FY 2021, we assumed that these legacy systems would begin to phase out and that their associated costs would likewise begin to decline. Therefore, the legacy cost estimates for the status quo would continue in full from FY 2019 through FY 2020 for Alternatives 2–7. Assuming IOC is met by the first quarter of FY 2021, the legacy systems' sustainment costs would decline as NAMS Increment 1 is installed from FY 2021 through FY 2022 at an assumed 25 percent of the total NAMS afloat and ashore sites. During FY 2022, we assumed that the legacy system annual sustainment costs would decline further to reflect an average of 50 percent of the total sites installed with NAMS Increment 1. During FY 2023 and leading up to FOC by the fourth quarter, we assumed that 75 percent of the NAMS sites

Table 4.1
Legacy Systems Potentially Subsumed by NAMS, with O&S Costs

Legacy (Non-NAMS) Appropriation	Program or System Name	Abbreviation	Annual O&S Cost (BY 2016 $millions)
O&MN	Aircraft Material Supply and Readiness Reporting	AMSRR	3.4
O&MN	Buffer Management Tool	BMT	0.2
O&MN	Virtual Fleet Support Cartridge-Actuated Device/Propellant-Actuated Device	VFS CAD/PAD	3.1
O&MN	All Weapons Information System	AWIS	6.3
Total estimate (FY 2016 $millions)			**13.0**

NOTE: Totals may not sum exactly because of rounding.

would have Increment 1 installed. By FY 2024, legacy systems would not be operating on any NAMS sites.

We calculated the O&S phase-out costs for the legacy system NALCOMIS. The assumption is that these costs would be the same across all alternatives (except the status quo), regardless of the course of action. These costs are not included in the Alternatives 2–7 ROM estimates, as those estimates include only costs that are part of the NAMS acquisition effort in order to best enable comparison of future alternatives with the baseline. However, we used the schedule analysis to inform potential additional NALCOMIS sustainment costs due to schedule delays in fielding NAMS, as summarized in Table 6.5. It is possible the costs could be even higher to NAMS because of schedule delays due to, for example, idling of implementation teams; however, this was not quantified in the study.

Another smaller impact we capture in our cost estimates because of schedule slip scenarios is increased inflation in out-years for implementation costs as a result of these activities shifting to the right.

Software Configuration and Custom Development to Close NAMS Requirement Gaps

To estimate the costs for software configuration and custom development, we used the level-of-effort estimates provided by vendors for those requirements identified as requiring configuration and customization. Vendors provided person-week estimates and binned requirements into "buckets" ranging from less than one person-week to more than five person-months. Vendor estimates were then adjusted to account for estimates that appeared to be underestimated based on follow-up interviews and discussion with selected vendors.

For each vendor's level-of-effort estimate, we summed the person-weeks for requirements involving configuration and customization. A fully burdened annual labor rate of $242,000 (BY 2016 dollars) was then applied to all vendor estimates. This labor rate was based on averages of actual rates across multiple vendors as supplied by SPAWAR 1.6. Where multiple vendors are binned to a single alternative, we used the average of all vendor estimates for that alternative.

The software configuration and customization estimates were phased assuming that 80 percent of development occurs pre-IOC and 20 percent of development occurs between IOC and FOC.

We also included maintenance of custom-developed software in the cost estimates. We calculated maintenance as a percentage of custom development cost based on cost-estimating relationships presented at an International Cost Estimating and Analysis Association training workshop. For ERP software maintenance, the annual staff (full-time equivalents) is approximately 16–43 percent of the ERP software development staff.

Cloud Hosting Fees

To estimate the cost of cloud hosting fees, we used the Amazon Web Services dedicated host pricing website. We assumed that hosting costs would be the same for Alternatives 2–7. Using the Amazon Web Services pricing model, the annual cost estimates ranged from $240,000–451,000 (BY 2016 dollars).

Recurring License Fees

Based on vendor responses and research on industry standards, we applied a factor of 21 percent to cumulative initial COTS software license fees to estimate the cost of annually recurring license fees for all alternatives with COTS license fees.

Risk Adjustment Methodology

We identified four risks that required cost adjustments to account for their mitigation. We calculated an expected cost-risk percentage and applied it to the unadjusted costs to account for the mitigation costs. The scoring, which was conducted by the risk integrated product team (using SME inputs), was used to inform the expected cost calculations. The expected cost percentage calculation takes the following form: expected cost risk % = probability of occurrence × cost impact score %.

Costs were adjusted to account for mitigation of those risks identified by the risk integrated product team as having a high probability of occurrence or a large cost impact. We identified four risks as meeting the high probability of occurrence or high cost impact threshold. These risks are identified in Table 5.5 and are listed below, accompanied by an explanation of where in the estimates the cost effects are accounted for (cost element and fiscal years) and which alternatives are affected:

- **Software must be flexible to incorporate requirement changes because the policy is limited (e.g., Navy Financial Improvement and Audit Readiness [FIAR] changes or new cybersecurity policies that cause unanticipated customization or enhancement).** This risk affects Alternatives 1 and 2 only and is applied to the custom software costs through FOC.
- **Overspecification of requirements (e.g., concept of operations [CONOPS] for expeditionary operations) causes a lack of interest in other transaction authority (OTA) requests for proposals (RFPs) for small vendors, the creation of an infeasible solution, or excessive customization.** This risk affects Alternatives 2–7 and is applied to the custom software costs and implementation costs during the OTA period and continuing through FOC.
- **Business process alignment discussions do not include experienced stakeholders (functional experience with the Navy business process) with decisionmaking authority.** This risk affects Alternatives 4–6 and is applied to the implementation costs through pre-IOC only.
- **Based on historical evidence, an inability to effectively develop a software architecture to satisfy the requirements (and integrate with existing moving**

target solutions) causes schedule delays and cost increases. This risk applies to Alternative 2 in the implementation costs.

Alternative 2 ROM Cost Estimate

Alternative 2 is a variation of the status quo (Alternative 1). It assumes that the legacy system, NALCOMIS, will continue but that new development will close any requirement gaps to meet the NAMS requirements and to modernize the current code to reduce sustainment costs. To estimate the level of effort to close gaps with NAMS requirements, SMEs completed the same questionnaire used by vendors. SMEs used their knowledge of the current NALCOMIS baseline to determine where the gaps exist and how much effort would be required to close these gaps. The costs were then estimated by using these level-of-effort estimates and applying the methodology mentioned in the "Cost-Estimating Ground Rules and Assumptions" section earlier in this chapter.

To estimate the integration effort (including all costs for program management, systems engineering, integration, test and evaluation, and initial training development), we used estimates from the vendor responses for other alternatives and identified a range. We used the lowest cost from Alternatives 4, 5, and 6 for the low end of the range and the highest cost from these alternatives for the high end of the range.

Similar to the method we used for integration, we also estimated site activation by using vendor responses from other alternatives. Alternatives 3, 5, and 6 provided the range of estimates for operational and site activation.

We anticipate O&S cost reductions after IOC while the Navy transitions legacy systems to NAMS through FOC over a ten-year sustainment period. These efficiencies are assumed given the modernized code baseline, with costs reduced by 20 percent when comparing legacy system O&S costs with NAMS budget estimates for O&S.

Finally, as noted in the "Cost-Estimating Ground Rules and Assumptions" section, hardware costs were not included, and hardware was assumed to be GFE from the NAMS program-of-record perspective.

Alternative 3 ROM Cost Estimate

Alternative 3 is a solution based on COTS software providers that specialize in enterprise systems and have experience in defense aviation. The cost estimates are largely based on the RFI responses by several vendors.

The initial procurement of software licenses, the integration and implementation costs, and the operational and site activation costs are based on RFI responses from commercial vendors binned into the *enterprise systems active in defense* category.

Software configuration and custom development were estimated using the methodology referenced in the "Methodology for Legacy O&S Estimates in Alternatives 2–7" section in this chapter.

As noted in the "Cost-Estimating Ground Rules and Assumptions" section in this chapter, hardware costs are not included and are assumed to be GFE from the NAMS program-of-record perspective.

Finally, the costs for recurring license fees and custom-developed software maintenance were estimated based on factors detailed in the "Methodology for Legacy O&S Estimates in Alternatives 2–7" section.

Alternative 4 ROM Cost Estimate

Alternative 4 is a solution based on COTS software providers that specialize in enterprise asset and service management systems. The cost estimates are largely based on the RFI responses by several vendors.

The initial procurement of software licenses and the integration and implementation costs are based on RFI responses from commercial vendors binned into the *enterprise asset and service management systems* category.

Because no vendors that were binned in this category provided operational or site activation estimates, we used Alternatives 3, 5, and 6 to provide a range of estimates for operational and site activation.

We estimated software configuration and custom development using the methodology described in the "Methodology for Legacy O&S Estimates in Alternatives 2–7" section.

As noted in the "Cost-Estimating Ground Rules and Assumptions" section, we did not include hardware costs, and hardware was assumed to be GFE from the perspective of the NAMS program of record.

Finally, the costs for recurring license fees and custom-developed software maintenance were estimated based on factors detailed in the "Methodology for Legacy O&S Estimates in Alternatives 2–7" section.

Alternative 5 ROM Cost Estimate

Alternative 5 is a solution based on COTS software providers with niche aviation MRO solutions. The cost estimates are largely based on the RFI responses by several vendors.

The initial procurement of software licenses, the integration and implementation costs, and the operational and site activation costs are based on RFI responses from commercial vendors binned into the *niche aviation MRO solutions* category.

Software configuration and custom development were estimated using the methodology referenced in the "Methodology for Legacy O&S Estimates in Alternatives 2–7" section.

As noted in the "Cost-Estimating Ground Rules and Assumptions" section, hardware costs were not included, and hardware was assumed to be GFE from the perspective of the NAMS program of record.

Finally, the costs for recurring license fees and custom-developed software maintenance were estimated based on factors detailed in the "Methodology for Legacy O&S Estimates in Alternatives 2–7" section.

Alternative 6 ROM Cost Estimate

Alternative 6 is a solution based on COTS software that is GFE. Despite the main MRO application being GFE, there are some COTS software requirements for third-party COTS software. Although some of these licenses may be captured under existing enterprise license agreements (ELAs), we included costs for these ELAs because once these agreements are renegotiated at a future date, the ELA costs are likely to increase, given the increase in the user base. The cost estimates are largely based on RFI responses by several vendors.

The initial procurement of third-party software licenses, the integration and implementation costs, and the operational and site activation costs are based on RFI responses from commercial vendors binned into the *COTS/GFE license* category.

Software configuration and custom development were estimated using the methodology referenced in the "Methodology for Legacy O&S Estimates in Alternatives 2–7" section.

As noted in the "Cost-Estimating Ground Rules and Assumptions" section, we did not include hardware costs, and hardware was assumed to be GFE from the perspective of the NAMS program of record.

Finally, the costs for recurring license fees and custom-developed software maintenance were estimated based on factors detailed in the "Methodology for Legacy O&S Estimates in Alternatives 2–7" section.

Alternative 7 ROM Cost Estimate

Alternative 7 is a solution that leverages the NAVAIR NDMS to manage I-level maintenance while relying on a COTS software product to manage O-level maintenance. The estimate assumes that a niche aviation MRO COTS software provider (see Alternative 5) would provide the O-level maintenance management. The cost estimates are largely based on the RFI responses by several vendors.

The initial procurement of software licenses, the integration and implementation costs, and the operational and site activation costs are based on RFI responses from commercial vendors binned into the *niche aviation MRO solutions* category. The quantity of software licenses was scaled down to account for the number of O-level users. Using historical data, we estimated the share of O-level users at 47 percent of total maintenance users.

Software configuration and custom development were estimated using the methodology referenced in the "Methodology for Legacy O&S Estimates in Alternatives 2–7" section.

As noted in the "Cost-Estimating Ground Rules and Assumptions" section, hardware costs are not included, and hardware was assumed to be GFE from the perspective of the NAMS program of record.

The costs for recurring license fees and custom-developed software maintenance were estimated based on factors detailed in the "Methodology for Legacy O&S Estimates in Alternatives 2–7" section. SMEs from the NDMS program office estimated that NDMS maintenance costs would likely double to account for the additional user base. Therefore, historical NDMS maintenance costs are included in the cost estimate to account for the additional maintenance to the NDMS baseline.

Cost Summaries

This section details risk-adjusted and unadjusted cost summaries.

Risk-Adjusted Cost Summary

Table 4.2 is a summary of the risk-adjusted cost estimates for all the alternatives. The first two cost columns present a low and high estimate for total LCC, including both NAMS costs and legacy system costs as they phase out. The rightmost two cost columns present a low and high estimate for NAMS-related costs only over the Program Objective Memorandum–19 Future Years Defense Program (FYDP).

Table 4.2
Risk-Adjusted Cost Summary, by Alternative (Relative Values; $millions)

	Total LCC FYs 2019–2034		NAMS FYDP Total FYs 2019–2023	
Alternative	**Low**	**High**	**Low**	**High**
1. Status Quo—NALCOMIS No Modernization	—	—	—	—
2. Status Quo—NALCOMIS New Development	41	169	26	118
3. COTS—Enterprise Systems Active in Defense Aviation	–53	66	–20	47
4. COTS—Enterprise Asset and Service Management Systems	–138	110	–28	76
5. COTS—Niche Aviation MRO Solutions	–91	117	–26	75
6. GOTS—ALIS	–124	—	–39	18
7. Hybrid—GOTS and NDMS	162	311	55	137

NOTE: All costs are in BY 2016 dollars.

Alternatives 4 and 6 had the lowest low-end risk-adjusted cost. Alternatives 1 and 6 had the lowest high-end adjusted cost.

Unadjusted Cost Summary

Table 4.3 presents the estimated costs for all alternatives prior to adjustments for risk. Again, the first two cost columns present a low and high estimate for total LCC, including both NAMS costs and legacy system costs as they phase out. The two rightmost cost columns present a low and high estimate for NAMS-related costs only over the Program Objective Memorandum–19 FYDP.

Alternative 4 has the lowest low-end LCC estimate and Alternatives 1 and 6 have the lowest high-end LCC estimate.

Cost Comparison, by Cost Element

Exploring alternative costs at the cost element level reveals interesting comparisons. Although Alternatives 4 and 6 have comparatively higher integration costs, their license fees are generally lower, thus lowering their LCCs. Alternative 6 assumes no top-level license cost because the F-35 program has already paid for it; however, we included costs for Oracle ELA and additives from dependent Microsoft licenses. Government program costs are between 23 percent and 34 percent of LCC, depending on the alter-

Table 4.3
Unadjusted Cost Summary, by Alternative (Relative Values; $millions)

	Total LCC FYs 2019–2034		NAMS FYDP Total FYs 2019–2023	
Alternative	**Low**	**High**	**Low**	**High**
1. Status Quo—NALCOMIS No Modernization	—	—	—	—
2. Status Quo—NALCOMIS New Development	75	188	55	134
3. COTS—Enterprise Systems Active in Defense Aviation	–19	88	8	66
4. COTS—Enterprise Asset and Service Management Systems	–113	117	–8	82
5. COTS—Niche Aviation MRO Solutions	–62	128	–2	83
6. GOTS—ALIS	–98	5	–18	22
7. Hybrid—COTS and NDMS	192	324	81	152

NOTE: All costs are in BY 2016 dollars.

native.[1] Alternatives 3 and 5 operate in the defense and aviation markets, meaning the market for their systems is smaller (relative to Alternative 4); therefore, they can or must offer a premium. Table 4.13 shows the high-end estimates.

Alternative 6 site activation and recurring software license fee estimates are significantly lower than they are in the other alternatives because the Navy has already paid for some of the capability under the F-35 program. Alternative 4's recurring license fees are the largest dollar-value change from the low estimate; similarly, Alternative 5 increased from the low estimate, and the recurring software license fees increased on average. The next-largest areas of uncertainty were integration and site activation, which increased from their low estimates. The high-end cost estimates for Alternatives 2–5 were higher than Alternative 1 costs. In general, we can conclude that savings in license costs (procurement and recurring maintenance) outweigh higher integration and implementation costs.

Relative Cost of the Program to the Systems It Supports

The F/A-18 is useful for comparison because it is the most common aircraft type in naval aviation. As noted in Chapter One, in the 2018 Consolidated Appropriations Act, Congress provided $739 million for ten new F-18 Super Hornets (U.S. Senate Appropriations Committee, 2018). Part of the reason for the procurement was to address a shortfall in available aircraft (Office of the Under Secretary of Defense [Comptroller]/Chief Financial Officer, 2017). The F/A-18 has a flyaway cost of approximately $73 million and a sustainment cost of $63 million to $94 million, for a total LCC of $136 million to $167 million.[2] Using the average risk-adjusted LCC across all seven alternatives, the cost of NAMS is roughly 2.3–2.8 life-cycle F/A-18Fs. Considering the Navy alone operates more than 500 F/A-18 Super Hornets, the cost of operating NAMS for 16 years is a very small percentage of the cost of buying and sustaining the Super Hornet fleet.[3] Furthermore, NAMS will support another 2,100 aircraft of varying types, models, and series across the Navy and Marine Corps, so the relative cost of the NAMS LCC compared with procurement and sustainment of the 2,700 aircraft fleet is negligible.[4]

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[1] Government program management includes financial and logistics management, installation planning and turnover, fleet engineering support, help desk, maintenance engineering support, life-cycle test support, general management, command O&S, acquisition and contracts, corporate strategy, and Navy Marine Corps Intranet seat costs. It is assumed in Alternative 7 that government program management costs are already included.

[2] Sustainment cost assumes a $10,500 per hour cost and 6,000–9,000 lifetime hours (McCarthy, 2016).

[3] The estimate uses a conservative $50 million flyaway cost and $70 million sustainment cost for 531 Super Hornets, totaling $63.7 billion.

[4] The 2,700 aircraft are calculated using a total of 3,700 Navy aircraft and subtracting 50 F-35s (supported under ALIS), 711 aircraft to be replaced by the F-35, and 331 trainer aircraft under contractor logistic support, rounded to the nearest whole aircraft. Given the relative cost of procuring and sustaining the 2,700 aircraft that this system will support, cost is less important as a relative metric.

Summary of Key Cost Analysis Findings

The analysis described in this chapter led us to the following conclusions:

- The cost of NAMS relative to the cost of procuring and sustaining 2,700 aircraft is negligible.
- Alternatives 4 and 6 have the lowest average risk-adjusted cost.
- The Navy can save money on NAMS with COTS if it can keep recurring license fees in check.
- Without keeping recurring license fees in check, it is unlikely that there would be any cost savings compared with the status quo.
- Alternative 6 presents a potential cost savings of $4 million per year, against the average cost of all COTS.
- Savings in license costs (procurement and recurring maintenance) outweigh higher integration and implementation costs.
- Alternatives 3 and 5 have higher overall license costs, likely because of the markets they operate in.
- High-end estimates reflect high recurring license costs and significant uncertainty in integration and site activation; as a result, Alternative 1 has the lowest high-end estimate.
- Government program management cost is 23–34 percent of the low-end LCC and 15–22 percent of the high-end LCC.

CHAPTER FIVE

Risk Analysis of the Alternatives

In addition to analyzing the capabilities of the alternatives, we also conducted an analysis of key risks to inform the cost and schedule analysis for the NAMS acquisition. We applied a group-based method consistent with DoD's guidance in the *Risk, Issue, and Opportunity Management Guide for Defense Acquisition Programs* (Office of the Deputy Assistant Secretary of Defense for Systems Engineering, 2017). We identified risks and iteratively evaluated their potential impact on the standard AoA metrics of cost, schedule, and operational performance. For this study, the method was informed by current practices for improving risk evaluation and relied on a small team of mixed-experience evaluators.

In this chapter, we first discuss the risk analysis approach we took and then the results of that approach.

Risk Analysis Approach

Human judgment is a typical aspect of risk analysis (Slovic, Fischhoff, and Lichtenstein, 1979; Rasmussen, 1981). Fischhoff describes *risk communication* as "an analytical-deliberative process in which analysts and decision-makers collaborate in managing risks" (Fischhoff, 2015, p. 527). During the analysis phase, identified risks are estimated. The assessment phase follows and constitutes the evaluation step. Previous work in risk analysis also shows that the assessment of experts over that of nonexperts tracks well in some areas but that experts and nonexperts are equally inaccurate as soon as uncertainty about context is introduced. However, uncertainty with respect to the real-world performance of a new system is inherent to most decisionmaking processes, and the reliability of expert opinions can be the same as that of nonexperts.

Multiple techniques implicitly identify and evaluate risk in the methods employed. Group-based techniques are often used as a way to identify and evaluate risk because they allow for many participants and strive to achieve consensus. Group-based analytical strategies that incorporate a mix of participant experiences and iterations with shared feedback can also converge toward an accurate assessment in the presence of incomplete information (Dalal et al., 2011). The interactive quality of these methods improves the group's assessment of critical factors by refining perceptions and, thereby, the interpretation of key factors that define decision points. Expert views are challenged by unassuming questions from nonexperts, and experts can verify their thought process by the degree to which they are able to inform or influence a nonexpert to consider their view as being valid. A structured approach to risk identification combined with a deliberative analysis phase involving open but guided group discussions has been shown to refine uncertainty ranges, improving the value of analysis results for decisionmakers, which also corresponds to methods of utility theory (Gregory and Keeney, 2017).

We have taken a standards-inspired approach to risk analysis for the NAMS AoA. The approach is consistent with the risk, issue, opportunity (RIO) guidance (Office of the Deputy Assistant Secretary of Defense for Systems Engineering, 2017) but also provides a structured way to develop the initial phase of the risk investigation. It is also supported by decisionmaking theory, enables quantification techniques, and is practical to implement.

Key aspects of the RIO guidance on major areas for managing risk in acquisitions are highlighted in Table 5.1.

The risk identification step is an essential, nuanced task that takes place before analysis. For the NAMS study, the goal for this step was to identify, standardize, and organize risk factors within a hierarchical structure to achieve or enable several goals that ultimately

Table 5.1
Key RIO Guidance Areas

Area of Risk Analysis	DoD RIO Guidance
Risk identification	• Primary assessment areas—performance, cost, and schedule • Clearly interpretable requirements • Open and collaborative communication involving all parties
Risk scoring and quantification	• Intended to enable decisionmaking and inform planning • Specify acceptable versus nonacceptable risks and identify risks that may require exception
Risk mitigation strategy	• Pre-materiel development, including experimentation and prototyping • Inclusive process involving stakeholders that promotes continuous, open input for concerns and issues at all levels • Development of detail mitigation plans
Framing assumptions	• Clear understanding of assumptions surrounding requirements achievability, schedule dependencies, procurement quantities, and threats
Contractor processes	• Selection of an appropriate contract type (e.g., cost type or fixed-price) • Understanding of roles and responsibilities for a given contractor

SOURCE: Office of the Deputy Assistant Secretary of Defense for Systems Engineering, 2017.

- capture detailed risk elements while allowing for variation in the character of systems proposed by vendors
- may be applied to differentiate equivalent risk ratings, with insight into motivating reasons
- allow stakeholders to independently but coherently value risk profiles for solutions against a common, baseline structure for informed decisionmaking
- allow stakeholder evaluations to use a consistent approach across multiple evaluations
- support the same set of metrics for input from a variety of sources and assessments at various times
- reflect risk perspectives, priorities, or importance for a category of risks among stakeholders.

Risk Scoring and Quantification

As motivated by DoD's RIO guidance, the essential goals for a risk evaluation are as follows:

- enable decisionmaking to inform planning while accommodating intrinsic limitations in available knowledge about solutions
- promote an understanding of acceptable risks, nonacceptable risks, and exceptions
- provide a basis to inform risk-mitigation strategies.

For the NAMS AoA, we used a three-round process to quantitatively evaluate risk likelihoods and impact on cost, schedule, and performance. The approach leveraged a group-based decision methodology for accommodating diversity in industry or domain experience, uncertainty of knowledge about a candidate solution, and a range of stakeholder perspectives.

An initial round established and introduced a structured list of risk factors for the risk areas shown in Table 5.1 based on information available to the study team. The identified risk factors were then introduced to the group to capture individual, quantitative estimates of the risk values for the set of candidate alternatives. We also provided a mechanism to comment on individual factors, convey additional remarks for discussion, and offer general guidance on interpreting the risk factors and scoring the corresponding risks. Participants were asked to score risks for consequence based on a set identified as "high-impact" risk candidates. This was followed by an intermediate round delivering feedback to participants on the current estimates for scores, along with discussions in which participants shared the reasoning behind their choices. Discussions during this round were focused on risks for alternatives in which there was significant variance in consequence scores for cost, schedule, and operational performance. A final round allowed stakeholders to reestimate the scores based on information gained from the preceding steps and through discussion.

These steps correspond to research applied by the ExpertLens methodology developed at RAND, which generalizes and extends other group-based decision methodologies, such as Delphi and Nominal Group Theory (Dalal et al., 2011). ExpertLens is a distributed group decision support system that builds on numerous decisionmaking methods and relies on a Bayesian approach and interpretation for probability.

The method aligns with the following needs of the NAMS AoA risk analysis effort to achieve results:

- accommodates limited knowledge about a proposed system's ability to achieve required goals
- promotes diversity in relevant experience
- supports a "large enough," non-collocated group of participants (who sufficiently span domains of required expertise and opinions)
- applies simple statistics to achieve consistent results (e.g., median, mean, variance)
- requires a low level of interaction
- uses a structured, iterative procedure to identify contrasting and converging views.

A pair of key observations stemming from ExpertLens research is that "diversity trumps ability and expertise" and that nonexperts improve the accuracy of group-sourced results. Furthermore, group sizes in five ExpertLens trials covering various topic domains ranged from four to 415, with sizes mostly in a range of ten to the low to mid-40s, thus representing a diverse range for applicability of the method. Although the full platform supports data collection online and uses tools to support collection and analysis for large groups of participants, we did not use these features in this study.

Key Risk Areas and Risks

We identified individual risks after initially organizing risks for acquisitions into several major categories. These categories are listed in Table 5.2, with descriptive examples for subareas or representative "high-level" risk factors defined within key risk areas. These key areas for risk were subsequently associated with one or more causal attributes to identify programmatic-, technical-, cost-, and schedule-type risks.

The individual risks were informed by a variety of sources, including high-level BPR requirements for NAMS, NAMS RFI responses, follow-up meetings with selected vendors, reviews of industry-based standards about technology risks,[1] and NAMS team discussions in conjunction with background information available to the study team.

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[1] For example, Open Group (2013) incorporates a factor analysis of an information risk approach to developing a risk taxonomy; Hillson (2002) proposes that a risk breakdown structure be codeveloped with a WBS and used for risk assessment; de Sá-Soares, Soares, and Arnaud (2014) develops a catalog of information outsourcing risks; and Ackerman et al. (2011) proposes a taxonomy for technological IT outsourcing risk.

Table 5.2
Key Risk Areas

Key Risk Area	Subareas or Representative "High-Level" Risk Factors
Compliance	• Security • Financial auditing • Hazardous materials tracking
Compatibility	• Forward and backward compatibility and near-term interoperability • Multi-modal communication (e.g., synchronous and asynchronous) • Standards-oriented interfaces and data structures
Deployment and testing	• Multiplatform, multisystem coordination • Operational scalability for realistic peak loads • Disconnected operations
Maturity	• Technical capabilities suitable for intended NAMS large-scale deployment • Vendor experience • Capacity for multivendor coordination
Functional requirements	• High level of detailed capability • Highly flexible functionality for diverse operational needs
Nonfunctional requirements	• Open, modular, and consistent system design • System design supports diverse present and future capabilities • Usability in a multisystem operating environment • Robust options for continuity of operations

Table 5.3 summarizes the risks considered to have the highest impact on cost, schedule, or operational performance.

Risk Analysis Results

Assessing Likelihood and Consequence

The objective of the risk assessment portion of the NAMS AoA was as follows:

- Inform the analysis of inherent factors that affect the delivery of a potential solution for a NAMS system.
- Inform the analysis of factors that influence project cost and schedule, detailing key interrelationships as possible.
- Enable decisions based on a cohesive methodology and structure applied to risk determination and related discussions.

As part of the overall scoring methodology, respondents were asked to consider three levels of risk (high, moderate, low), based on the descriptions shown in Table 5.4, and to enter consequence scores on a three-point scale when considering cost, schedule,

Table 5.3
High-Risk Elements: Categories and Descriptions

Risk	Category
There is an inability to agree to or standardize a forward-compatible interface between NOSS and NAMS.	Compatibility
NAMS is not sufficiently backward compatible with NALCOMIS. During rollout, an aircraft belonging to a squadron that has been migrated to NAMS gets reassigned to a squadron not running NAMS, causing data gaps, data duplication, and an inability to maintain the aircraft.	Compatibility
The quality of historical maintenance data is poor, requiring an excessive effort to extract, transform, and load (ETL) for use in the new system.	Deployment and testing
The as-maintained aircraft configurations (e.g., serial numbers) are inaccurate, and an extensive data validation effort is required.	Deployment and testing
The scope of the OTA in terms of the number of types, models, and series is too large and would cause the OTA to have significant schedule delays.	Deployment and testing
Proprietary components are incorporated in a way that creates vendor lock-in, a costly change down the road, or an inability to move to another provider.	Compatibility
There are unclear interface definitions or lack of specificity about the quantity and complexity of interfaces necessary for NAMS to operate for an OTA relative to IOC, causing schedule delay when it is finally determined that additional interface work is necessary.	Deployment and testing
A structured plan for data migration efforts is not available to detail the roles and responsibilities of the Navy and systems integrator, or the approach (method and tools) for selecting, cleaning, transforming or mapping, or ingesting data or for resolving data issues leads to significant delays, unexpected tool development, and data quality issues in NAMS.	Deployment and testing
Business process alignment discussions do not include experienced stakeholders (who have functional experience with the Navy business process) with decisionmaking authority.	Deployment and testing
There is a lack of availability of Navy personnel to support the integration or implementation, especially for the OTA prototypes.	Deployment and testing
There is a lack of specificity in requirements, or overanalysis (e.g., CONOPS for expeditionary operations) causes schedule delays during which a systems integrator needs to refine requirements.	Functional, deployment and testing
An overspecification of requirements (e.g., CONOPS for expeditionary operations) causes lack of interest in OTA RFPs for small vendors, creates an infeasible solution, or requires excessive customization.	Deployment and testing
Ship availability is limited.	Deployment and testing

Table 5.3—Continued

Risk	Category
Security-related access controls must be lowered during deployment because of the poor quality of test environments, resulting in ATO delays.	Compliance
A significant rework of the software base is required, stemming from an underdeveloped cybersecurity risk management plan and resulting in unforeseen, ATO-driven challenges or delays.	Compliance
The solution has not been sufficiently proven on a full Consolidated Afloat Networks and Enterprise (CANES) stack.	Compatibility
The flexibility of the software to incorporate requirement changes because of policy is limited (e.g., FIAR changes or new cybersecurity policies cause unanticipated customization or enhancement).	Compliance, functional, nonfunctional
The Navy must spend significant time each release to test and migrate customizations.	Deployment and testing
Based on historical evidence, an inability to effectively implement agile software development methods and to establish traceability from development to testing causes delays in program fielding and increases cost.	Development
Based on historical evidence, an inability to effectively develop a software architecture to satisfy the requirements (and integrate with existing moving target solutions) causes schedule delays and cost increases.	Development
A perceived shortcoming during prior implementations leads to risk of nonacceptance.	Deployment

Table 5.4
Risk Scoring for Probability and Impact

Risk Area	Score	Risk Level	Description
Operational performance	3	High	"Showstopper"—system unavailable or NAMS functions so poorly that aircraft likely cannot be maintained sufficiently to meet mission capability or be ready for tasking demands
	2	Moderate	System is partially available, but unclear whether it is doing enough to meet some or all mission capability or is ready for tasking demands
	1	Low	System is available and likely can still meet mission capability and ready for tasking demands
Cost	3	High	Greater than 50% increase over planned procurement or sustainment cost
	2	Moderate	15–50% increase over planned procurement or sustainment cost
	1	Low	Less than 15% increase over planned procurement or sustainment cost
Schedule	3	High	Greater than 24-month delay
	2	Moderate	6- to 24-month delay
	1	Low	Less than 6-month delay

and operational performance.[2] The likelihood or probability of the risk to occur (i.e., to manifest as an issue) was also scored as a percentage from 0 to 100.

High-impact risks are defined as having a likelihood of occurrence greater than or equal to 50 percent and a consequence score greater than or equal to 2.5. The results for high risks to cost, schedule, and operational performance are shown in Tables 5.5, 5.6, and 5.7, respectively.

Table 5.5 shows that high operational performance risks are distinguished by an emphasis on interoperability, backward-compatibility, and the establishment of a robust data migration plan. Similarly, Table 5.6 shows that high risks to schedule are represented by data quality issues, the availability of Navy ships for NAMS deployment and testing, implementation of functional requirements, and an ability to develop the required software architecture or implement agile software methods. Table 5.7 shows the risks to operational performance, specifically backward compatibility with NALCOMIS.

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[2] We selected a three-point scale to maintain the simplicity of the scoring process within the time frame available for the study. An expanded scale would require additional definitions and may be considered for future studies.

Table 5.5
High Risks to Costs

Risk	Alternatives Affected	Average Probability (%)	Average Cost Impact (scale of 1–3)
The flexibility of the software to incorporate requirement changes because of policy is limited (e.g., FIAR changes or new cybersecurity policies cause unanticipated customization or enhancement).	1	97	3
	2	50	2.5
An overspecification of requirements (e.g., CONOPS for expeditionary operations) causes lack of interest in OTA RFPs for small vendors, creates an infeasible solution, or requires excessive customization.	2	65	2.5
	3	55	3
	4	60	3
	5	60	3
	6	50	3
	7	65	3
Business process alignment discussions do not include experienced stakeholders (who have functional experience with the Navy business process) with decisionmaking authority.	4	50	2.5
	5	50	2.5
	6	63	2.5
Based on historical evidence, an inability to effectively develop a software architecture to satisfy the requirements (and integrate with existing moving target solutions) causes schedule delays and cost increases.	2	60	3

Across alternatives, we also examined the number of risks by impact type and area of consequence to assess the general posture for risk for each NAMS alternative. Because each NAMS alternative represents a unique approach for NAMS, each can be exposed to a different risk profile. This trend is observable in the results, where some risks significantly affect a few alternatives while other risks have a broader range of impact across many alternatives. For example, the risk for the flexibility of the software to incorporate requirement changes is high for NAMS Alternative 1 across the metrics for cost, schedule, and performance. The risk for overspecification of requirements affects NAMS Alternatives 2–7 with respect to cost because it pertains to use of the OTA, which is applicable with varying probability across the group. It occurs again as a high-impact schedule risk but only for NAMS Alternatives 2 and 7.

Roll-Up of Number of Risks, by Alternative

Table 5.8 shows the number of risks with a high impact, by alternative, in each of the areas of cost, schedule, and operational performance. High-impact risks were identified as those with average consequence scores greater than or equal to 2.5 and an aver-

Table 5.6
High Risks to Schedule

Risk	Alternatives Affected	Average Probability (%)	Average Schedule Impact (scale of 1–3)
The flexibility of the software to incorporate requirement changes because of policy is limited (e.g., FIAR changes or new cybersecurity policies cause unanticipated customization or enhancement).	1	97	2.7
The as-maintained aircraft configurations (e.g., serial numbers) are inaccurate, and an extensive data validation effort is required.	3	50	2.5
	4	54	2.5
The Navy must spend significant time each release to test and migrate customizations.	1	95	2.7
An overspecification of requirements (e.g., CONOPS for expeditionary operations) causes lack of interest in OTA RFPs for small vendors, creates an infeasible solution, or requires excessive customization.	2	65	2.5
	7	65	3
Ship availability is limited.	2	85	2.5
	3	77	2.7
	4	77	2.7
	5	77	2.7
	6	77	2.7
	7	85	3
Based on historical evidence, an inability to effectively develop a software architecture to satisfy the requirements (and integrate with existing moving target solutions) causes schedule delays and cost increases.	2	60	3

age probability of 50 percent or greater. Medium-impact risks are shown (in addition to high-impact risks) in Table 5.9 to provide a broader view of each alternative's overall relative position. Medium-impact risks are defined as having an average consequence score greater than or equal to 2 and an average probability of greater than or equal to 25 percent.

With this characterization of risk posture, Table 5.8 shows that none of the alternatives has fewer than four risks with high-impact scores. By expanding the scores to include risks with medium impact, a more complete view of the risk portion of the decision space is visible. In Table 5.9, Alternative 1 has the lowest total number of medium- and high-impact risks. However, as the previous analysis has shown, Alternative 1's risks are highly likely and highly consequential.

Table 5.7
High Risks to Operational Performance

Risk	Alternatives Affected	Average Probability (%)	Average Operational Impact (scale of 1-3)
The flexibility of the software to incorporate requirement changes because of policy is limited (e.g., FIAR changes or new cybersecurity policies cause unanticipated customization or enhancement).	1	97	3
NAMS is not sufficiently backward compatible with NALCOMIS. During rollout, an aircraft belonging to a squadron that has been migrated to NAMS gets reassigned to a squadron not running NAMS, causing data gaps, data duplication, and an inability to maintain the aircraft.	3	50	2.6
	4	50	2.6
	5	56	2.6
	6	56	2.6
	7	50	2.5
There is an inability to agree to or standardize a forward compatible interface between NOSS and NAMS.	1	83	2.8
A structured plan for data migration efforts is not available to detail the roles and responsibilities of the Navy and systems integrator, or the approach (method and tools) for selecting, cleaning, transforming or mapping, or ingesting data or for resolving data issues leads to significant delays, unexpected tool development, and data quality issues in NAMS.	6	50	2.7

One medium-impact risk that is worth mentioning is for unclear interface definitions or a lack of specificity about the quantity and complexity of interfaces necessary for NAMS to operate for an OTA relative to IOC, causing schedule delay when it is finally determined that additional interface work is necessary. We had difficulty identifying the readiness of many of the systems to be interfaced into NAMS or even whether it was necessary for IOC.

Summary of Key Risk Analysis Findings

To understand the relative risk posture among the seven identified NAMS alternatives, we did a roll-up across risk factors and areas of cost, schedule, and operational performance. Risk likelihoods were first multiplied with each consequence score and

Table 5.8
Number of High-Impact Risks, by Alternative

Alternative	Cost	Schedule	Operational Performance	Total
1. Status Quo—NALCOMIS No Modernization	1	2	2	5
2. Status Quo—NALCOMIS New Development	3	4	0	7
3. COTS—Enterprise Systems Active in Defense Aviation	1	2	1	4
4. COTS—Enterprise Asset and Service Management Systems	2	2	1	5
5. COTS—Niche Aviation MRO Systems	2	1	1	4
6. GOTS—ALIS	2	1	2	5
7. Hybrid—COTS and NDMS	1	2	1	4

Table 5.9
Number of Medium- and High-Impact Risks, by Alternative

Alternative	Cost	Schedule	Operational Performance	Total
1. Status Quo—NALCOMIS No Modernization	3	4	2	9
2. Status Quo—NALCOMIS New Development	12	16	7	35
3. COTS—Enterprise Systems Active in Defense Aviation	9	13	5	27
4. COTS—Enterprise Asset and Service Management Systems	9	13	5	27
5. COTS—Niche Aviation MRO Systems	10	14	5	29
6. GOTS—ALIS	9	13	4	26
7. Hybrid—COTS and NDMS	11	16	5	32

summed for each alternative, followed by a calculation for the mean and standard deviation of totals across alternatives.[3]

The stoplight color coding in Table 5.10 characterizes the risk assessment through two lenses, one focused solely on high risks and the other on high and medium risks. High-risk designations are shown in red; medium, in yellow; and low, in green. NAMS alternatives that have risk roll-ups below half of a standard deviation from the average are colored in green, those above half of a standard deviation from the average are colored in red, and those within half of a standard deviation of the average are colored in yellow.

As mentioned, Alternative 1 has fewer risks than other alternatives, but the high-impact risks are highly likely and highly consequential. In contrast, NAMS Alternatives 2 through 7 collectively have a reduced risk posture. Even though there are more risks, they are moderately likely and of moderate consequence. Although interdependencies among risks were not captured in this study, their cumulative effects are suggested.

The analysis described in this chapter led us to the following conclusions:

- COTS Alternatives 3 and 5 have the lowest overall exposure to high risks.
- Alternative 1 has few risks, but they are highly consequential.
- Alternatives 2–7 have many risks, but they are of moderate likelihood and consequence.

Table 5.10
Exposure to Risks, by Alternative

Alternative	Exposure to High-Scoring Risks	Exposure to High- and Moderate-Scoring Risks
1. Status Quo—NALCOMIS No Modernization	High	Low
2. Status Quo—NALCOMIS New Development	High	Moderate
3. COTS—Enterprise Systems Active in Defense Aviation	Low	Low
4. COTS—Enterprise Asset and Service Management Systems	Moderate	High
5. COTS—Niche Aviation MRO Systems	Low	Moderate
6. GOTS—ALIS	Moderate	Low
7. Hybrid—COTS and NDMS	Moderate	High

[3] Stakeholder priorities based on risk categories can be accommodated directly by introducing an additional weighting factor for each risk using the hierarchical structure developed, but these results do not include additional scoring factors or weights.

- The biggest risk to operations is that NAMS is insufficiently backward compatible with NALCOMIS.
- The biggest risks to cost are overspecification of requirements, infeasible solutions, excessive configuration or customization requirements, and a lack of authority to authorize business process changes.
- The biggest risks to schedule are overspecification of requirements, infeasible solutions, excessive configuration or customization requirements, inaccuracy in as-maintained aircraft configurations, and limited ship availability.
- The biggest risks to operational performance are backward compatibility to NALCOMIS and an inability to agree on a forward compatible interface between NOSS and NAMS.
- NAMS includes many interfaces of unknown complexity, representing a moderate degree of risk to NAMS acquisition.

CHAPTER SIX

Schedule Analysis of the Alternatives

We conducted a schedule analysis to project the ability of the alternatives to meet IOC and FOC dates. In this chapter, we discuss the schedule analysis approach, followed by a discussion of the results.

Schedule Analysis Approach

Baseline Schedule Goals

The study guidance dictated that a schedule analysis answer several questions, including the following:

- When can IOC be achieved?
- When can FD be achieved?
- What are the high-level tasks necessary to achieve FD, and what are their durations?
- What sensitivities and risks are associated with each activity?
- What is the optimal solution based on the schedule analysis?

Answering these questions involves both creating schedule estimates for the different alternatives under consideration and assessing the possible risks to schedule that might cause unacceptable delays. The Navy also expressed a desire to proceed with OTA to expedite the future acquisition of NAMS, and we were instructed to model potential schedule estimates around that approach. In such an approach, the Navy would make awards to multiple vendors to create COTS prototypes that would allow the vendors to demonstrate their ability to meet NAMS requirements with their solutions. Thus, the AoA team assumed the following:

- A prototype award date would be made to vendors between September 1 and November 30, 2018.
- The subsequent prototype evaluation phase would last no longer than 12 months, with an objective prototype selection date three to six months after awards.

- The selected prototype would be transitioned to a production OTA to fund it through IOC.
- The objective IOC date would be the first quarter of FY 2021.
- A threshold date would be the fourth quarter of FY 2021.
- FD was targeted for the first quarter of FY 2024.

The baseline goals for the project are summarized in Figure 6.1.

Monte Carlo Schedule Model

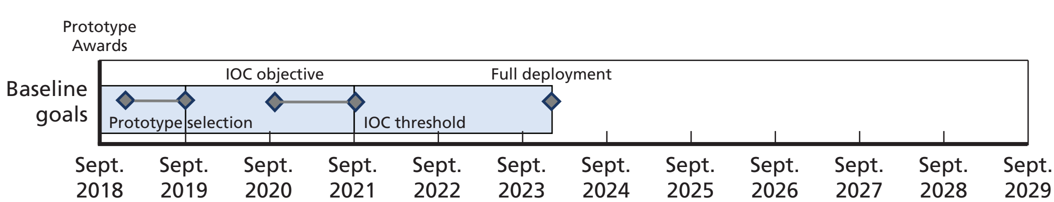
In approaching our schedule assessment, we first consulted the GAO *Schedule Assessment Guide* for guidelines on best practices for project schedules and for performing a schedule risk analysis (GAO, 2015). We opted for an approach that would lead to a statistical determination of phase durations and overall project durations for the various alternatives by developing and using a Monte Carlo model. This model requires the identification of all factors that would substantially contribute to the overall project duration, as well as statistical distributions for each factor. The model then simulates potential schedules for each alternative by selecting values for each factor and determining the critical path toward project completion in each simulation. This process was repeated thousands of times to create statistical distributions of overall project duration for each alternative.

Data Acquisition

To create a useful statistical model, we needed to obtain information on phases of software acquisition projects, typical phase durations, and statistical distributions of phase and risk factors contributing to the project's schedule. To acquire this information, we first requested data from vendors in the RFI. In the schedule section of the RFI, we asked those who responded to provide a recommended deployment approach and schedule, a breakdown of the high-level required tasks and their durations, estimates for achieving IOC and FD, and estimates of the time required for data migration.

The vendor responses to the RFI were varied. Many responded with very detailed breakdowns of the expected schedule for a notional project, with answers to all the schedule-related questions, expected high-level tasks and subtasks within them, and suggestions on potential schedule risk areas. Some vendors provided only simple

Figure 6.1
Baseline Program Schedule Goals



answers to the high-level questions, such as expectations of their ability to meet IOC or FD within the specified time ranges. Still others ignored the schedule-related questions altogether or stated that they would not be able to provide even a notional schedule until they knew more about the proposed project or worked with a systems integrator. However, most of the vendors that responded did fill out a questionnaire detailing the level of effort they anticipated would be required to meet each of the requirements, regardless of whether they offered other notional schedule data. These data were usually given in person-days to accomplish a task, allowing us to compile estimates of the total person-years of effort that each vendor estimated would be needed to develop a solution. Finally, meetings with many of the vendors provided other invaluable information on schedule. Vendors that attended provided both additional information on their processes and notional schedules and helpful discussion on areas where they expected significant schedule risk.

Acquisition Phase Standardization

Upon reviewing the RFI responses, we found that each vendor that provided a recommended notional schedule had a different approach to the acquisition. Although most approaches would, of necessity, perform many of the same tasks—such as clarifying requirements, configuring custom software, and migrating data—most vendors grouped these tasks into distinct phases with their associated durations. This differentiation presented a challenge, given that our analytical approach grouped categories of vendors into defined acquisition alternatives, rather than analyzing individual vendors. We therefore needed a way to group multiple vendor schedules in some standard way within each alternative. Even if we had chosen to take an approach that examined individual vendors, the lack of external benchmarking schedule data and the resulting need to rely solely on vendor-provided schedule data in each case would likely have made the analytical approach impractical, especially given that many vendors did not provide data.

Our approach to this challenge was to create standard phase "bins" that would encompass all the necessary activities in a software acquisition of this kind and into which we could group all the disparate activities proposed by the vendors. The methodology for binning the phases was created using researcher judgment after examining the software development processes provided by vendors and other publicly available software development processes (Azarian, 2013; Stackify, 2017; Tyagi, 2012). Insights from these sources were synthesized into five bins of activity:

- **Bin 1: Initiation and planning.** This phase includes all activities needed to prepare for the eventual creation, configuration, and implementation of the end product. Activities include scope verification, the requirements finalization, planning for the design and rollout of the product, and software design finalization.

- **Bin 2: Creation.** This phase includes all changes to create the end software product. Activities in this phase include the creation, customization, or configuration of the software package; integration of all software packages with legacy software; tool development; management of required interfaces; and preparations for data migration.
- **Bin 3: Test.** This phase encompasses all necessary activities to adequately test the product before rollout. Activities include software testing, simulations, fixing discovered software bugs, and user acceptance testing. We also included security accreditation activities in this phase.
- **Bin 4: IOC implementation.** This phase encompasses all activities required to obtain a live, operational version of the product at the initial sites required for IOC. Activities include user training, go-live support, installation activities, and any other pilot activities necessary to meet the definition of IOC.
- **Bin 5: Post-IOC implementation.**[1] This phase includes all activities that occur after IOC at the initial sites. Activities consist primarily of user training and installation of the end product at the remaining sites but would also include any potential post-IOC creation or test activities that may be necessary.

In addition to these five bins, we identified data migration as an activity that would likely occur concurrently with many of the other activities. It was included as a cross-cutting activity, both because many of the phases included activities related to data migration and because of its potential to be one of the limiting factors extending multiple phase durations and the overall schedule in the eventual acquisition path.

After finalizing the phase binning, we used our judgment to sort the disparate development activities provided by each of the vendors into the appropriate phase bins. The durations of the included activities were then combined to create an overall duration for each phase bin for each vendor that provided sufficient schedule data. Table 6.1 shows an example of how we grouped these activities into the identified phase bins for one of the vendors. The standardization of activities across each vendor was a critical step that allowed us to incorporate all the disparate data we received in a standard way for incorporation into a statistical model assessing schedule variability across alternatives.

Building the Statistical Model

We opted to use a Monte Carlo model for the schedule analysis. We intended to use the model to incorporate all of the factors affecting schedule into simulations that would be run many times to create statistical distributions of the time to IOC and to FD. The following components supported the creation of the Monte Carlo model:

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[1] Note that there would be a project phase beyond FD when the program enters sustainment. However, examining this phase was outside the scope of the schedule analysis, and an analysis is not included here.

Table 6.1
Example Bin Mapping for One Vendor

Activity Provided by Vendor	Phase Bin Mapping
Gather and document business requirements processes and functional requirements	Initiation and planning
Gather and document technical requirements	Initiation and planning
Plan user acceptance testing, pilots, and rollouts	Initiation and planning
Set up hosted infrastructure	Creation
Load data and configure software	Creation
Design, develop, and test integration processes	Creation
Run simulation and tune-up	Test
Test end-to-end solution	Test
Facilitate user acceptance testing process	Test
Implement pilot	IOC implementation
Support launch	IOC implementation
Transition to long-term support	Post-IOC implementation

- a standardized list of the phases and factors affecting schedule for each alternative
- distributions of the impact of each factor on schedule and the likelihood of that impact
- rules for determining the critical path incorporating these factors
- the means to run many simulations using these distributions.

The phase bins created to group and incorporate vendor data allowed us to create the first primary factors used in the model. In each alternative, we had multiple data points from RFI responses about the estimated duration for several of the phases. We opted to use a PERT distribution to estimate probability distributions for each factor. The PERT distribution estimated probability distributions by weighting the most likely duration four times more heavily than the minimum and maximum values. We observed the minimum and maximum estimated durations in vendor estimates for each phase, and we took the average of the values provided to us to calculate a most likely duration. We then applied the PERT distribution to obtain overall probability distributions.

We developed the factors and distributions from the RFI and stakeholder interviews, as described earlier in this chapter. The factors were broken down into three categories of assumptions:

- initiation and planning, creation, and test
- data migration
- implementation.

Initiation and Planning, Creation, and Test Assumptions

Vendors provided sufficient data to easily develop factors for the initiation and planning, creation, and test phases. Furthermore, vendor responses to the questionnaire that accompanied the RFI provided additional data on the level of effort to perform various activities associated with the creation phase. The data were aggregated to estimate a total number of person-years of effort each vendor estimated for initiation and planning, creation, and test phase tasks with low, most likely, and high estimates. We assumed each vendor would have a ten-person team working on these tasks and calculated the resultant number of days expected for the creation phase. These results roughly matched the estimate generated from the RFI responses, so they were used in the distributions for the creation phase.

In addition to factors representing the time for initiation and planning and for testing, we included one risk factor related to requirement changes extending the duration of the creation phase because additional effort would be required. The minimum value in its distribution was 1 and assumed no changes to the creation duration. The most likely value was 1.1 and assumed only minor changes and additional effort would be required. The maximum value was 2 and assumed a doubling of the creation phase duration. This value was included as a simple multiplier applied to the duration of the creation phase in each simulation. Table 6.2 lists these factors.

Data Migration Assumptions

Although we had relatively robust data for the initiation and planning, creation, and test phases, many vendors gave little consideration to the data migration and implementation phases in their responses, especially post-IOC implementation. Further-

Table 6.2
Initiation and Planning, Creation, and Test Factors

		Estimates		
Factor	**Unit**	**Low**	**Most Likely**	**High**
Initiation and planning	Months	3	5	9
Creation (high estimate factors in risk)	Months	4	9	12
Requirement changes extend creation (risk)	Multiplier	1	1.1	2
Test	Months	3	5	10

more, although many vendors noted that data migration was a significant risk factor to schedule, very few gave any estimates on duration of the activities associated with it.

Data migration was split into two phases for efforts required at the sites for IOC and for post-IOC. We spent a considerable amount of time at vendor meetings discussing data migration as a potential risk factor, and these discussions were used to identify the factors affecting the duration of data migration phases. The following four significant unknown factors that would likely affect the duration of data migration efforts were identified:

- the scope of work required to migrate aircraft configuration data
- the time required to migrate historical work order data, assuming data were in a reasonably clean state
- a risk factor accounting for variability in the quality of the data or the cleansing that the data may require
- a risk factor accounting for variability in data structure between sites that may limit the reusability of the ETL process developed for data migration.

In addition to these four factors, the total time for data migration in each phase also depended on the number of sites required in that phase and the number of teams performing the work.

We created value distributions for each of the factors affecting the data migration phases. For the factor related to time per site to extract and cleanse aircraft configuration data, researcher judgment and SME input were used to estimate the minimum duration of the work per site if NALCOMIS data were migrated as-is with no changes, a most likely duration if part and component numbers were validated for each aircraft, and the maximum duration if as many serial numbers as possible were validated.

For the factor related to time per site to extract and cleanse historical work order data, researcher judgment and SME input were used to estimate the minimum duration of the work per site if only open work orders were migrated, a most likely duration if 13 months of work orders were migrated, and the maximum duration if three years of work order data were migrated. The scope of work for the minimum, most likely, and maximum cases in both of these factors was selected based on conversations with Navy personnel.

We applied the data quality factor as a simple multiplier and assumed a minimum value of 0.5 (implying it took half the time expected because data quality was good), a most likely value of 1 for the baseline case, and a maximum value of 2 (implying it took twice the time expected because data quality was bad).

The factor for the reusability of the ETL process was also a simple multiplier, with the minimum value speeding the process by a factor of 2, a most likely value speeding it by 50 percent, and the maximum value speeding it by only 10 percent.

We calculated the total time for each data migration phase in each simulation by first adding the time per site to extract and cleanse aircraft configuration data and the time to extract and cleanse work order data. We then multiplied this value by the number of sites and the multipliers selected based on data quality and ETL process reusability and divided by the number of data migration teams. Table 6.3 summarizes the data migration factors.

Implementation Assumptions

As was the case with data migration, we had to build up the IOC implementation and post-IOC implementation phases in the model from other known or estimated factors.

The implementation phases were built up from the following factors:

- Distributions were calculated for the time to install the end solution at each site and the number of teams performing installations.
- Total time for each implementation phase was calculated by multiplying the number of sites in each phase by the installation time per site and then dividing by the number of installation teams.
- The number of site installations required at IOC was also allowed to vary, with a distribution based on likely numbers of squadrons, afloat sites, and fleet readiness centers that the Navy may require at IOC in several courses of action that were considered. This distribution also affected post-IOC implementation, because the

Table 6.3
Data Migration Factors

		Estimates		
Factor	**Unit**	**Low**	**Most Likely**	**High**
Time to extract, cleanse, and transform aircraft configuration data	Days	2	10	30
Time to extract and cleanse open and historic work order data	Days	5	10	30
Quality of data (risk)	Multiplier	0.5	1	2
Total activities migrated at IOC	Number of activities	3	14	77
The number of IOC data migration teams (10-person teams)	Number of teams	4	2	1
Reusability of ETL process, generating increased rate of data migration	Percentage	100	50	10
The number of FD data migration teams (10-person teams)	Number of teams	12	8	4

number of site installations post-IOC was calculated as the total number of sites minus those implemented during IOC.
- Total implementation time for both IOC and post-IOC also included factors accounting for delays because of ship or site availability owing to deployment schedules and other issues.
- The distributions for installation time and site availability were created using SME judgment from the research team and additional input from Navy personnel.

The model calculated the total time for each implementation phase by comparing the total time for site installation with the selected duration because of ship availability and selected the greater of the two as the duration of the phase in each simulation. Table 6.4 summarizes the factors.

Using the Model

Once all the factors and risks affecting the project schedule had been identified, we developed the Monte Carlo model, rules for determining the critical path for the project, and the instructions for simulating the project schedule using Microsoft Excel. We created a spreadsheet for each alternative with each of the factors and their distributions of minimum, most likely, and maximum values. Once the simulation began, the model randomly selected one value from each of the factors, used these values to calculate the duration of each phase, and followed the rules governing the determination of the critical path to derive the overall times until IOC and FD were achieved. The most likely values were four times more likely to be selected than the minimum or maximum values, in keeping with a PERT distribution. The model then repeated the process for 10,000 iterations. Upon completion of all iterations, the model used the results to generate expected completion dates for IOC and FD, as well as a best-case and worst-case scenario for each. The expected completion time was the average duration from all simulations, the best-case duration was the point at which the shortest 5 percent of iterations had finished, and the worst-case duration was the point at which the shortest 95 percent of iterations had finished.

Table 6.4
Implementation Factors

		Estimates		
Factor	Unit	Low	Most Likely	High
Time per activity to install NAMS solution	Days	2	8	14
The number of install teams for IOC	Number of teams	4	2	1
The number of install teams for FD	Number of teams	6	4	2
Activity availability (risk)	Years	3	4	5

Schedule Analysis Results

We made schedule projections using the same model. Schedules were calculated with an expected start date of September 1, 2018, and IOC and FD completion dates were calculated from the results of the Monte Carlo analysis for each alternative. Actual start dates may, of course, differ from this plan, but the general conclusions of the schedule analysis are unlikely to be affected. We omitted Alternative 1 from the schedule analysis based on the rationale that it represents a program that is already in place and complete. We also assumed that Alternative 2 did not proceed with an OTA approach and instead involved the Navy engaging in in-house development, while Alternatives 3–7 were assumed to proceed with an OTA approach. In this case, we assumed that work would begin on September 1, 2018, with awards to a few vendors for the creation of prototype NAMS solutions. Before September 2019, one of the prototypes would be selected as the NAMS solution, and the selected vendor would then proceed with development of its prototype product to achieve IOC. Table 6.5 shows alternative best-case, worst-case, and expected IOC and FD completion dates for each alternative. The baseline goals from Figure 6.1 are included at the top of Figure 6.2, which shows the projected schedules. None of the alternatives is likely to meet the FD date.

Sensitivity Analysis

After completing the modeling for each alternative, we also performed a logistic regression analysis on the schedule model results to understand the relative impact of acquisition stages and risk factors. The model predicts the completion date for FD, controlling for the following:

- time per site to extract and cleanse aircraft configuration data

Table 6.5
Alternative Completion Dates

	IOC			FD		
Alternative[a]	**Best Case**	**Expected**	**Worst Case**	**Best Case**	**Expected**	**Worst Case**
Alternative 2	May 2021	May 2022	Nov. 2023	Dec. 2024	Aug. 2026	Dec. 2028
Alternative 3	July 2020	March 2021	Jan. 2023	Nov. 2023	June 2025	Nov. 2027
Alternative 4	April 2020	March 2021	April 2023	Oct. 2023	June 2025	April 2028
Alternative 5	Oct. 2019	Sept. 2020	Nov. 2022	April 2023	Dec. 2024	Sept. 2027
Alternative 6	Aug. 2020	April 2021	Nov. 2022	Dec. 2023	July 2025	Oct. 2027
Alternative 7	July 2020	July 2021	March 2023	Jan. 2024	Sept. 2025	Feb. 2028

[a] We omitted Alternative 1 because it represents a program that is already in place.

- time per site to extract and cleanse historical work action data
- quality of the data
- total number of sites migrated at IOC
- number of data migration teams for IOC
- reusability of configuration of extract and cleanse process
- number of teams for FOC data migration
- time per site for IOC implementation
- number of install teams for IOC
- number of install teams for FOC
- increasing requirements over time
- ship availability.

Table 6.6 highlights the high-impact schedule factors resulting from the regression analysis.

Ship availability is by far the most important factor driving schedules. Additionally, the quality of the data, which affects the time to extract and transform into the new system, is an important factor. Essentially, the value assumes 60 days (at worst) to extract and transform per activity. Table 6.7 highlights the low-impact schedule factors resulting from the regression analysis.

These factors do not significantly affect the schedule.

Figure 6.2
Calculated Schedule for Each Alternative

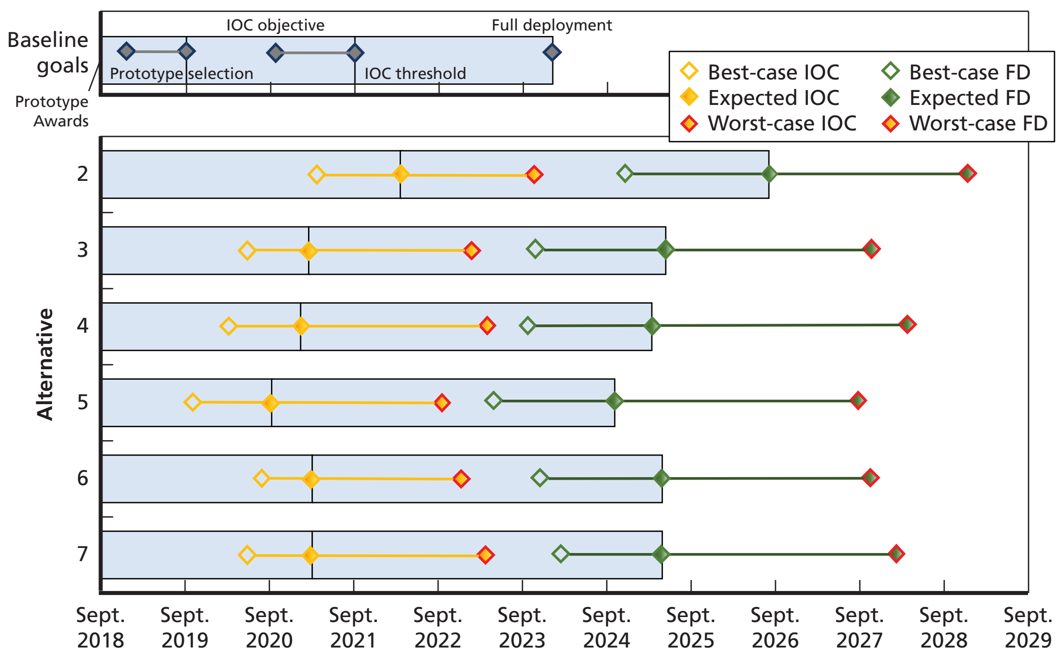

Table 6.6
High-Impact Schedule Factors

Factor	Value	Impact (Odds Ratio)
Ship availability for installations	5 years vs. 4 years 4 years vs. 3 years	72x more likely to miss FD goal 6x more likely to miss FD goal
Requirements creep	High vs. expected	12x more likely to miss FD goal
Total activities migrated at IOC	77 activities vs. 14 activities	6x more likely to miss FD goal
Quality and cleanliness of current and historical aircraft configurations and work actions	Twice the time to extract and cleanse	5x more likely to miss FD goal
Time to extract and cleanse aircraft configuration data per activity	30 days vs. 10 days	3x more likely to miss FD goal
Number of concurrent FD data migration teams	4 teams vs. 8 teams	3x more likely to miss FD goal
Time to extract and cleanse work action data per activity	30 days vs. 10 days	3x more likely to miss FD goal

Table 6.7
Low-Impact Schedule Factors

Factor	Value
Number of data migration teams for IOC	2 teams vs. 4 teams
Number of install teams for IOC	1 team vs. 2 teams
Number of install teams for FD	4 teams vs. 6 teams
Total activities migrated at IOC	3 activities vs. 14 activities
Reusability of the ETL process and translator	10% vs. 50% reusable

Summary of Schedule Analysis Results

The results of the Monte Carlo modeling and the sensitivity analysis led to the following results for the overall schedule analysis:

- All the alternatives exhibit a large degree of schedule uncertainty. Although Alternative 5 is most likely to be implemented within expectations for the program, all the alternatives have wide ranges for expected completion dates for IOC and FD. Alternatives show ranges of approximately three years between the best- and worst-case results for IOC and approximately four years between the best- and worst-case results for FD.

- All the alternatives are expected to meet IOC within the threshold range. Increasing the number of sites required for implementation at IOC may push the schedule beyond the threshold dates for IOC, but all alternatives should be able to meet IOC within the deadline. Even Alternative 2, for which an OTA approach does not apply and which is likely to require significantly more effort in the early phases, has an expected IOC completion date within the threshold range. The Navy should consider the trade-off in potential schedule delays when assessing the number of sites it will require for IOC.
- None of the alternatives is expected to meet the goal for FD. Although some of the alternatives have best-case scenario results ahead of the recommended FD deadline, none has expected completion dates within the range. The risk factors and expected delays inherent in the program are likely to push the completion of the project years beyond current Navy expectations for completion. With that in mind, the Navy should strongly consider any changes it can make to mitigate risk from the high-impact factors.
- The following factors affecting the scope of work for data migration together have the greatest potential effect on program schedule:
  - Reducing the required amount of historical work order data or aircraft configuration data for data migration could reduce the expected completion date by a year or more.
  - The Navy should also consider measures to assess data quality and ensure appropriate allocation of effort to data migration and site installation efforts.
  - Mitigating delays because of the lack of site availability is also likely to have a strong, positive effect on the overall program schedule.

CHAPTER SEVEN

Conclusions and Recommendations

Overall Conclusions

Table 7.1 shows the summary roll-up of all factors considered in our analysis.

Table 7.1
Roll-Up of Summary Analysis Factors

Alternative	Capability Factor (out of 100)	Exposure to High-Scoring Risks	LCC, Relative Values ($millions)			Scheduled FD Date		
			Low	Mid	High	Best Case	Most Likely	Worst Case
1. Status Quo—NALCOMIS No Modernization	48	High	—	—	—	In use	In use	In use
2. Status Quo—NALCOMIS New Development	93	High	41	104	169	Dec. 2024	Aug. 2026	Dec. 2028
3. COTS—Enterprise Systems Active in Defense Aviation	**89**	**Low**	**–53**	**6**	**66**	**Nov. 2023**	**June 2025**	**Nov. 2027**
4. COTS—Enterprise Asset and Service Management Systems	90	Moderate	–138	–14	110	Oct. 2023	June 2025	April 2028
5. COTS—Niche Aviation MRO Systems	81	Low	–91	12	117	April 2023	Dec. 2024	Sept. 2027
6. GOTS—ALIS	80	Moderate	–124	–62	—	Dec. 2023	July 2025	Oct. 2027
7. Hybrid—COTS and NDMS	70	Moderate	162	236	311	Jan. 2024	Sept. 2025	Feb. 2028

NOTE: Color codes for capability, risk, and cost are based on relative values above or below one-half of the standard deviation from the mean value. Color coding for schedule is based on the time beyond the threshold.

There is no question that COTS Alternatives 3 and 4 provide more-configurable capability and quality than the current NALCOMIS, as would a more hypothetical Alternative 2. A more supportable, configurable, usable, and interoperable system would improve the fleet's ability to respond to security requirements and future needs.

Alternatives 3 and 5 have less exposure to critical risks. Alternative 4 is riskier because these systems do not operate in the defense realm or aviation maintenance.

All alternatives have challenges in meeting schedule goals. If the Navy wants to meet schedule objectives, it will likely have to give up goals to make near-term gains in readiness derived from analytics. Beneficial analytics depend on clean and accurate historical data on maintenance actions and aircraft configurations. It is unclear to what extent current data are accurate. However, one 2017 Center for Naval Analyses and Digital Warfare Office study of Super Hornet radars showed that only 25 percent of the available data set was usable because of missing serial numbers, inconsistent time lines, and aircraft mismatch (Zolotov and Palmieri, 2017). If it takes the Navy two months per activity to extract, transform, and load historical data on maintenance actions and configurations, it will be five times more likely to miss the FD goal. Furthermore, ship availability is by far the largest driver of the ability of any NAMS alternative to meet the FD goal.

Alternatives 4 and 6 have the best cost profiles. Alternative 3 options have higher recurring license fees. In general, however, the cost of NAMS pales in comparison with the cost of fleet procurement and sustainment. By one estimate, the cost of operating a COTS version of NAMS for 16 years is a very small percentage of the cost of buying and sustaining the Super Hornet fleet, and NAMS will support 2,100 additional non–Super Hornet aircraft.

Therefore, there is no silver bullet, but COTS Alternatives 3 and 4 offer the best chance for capability gain, the best potential to meet schedule demands, modest cost savings with the right recurring license contract, and limited scope of migration. **Alternative 3 poses less overall risk than Alternative 4.**

The Navy should consider increasing the budget to improve the odds that NAMS can improve readiness more quickly. As noted, the cost of NAMS is negligible compared with the cost of procuring and sustaining the 2,700 aircraft fleet. The cost to extract and clean historical data may be an additional $200 million over 16 years, which is a reasonable trade-off for a system that supports so many aircraft. Increasing efforts to clean data will get more aircraft into the new system faster and with better-quality data, thereby increasing the ability of the software to conduct analytics useful for improved maintenance execution and, ultimately, aircraft readiness.

If the Navy does not increase its efforts to clean historical data up front, its ability to improve readiness and reduce demands on its workforce will be hindered. It can try to forgo migrating historical maintenance action data, but it must migrate current as-is aircraft configuration data at some level. If it loads inadequate configuration data, then it merely shifts the problem of cleaning to NAMS sustainment, resulting in misleading analytics along the way. Many vendors stressed the need to get the data problem corrected as much as possible up front.

Further confounding the problem is the fact that fully verifying an aircraft's as-is configuration can require deconstructing the aircraft. This is an arduous task, to say the least—and a nonstarter in some circles. All these challenges point to the reason the Navy needs a pragmatic yet aggressive approach to handling its existing aircraft maintenance data, with the understanding that not doing so will minimize the ability of NAMS to positively affect readiness across the fleet. Addressing data cleanliness, whether before, during, or following the rollout of NAMS, is a key success factor for the systems integrator.

Another area where the Navy must be smart is in how it manages its contract for the new software. It makes sense to separate out control of the interfaces for NOSS, NOME, and other key systems rather than including the solution as part of the overall NAMS contract. If the Navy retains control of those interfaces, it will be better able to change the software vendor in the future as technology changes. Additionally, the primary area to control cost is through recurring software maintenance fees.

Recommendations

Given these conclusions, we offer the following specific recommendations:

- Pursue a COTS migration with a focus on prototyping Alternatives 3 and 4. Alternative 3 options are preferred because they pose less risk to unclear business process definitions and have lower overall risk.
- Study data quality and implement improvement plans, where necessary, for targeted types, models, and series to improve future analytical outcomes. This includes increasing spending to clean historical data, better enabling analytics, and improving aircraft availability.
- Acquire a separate interface layer through commercial application programming interface management, GOTS enterprise service bus, domestic technology transfer plan, or NOSS acquisition; make vendors work through this layer.
- Actively negotiate the terms for recurring software maintenance fees before the down-select (particularly if an Alternative 3 option is the choice).
- Make knowledgeable personnel available in sufficient numbers for OTA participation.
- Ensure that authorized personnel are available after the post-OTA down-select to authorize changes to the NAMP or execute other policies and processes as required.

- Reach out to the GCSS-A Army Enterprise Systems Integration Program for information on Army aviation tactical maintenance modernization and aviation notebook lessons learned.
- Reengage with Southwest Airlines for lessons learned from its migration to COTS software, which was ongoing during our analysis.
- Simplify maintenance processes as much as possible to increase the rate of adoption into COTS business processes.
- Analyze requirements of VFS CAD/PAD, AWIS, BMT, and AMSRR to NAMS and consider consolidating the maintenance function as much as possible into NAMS and the supply function into NOSS.
- Closely manage the interface between NOSS and NAMS to ensure forward compatibility.
- Study and quantify the potential gain from an improved maintenance process in terms of aircraft readiness.
- Make every possible effort to adjust to ship availability—a large schedule risk.

Some Perspective on the Challenges Ahead

Moving forward, the Navy needs to maintain some perspective on the challenges it faces. The major North American commercial airlines tend to mirror the current NTCSS arrangement: an in-house custom solution with multiple separate systems providing financial, supply, and planning data and maintenance management. The reasons for this arrangement are primarily the cost and time to migrate and the perceived lack of readily tailorable software to meet the airlines' stringent operational requirements. Put succinctly, most airlines think they can still do it better themselves or are so invested in their current solutions that it is impractical to change. Modernization is continuously explored. Southwest Airlines is in the midst of a three-year migration to a COTS solution. The airline is not expecting significant cost savings; rather, it is focused on improved compliance with Federal Aviation Administration regulations.

These facts should rightly concern the Navy, as our analysis shows. If the Navy does not control its implementation scope, it could cause serious delays well beyond the 2024 FD goal, out to 2028 and potentially beyond. A single cutover, similar to Southwest's plan, seems impossible, but the alternative phased approach is equally challenging.[1] A single cutover forces the Navy to have a strong interface to NALCOMIS because of how aircraft can move from activity to activity. If this approach is a nonstarter, then the Navy will have to change some of its core business processes for using aircraft and exchanging parts.

1 A single cutover event is one that transfers all users to the new system overnight.

Although the Navy has challenges with the proposed approach, it also has legitimate challenges with the current system, with software problems affecting supportability and the ability to provide mission-capable aircraft, among other tasks. Gains in supportability will come quickly with the new system; however, improving readiness will not.

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The U.S. Navy's aviation maintenance capability suffers from supportability issues because of its antiquated software architecture and codebase. This report presents the results of an analysis of alternatives for fielding the Naval Aviation Maintenance System (NAMS), which is intended to help modernize the Navy's afloat and ashore maintenance capabilities.

The Navy identified several key attributes and 269 high-level requirements for NAMS to meet the demands of the current and future aviation logistics enterprise. The RAND research team used this guidance to evaluate seven alternatives in terms of effectiveness (capability and quality), cost, risk, and schedule. The primary sources of data used for these analyses were industry and government responses to a request for information, follow-up discussions with selected industry and government experts, interviews with stakeholders, a literature review, and study guidance and the study problem statement provided by the research sponsor.

Broadly speaking, the alternatives studied included maintaining the status quo, a commercial off-the-shelf solution, a government off-the-shelf solution, and a hybrid alternative combining a commercial off-the-shelf solution with the Naval Depot Maintenance System. The authors find that a commercial off-the-shelf solution is the best option.

All alternatives have challenges in meeting schedule goals. If the Navy wants to meet schedule objectives, it will likely have to give up goals to make near-term gains in readiness derived from analytics. Beneficial analytics depend on clean and accurate historical data on maintenance actions and aircraft configurations, and it is unclear to what extent current data are accurate.

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