RAND PROJECT AIR FORCE

Exploring Parallel Development in the Context of Agile Acquisition

Analytical Support to the Air Superiority 2030 Enterprise Capability Collaboration Team

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Prepared for the United States Air Force

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Preface

The research presented in this report is part of a larger project providing analytical support to the U.S. Air Force's Air Superiority 2030 Enterprise Capability Collaboration Team across several dimensions, including strategies to more rapidly transition new technologies and concepts to the fleet, such as parallel development.[1]

This research—a think piece—was conducted over a three-month period with limited objectives. It describes an initial analytical framework for enabling parallel development in an agile acquisition context, and it identifies some implementation challenges and ways to mitigate those challenges. *Agile acquisition* is an approach that is more responsive, flexible, and adaptive to changes in threat, technology, or environment than traditional acquisition processes and can more rapidly develop, test, and deploy new capabilities. *Parallel development* is an approach to developing and fielding capabilities that intentionally decouples the technology development and program management of core elements of a weapon system. This framework is not the definitive word on parallel development; rather, the framework is intended to be a first step in defining and understanding parallel development in an agile acquisition context.

The research reported here was commissioned by the Director, Operational Capability Requirements, Deputy Chief of Staff for Strategic Plans and Requirements, Headquarters U.S. Air Force. The work was conducted within the Force Modernization and Employment Program of RAND Project AIR FORCE as part of a fiscal year 2016 core funded study, "Supporting, Improving, and Maturing Enterprise Capability Collaboration Teams." It should be of interest to those involved in or responsible for capability and technology development, as well as acquisition strategy and program management.

RAND Project AIR FORCE

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[1] See U.S. Air Force, *Air Superiority 2030 Flight Plan*, Enterprise Capability Collaboration Team, May 2016.

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Summary

The U.S. Air Force's Air Superiority 2030 Enterprise Capability Collaboration Team was formed to explore innovative technological, operational, and acquisition concepts for developing and fielding future capability in a core mission area. The RAND Corporation's Project AIR FORCE provided analytical support to the Air Superiority 2030 Enterprise Capability Collaboration Team across several dimensions, including strategies to more rapidly transition new technologies and concepts to the fleet. This report is one result of that effort.

Framework

Agile acquisition is an approach that can more rapidly develop, test, and deploy new capabilities. It is more responsive, flexible, and adaptive to changes in threat, technology, or environment than traditional acquisition processes. Agile acquisition is not, however, a single process or strategy. Rather, it comprises many distinct processes and strategies that can enable the responsiveness and flexibility that characterize agile acquisition as a whole.

Parallel development is an approach to developing and fielding capabilities that falls within the set of agile acquisition processes. Parallel development intentionally decouples the technological development and management of core elements of a weapon system. This can include decoupling platform and mission system equipment or software architecture and applications. In parallel development, the development of new technologies (and associated operational concepts and capabilities) for platforms, mission systems, software, and architecture can be on separate paths and timelines, managed by separate entities, with explicit attention to system integration. Managing the risk associated with system integration thus becomes one of the key management tasks in the program.

The objective of this research is to identify and describe how parallel development can work in the context of an agile acquisition process. This includes offering an initial definition of key concepts and identifying key enablers of parallel development. We also identify key implementation challenges and constraints of widespread adoption of parallel development approaches, and we outline strategies to mitigate and address those challenges. Our intention is to begin to define parallel development and illustrate practical application of the concept by using historical examples.

For purposes of this research, we adopt the perspective of a new-start program. That is, our framework assumes that the key management activities that we identify as enabling parallel development can be designed into the acquisition strategy in the early stages.

This was a short and narrowly focused research effort. Our approach thus relies on and draws from existing material. We reviewed select literature on the concepts of agile acquisition and

parallel development in order to provide context and an analytical framework consisting of management actions that enable parallel development. We also reviewed existing RAND case studies of select programs that illustrate these enablers. Although these programs do not necessarily exhibit a "pure" parallel development approach, they did implement key management activities that can enable parallel development.[1] Lessons from these programs provide insight into the key enablers of a successful parallel development approach.

The short time frame and limited program sample we draw on raises certain limitations of the analysis. One limitation is the minimal reference to the concept in either past RAND research or U.S. Department of Defense policy guidance documentation. Our review of the program case studies was limited to identifying likely aspects of parallel development, with few explicit references to the concept. The lack of direct references in prior research thus infuses a degree of subjectivity into our analysis.

The size of our program sample poses another constraint. Establishing a robust set of guiding principles for parallel development would ideally entail a much broader program sample in order to test the legitimacy of our findings (and, presumably, identify additional enablers of parallel development not present in our limited sample).

Another limitation is our use of published sources, predominantly RAND reports, from which we derive lessons on how to enable parallel development. A more rigorous study would include extensive interviews with program office and industry personnel and original research on specific programs, drawing on a much wider range of published reports and official program documentation.

Our review of historical program developments resulted in identifying five sets of *management actions* that can facilitate parallel development; in this report, we call each of the five sets an *enabler of parallel development*.[2] These enablers are meant to be implemented in concert with each other; there are multiple interdependencies that strengthen the effect of each management action to contribute to program success and an agile acquisition environment. The five enablers of parallel development, along with each enabler's underlying management actions, are as follows:

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[1] By *pure*, we mean that a program's strategy exhibits all the elements of parallel development in our framework. This includes adhering to a comprehensive set of well-defined engineering or management attributes, including decomposition of the desired system design into discrete subsystems or components; an intentional plan to develop, mature, and deploy system capabilities incrementally in parallel (same general time frame) but independent of each other; separate design, development, and testing of major subsystems or components, allowing subsystem maturation at a pace suitable for that subsystem; separate management of each subsystem using a tailored development approach specific to that subsystem; a focus on introducing one new capability or technology at a time, to the extent possible; and modularity and open systems or open architectures as a design feature of the system.

[2] We distinguish between *management actions*, which are specific activities that a program office can perform, and *enablers of parallel development*, which each represent a set of interdependent management actions that can enable parallel development when performed together.

1. effective assessment of technological risk and maturity
    a. early and continual assessment of technological risk and maturity
    b. maximized use of mature systems
2. effective management of system integration risk
    a. early and continual assessment of integration risk
    b. roles and responsibilities appropriately assigned according to organizational capability
    c. isolated subsystem integration risk
3. planned incremental approach to fielding capabilities
    a. capability increments planned early in development and updated continually based on new information
    b. intention to accelerate fielding of initial capability improvements, even if less than full capability
4. tight alignment of requirements, acquisition, and budget stakeholders
    a. close collaboration between the user (warfighter) and developer (industry and government)
    b. flexible technical requirements and stable funding
    c. sufficiently empowered program office management
5. strong contingency planning
    a. rigorous contingency planning conducted early in development
    b. effectively restructured development program according to contingency plans.

These enablers are best understood as specific management actions or activities at the program level. This is an initial list based on a limited analysis and is not meant to be exhaustive. However, the experience across our program sample consistently suggested the above sets of actions as some of the most universal and critical enablers of parallel development.

Lessons from Historical Examples

While none of the programs that we reviewed planned and executed a pure parallel development strategy, most of them exhibited one or more of the management actions that can enable parallel development to be successful. The ten programs we reviewed (and the enablers they exhibited) included the following:

- *F-22 Raptor multi-role stealth fighter*: The F-22 program's acquisition strategy included co-development of the engine, airframe, and mission systems to be integrated into full capability. Parallel development was not used, and the highly integrated nature of the platform suggests that parallel development may not have been appropriate. We therefore chose to include the F-22 program as an interesting contrast to the other aircraft development programs we examined.

- *F/A-18E/F Super Hornet*: The F/A-18E/F was a major modification program, including both the airframe and mission systems, which explicitly used parallel development. Changes to the airframe were introduced first, and mature legacy mission systems were integrated in the initial versions of the system. New mission systems, such as an active electronically scanned array radar, were integrated as they matured.
- *F-16 Multinational Staged Improvement Program (MSIP)*: Like the F/A-18E/F, the F-16 MSIP was expressly conceived as a parallel development process. The program established a clear blueprint for incrementally upgrading the F-16C/D airframe with advanced subsystems developed in parallel. The program office planned to execute the upgrade program in three stages, with mini-block upgrades in each stage. The more-significant technological advances were pushed to the later stages to allow them to fully mature. Parallel development of the major subsystems was managed by separate program offices, but the F-16 System Program Office collaborated closely with each to incorporate MSIP-specific design elements.
- *B-1B Lancer bomber*: Parallel development of key subsystems was critical to the desired agility in the B-1B's acquisition strategy. Planners attempted to achieve significant commonality with the B-1A airframe and incorporate mature propulsion and electronics technologies to minimize technological risk, with the expectation that mature subsystems could be incrementally upgraded as technologies matured in parallel. We included the B-1B program as an example of a parallel development process specifically designed to accelerate fielding of the system. However, the program also reflects the importance of maximizing the number of enabling management strategies used—and, in particular, the potentially negative consequences of employing parallel development in the absence of several such management strategies.
- *Advanced Medium-Range Air-to-Air Missile (AMRAAM)*: Parallel development was not initially pursued in this case, which ostensibly violates the spirit of our conceptual definition (that embedding parallel development approaches into the early planning process is critical to successful implementation). However, the AMRAAM acquisition program was specifically designed to be agile. Parallel development was implemented during the engineering and manufacturing development (EMD) phase and proved a highly effective approach at isolating technological risk, aligning technological maturity levels with fielding timelines, and, ultimately, facilitating rapid fielding of the basic system. Although the program thus does not completely adhere to our definition of a parallel development *acquisition strategy*, it is instructive to view in the context of the management strategies that it did and did not implement, as well as its relative effectiveness as an agile acquisition program.
- *Low Altitude Navigation and Targeting Infrared for Night (LANTIRN)*: Like the AMRAAM program, the LANTIRN acquisition program was designed to rapidly field a critically needed capability and did not initially pursue parallel development. Also like the AMRAAM program, parallel development was attempted as a contingency during EMD. In contrast, however, the LANTIRN program limited the use of parallel development to a few critical technologies, such as the Automatic Target Recognition, with most components developed alongside the platform in the EMD program. The LANTIRN program thus serves as an interesting counterpoint to the AMRAAM program—that is, similar fielding and acquisition strategies, initial absence of parallel development, and eventual use of parallel development as a contingency, contrasted with

significant differences in scope and type of parallel development strategies employed, number of "enablers" pursued, and program outcomes.

- *F-117 Nighthawk stealth fighter*: The F-117 program's primary focus was on pushing the state of the art in stealth technologies, principally the airframe and engine, while still maintaining an emphasis on rapid fielding. Mature mission systems operating on other aircraft were used to accelerate deployment of the basic capability. The F-117 program constitutes one of the few pure examples of parallel development. We include it not only on its own merits as a parallel development program but also as a point of comparison with other pure parallel development programs in the broader context of agile acquisition. That is, although the F-117 acquisition program generally fits our definition of *parallel*, we attempt to identify the extent to which it did or did not exhibit the enabling management actions outlined earlier and, in turn, how its use of these enablers contributed to its effectiveness as an agile acquisition program.
- *DDG-51* Arleigh Burke*–class destroyer*: The ship and its critical Aegis combat system were separate acquisition programs managed by separate program offices in different program executive offices. The DDG-51 was expressly conceived as a parallel development acquisition program, whereby the hull and mature capabilities would be rapidly fielded and incrementally upgraded as subsystems—particularly the Aegis technology—matured in parallel. In addition to the utility the program thus provides as a pure example of parallel development, it further provides a useful contrast to the DDG-1000 program (see below), which initially planned to follow a similar development outline but ultimately diverged.
- *DDG-1000* Zumwalt*-class destroyer*: Although the original DD(X) program planned multiple hull flights and mission system capability upgrades, a challenging mix of budget constraints and rigorous oversight from the Navy and Office of the Secretary of Defense ultimately led to a "single step to full capability" approach. There were ten major subsystems based on new technology that would be integrated together, and, although each had a prototyping program (called engineering development models) to reduce risk, all were developed on the same timeline and introduced together. Unlike the DDG-51 program, on which the original acquisition strategy was loosely modeled, all development activities were also organized under one program office.
- *Littoral combat ship (LCS)*: Two separate hull variants and three unique mission system packages (for mine countermeasures, antisubmarine warfare, and surface warfare) were developed independently, as separate acquisition programs managed by distinct program offices. The LCS program was explicitly conceived to be agile, with the lead ship to be rapidly fielded and equipped with mature mission systems. New mission-module technologies were designed to be modular and introduced incrementally as they matured in parallel. The LCS thus represents another pure example of parallel development, in both program structure and desired agility. However, the program provides an important counterpoint to other pure parallel development programs because it exhibits far fewer enablers and (we argue, not incidentally) is relatively less effective at employing parallel development than others in our sample.

Implementation Considerations

Parallel development can be applied to a program in multiple ways, depending on identified needs. When deciding which parallel development strategies may be appropriate, it is essential to not only pursue the sorts of broad approaches detailed in this document but also consider whether there are enablers that are both applicable to the given program and capable of meaningfully facilitating parallel development.

An important takeaway from our research is that no single enabler is sufficient to ensure successful implementation of parallel development. Programs in our sample that were relatively more successful at leveraging parallel development strategies tended to exhibit a greater number of the enablers. Maximizing the use of the management actions can have a considerable enabling effect on the success of parallel development and can facilitate a more rapid fielding of a basic level of capability.

At one level, the management actions we have identified as enabling parallel development can also be considered as good program management practice. Our review of programs suggests that many programs commonly include one or more of these actions, and although that does not meet our definition of a parallel development program (which requires implementing all the identified management actions together), it does allow us to derive lessons on practical applications of such actions from past experiences of programs that have successfully implemented them.

We have examined enablers of parallel development at the program level. The fact that so few programs can be characterized as using a complete parallel development approach (e.g., DDG-51, F/A-18E/F, and F-117 come closest in our small sample) suggests that broader and more-widespread use of this approach constitutes a significant change from traditional acquisition strategies, particularly for major weapon system programs. Transition to widespread use of parallel development in an agile acquisition context should be viewed as a multiyear, continuous process. Parallel development is sufficiently different from traditional single step to full capability development that a transition to this new way of thinking requires significant change, which in turn requires significant time.

The single most important issue is performing and acting on an honest assessment of technological risk and maturity. This requires an independent, unbiased assessment of that risk, including system integration risk. Only technologies that are mature and well understood should be incorporated into the design of new systems. One relatively objective measure of maturity is performance demonstrated through rigorous testing.

U.S. Department of Defense experience with developing modular systems offers a model of how parallel development can be implemented. Modularity is designed into a system or family of systems through the expected use of common subsystems or components. Historical experience suggested mixed success with this approach. The UH-60 variants can be viewed from this perspective as a success, while the Family of Armored Vehicles program in the 1980s and the

Future Combat System's manned vehicle systems in the 2000s were less than successful, illustrating the risks and challenges of this kind of approach.[3]

Implementing agile acquisition and parallel development on a large scale (i.e., above a single program at a time) is particularly challenging because it requires a fundamentally different way of conceiving of capability development, system design, and fielding. Organizational change management strategies offer useful guidance.[4] This literature identifies strategies that can enable large organizations to change business processes and associated cultural elements. Specific strategies of these change management approaches relevant to implementing parallel development in an agile acquisition context include the following:

- *Provide senior leadership support*, which includes communicating a compelling need for change, articulating a specific plan to accomplish it, and providing sustained support over time.
- *Establish a sense of urgency*, which helps stakeholders solve problems and overcome the challenges involved in following nontraditional processes.
- *Create a coalition of relevant stakeholders* at two levels: An executive level (political appointee, general/flag officer, and Senior Executive Service level) provides support for the change effort and monitors it regularly to ensure that it continues to advance the broader goals of the organization, and a management level (O-6/GS-15 level) works the details and maintains coordination and information flow among stakeholder organizations.
- *Build on incremental successes* by tracking and communicating performance in short intervals to build experience and confidence.
- *Consolidate and institutionalize changes*: Consolidate the incremental successes to date by incorporating them into policy and practice and using them as a foundation for further change.

Over time, new participants come to an activity with no knowledge of what it looked like before formal change management had taken place. The new approach is fully internalized and taken for granted; it becomes routine. As noted earlier, that does not mean that change ceases to occur. It means only that, when personnel in the activity today happen to stumble across the language spoken in the activity before the change management exercise, it sounds archaic and nonsensical to them. Change is truly complete when the new policies and practices have been fully adopted and become standard operating procedure.

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[3] For a good discussion of modularity, see Jean M. Dasch and David J. Gorsich, "Survey of Modular Military Vehicles: Benefits and Burdens," *Defense ARJ*, Vol. 23, No. 1, January 2016.

[4] See John P. Kotter, *Leading Change*, Boston: Harvard Business School Press, 1996; Frank Camm, Laura Werber, Julie Kim, Elizabeth Wilke, and Rena Rudavsky, *Charting the Course for a New Air Force Inspection System*, Santa Monica, Calif.: RAND Corporation, TR-1291-AF, 2013; and National Defense Research Institute, *Sexual Orientation and U.S. Military Personnel Policy: An Update of RAND's 1993 Study*, Santa Monica, Calif.: RAND Corporation, MG-1056-OSD, 2010, Chapter 11.

Conclusions

Although the sample size was small, our review of programs exhibiting one or more management actions that enable parallel development suggests that this approach is applicable under certain conditions. Successful application of parallel development management actions can help to address technological risk and accelerate the delivery of new capabilities through incremental fielding, one of the goals of agile acquisition.

Accurate assessment of technological risk and maturity in key subsystems is critical in the successful application of parallel development. System integration must be explicitly managed and technological risk must be fully understood. The roles and responsibilities of and within the government and contractor teams must be laid out as part of program planning, with particular emphasis on integration and test functions. Finally, parallel development is relatively more successful when applied incrementally, focusing on introducing one major new subsystem at a time. A block upgrade strategy can enable this, focusing on an element of either a mission system or the platform, but not both in the same increment.

Parallel development can be applied to a program in multiple ways, depending on identified needs. It can enable flexibility and focus on specific elements of a design or a system by decomposing large, complex programs into more-manageable pieces. Similarly, it allows a program to plan for and adapt to changes in threat or requirements. It can also be employed as a contingency tool by isolating problematic elements of a program or as a strategy to mitigate the effects of concurrency.

While parallel development allows increased focus on a narrower set of issues, it also increases the importance and risk of system integration. That is the paradox of parallel development. Decoupling subsystems allows a narrower focus on a more limited set of technical challenges, but because the subsystems are designed and developed separately, integration risk may increase. Such risk can be mitigated by managing software and hardware interfaces through specifications and standards.

Parallel development has the potential to reduce the time from technology development to the fielding of new capabilities, but it is not a panacea for the persistent acquisition challenges that affect complex system development. It must be carefully and wisely applied, and it may not always be an appropriate development approach. For instance, parallel development may have more-limited application for fully integrated systems requiring unique interfaces.

A Path Forward

This research was limited in both scope and time. Therefore, we focused on identifying an initial list of management actions that enable parallel development and agile acquisition. Our intention was to begin the discussion by establishing a framework that can then be refined through further research.

This begs the question of where further research efforts could be usefully applied. The following possibilities occur to us:

- Review additional programs to identify other important enablers, such as open systems and open architectures.
- Determine how many of the management actions enabling parallel development need to be present to ensure successful application. With this quick look, we are only able to say that all are required; we suspect that a more thorough analysis could better identify interdependencies and thus refine the range of parallel development approaches.
- Provide more depth to the analysis by diving deeper into the details of each program. This could identify important nuances to consider when transferring lessons from one program to another.
- Derive the characteristics of a program and environmental factors that define when a parallel development approach would be appropriate.

Future research should adopt a more rigorous methodological approach, addressing the three main limitations of the current work. The minimal reference to the concept of parallel development in program case studies could be mitigated by using a much broader survey of the literature, including broadening the program sample to programs below the major defense acquisition programs used here. The size of the program sample should be significantly increased along several dimensions—size, commodity type, time frame—to better capture the full range of management actions that may enable parallel development. Finally, a more rigorous study would include extensive interviews with program office and industry personnel and original research on specific programs, drawing on a much wider range of published reports and official program documentation.

Acknowledgments

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Any errors of omission or commission are the sole responsibility of the authors.

Abbreviations

AESA	active electronically scanned array
AMRAAM	Advanced Medium-Range Air-to-Air Missile
APREP	AMRAAM Producibility Enhancement Program
A-RCI	Acoustic Rapid Commercial-off-the-Shelf Insertion
ATR	Automatic Target Recognition
CONOPS	concept of operations
Dem/Val	demonstration and validation
DoD	U.S. Department of Defense
EDM	engineering development model
EMD	engineering and manufacturing development
FY	fiscal year
GAO	U.S. Government Accountability Office
IOC	initial operational capability
JSPO	joint system program office
LANTIRN	Low Altitude Navigation and Targeting Infrared for Night
LCS	littoral combat ship
LRIP	low-rate initial production
MS	milestone
MSIP	Multinational Staged Improvement Program
OSD	Office of the Secretary of Defense
PEO	program executive office
SPO	system program office
SST	solid-state transmitter
TMRR	technology maturation and risk reduction

Chapter One. Introduction

The U.S. Air Force's Air Superiority 2030 Enterprise Capability Collaboration Team was formed to explore innovative technological, operational, and acquisition concepts for developing and fielding future capability in a core Air Force mission area. RAND's Project AIR FORCE provided analytical support to the Air Superiority 2030 Enterprise Capability Collaboration Team across several dimensions, including strategies to more rapidly transition new technologies and concepts to the fleet. This report is one result of that effort.

Agile acquisition is an approach that can more rapidly develop, test, and deploy new capabilities. It is more responsive, flexible, and adaptive to changes in threat, technology, and environment than traditional acquisition processes. Agile acquisition is not, however, a single process or strategy. Rather, it comprises many processes or strategies that can enable the responsiveness and flexibility that characterize agile acquisition as a whole.[1]

Parallel development is an approach that falls within the set of agile acquisition processes. This concept is a way to manage technological risk in order to accelerate the fielding of new capabilities. We define *parallel development* as an approach that intentionally decouples the technological development and management of core elements of a weapon system. Examples include decoupling platform development from development of mission system equipment and decoupling the development of software architecture from applications that will run in that software environment. In parallel development, the development of new technologies (and associated operational concepts and capabilities) for platforms, mission systems, software, and architecture are on separate paths managed by separate entities, with explicit attention to system integration. Subsystem development, testing, and maturation may happen at the same time, but each subsystem is refined, enhanced, and matured at its own pace. When a subsystem reaches maturity, it can be integrated into the overall weapon system.

There is no single model of parallel development; rather, there are multiple approaches tailored to the unique characteristics of a program and the program's underlying technology. But all models share some basic attributes at a general level, including

- decomposition of the desired system design into discrete subsystems or components
- an intentional plan to develop, mature, and deploy system capabilities incrementally in parallel (same general time frame) but independent of each other

[1] See, for instance, Mark A. Lorell, Julia F. Lowell, and Obaid Younossi*, Evolutionary Acquisition: Implementation Challenges for Defense Space Programs*, Santa Monica, Calif.: RAND Corporation, MG-431-AF, 2006; Pete Modigliani and Su Chang, *Defense Agile Acquisition Guide: Tailoring DoD IT Acquisition Program Structures and Processes to Rapidly Deliver Capabilities*, The MITRE Corporation, 14-0391, March 2014; and Matthew R. Kennedy and Dan Ward, "Inserting Agility in System Development," *Defense ARJ*, Vol. 19, No. 3, July 2012.

- separate design, development, and testing of major subsystems or components, allowing subsystem maturation at a pace suitable for that subsystem
- separate management of each subsystem using a tailored development approach specific to that subsystem
- a focus on introducing one new capability or technology at a time, to the extent possible
- modularity and open systems or open architectures as a design feature of the system.

We do not intend this definition of parallel development to be definitive but rather a starting point to enable subsequent refinement of the concept. But it does reflect certain basic characteristics of a parallel development approach—planned or intentional, decomposition of technical challenges, separate management and development, incremental introduction of capabilities—that we use as criteria to identify examples from which lessons can be drawn on how to implement this approach more broadly.

Parallel development shares many attributes with other approaches to system development intended to field capabilities more rapidly by managing risk differently; such approaches include evolutionary acquisition, spiral or incremental development, and modularity. Because these approaches are all in the same family of development approaches with the same goal, we do not think that it is particularly useful to distinguish among them here. Program execution, including capability and system development approaches, tends to be unique, reflecting specific characteristics of a program's (or system's) political, technological, and economic environment.

Objectives

The objective of this research is to identify and describe how parallel development can work in the context of an agile acquisition process. This includes offering an initial definition of key concepts and identifying key management actions that enable parallel development. We also identify primary implementation challenges and constraints of widespread adoption of parallel development approaches, and we outline strategies to mitigate and address those challenges. Our intention is to begin to define parallel development and illustrate practical application of the concept by using historical examples.

This was a short and narrowly focused research effort. Our approach thus relies on and draws from existing material. We reviewed select literature on the concepts of agile acquisition and parallel development in order to provide context and an initial analytical framework. We then reviewed select programs that illustrate management actions that can enable parallel development and agile acquisition. Given our limited time and resources, we drew on existing case studies, many of which were published in prior RAND research. Although these programs do not necessarily exhibit a "pure" parallel development approach, they did implement critical management actions, as part of their overall acquisition strategy, that can enable parallel development.[2] Lessons from these programs provide insight into the key enablers of a successful parallel development approach.

Analytical Framework

The concept of agile acquisition is not new. It was originally applied to software development,[3] but it shares attributes with other alternative approaches to traditional acquisition processes, such as spiral development, evolutionary acquisition, and incremental development. All of these approaches are aimed at shortening the time from the technology development phase to fielding a capability.[4]

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[2] By *pure*, we mean that a program's strategy exhibits all the elements of parallel development in our framework. This includes adhering to a comprehensive set of well-defined engineering or management attributes, including decomposition of the desired system design into discrete subsystems or components; an intentional plan to develop, mature, and deploy system capabilities incrementally in parallel (same general time frame) but independent of each other; separate design, development, and testing of major subsystems or components, allowing subsystem maturation at a pace suitable for that subsystem; separate management of each subsystem using a tailored development approach specific to that subsystem; a focus on introducing one new capability or technology at a time, to the extent possible; and modularity and open systems or open architectures as a design feature of the system.

[3] Mary Ann Lapham, Ray Williams, Charles Hammons, Daniel Burton, and Alfred Schenker, *Considerations for Using Agile in DoD Acquisition*, Software Engineering Institute, Carnegie Mellon University, Technical Note CMU/SEI-2010-TN-002, April 2010. Also see Modigliani and Chang, 2014.

[4] The RAND Corporation has conducted extensive research on such alternative approaches to acquisition. For further reading, see Lorell, Lowell, and Younossi, 2006; Michael G. Anderson, *The Air Force Rapid Response Process: Streamlined Acquisition During Operations Desert Shield and Desert Storm*, Santa Monica, Calif.: RAND Corporation, N-3610/3-AF, 1992; John Birkler, *Untying Gulliver: Taking Risks to Acquire Novel Weapon Systems*, Santa Monica, Calif.: RAND Corporation, OP-268-OSD, 2009; John Birkler, C. Richard Neu, and Glenn Kent, *Gaining New Military Capability: An Experiment in Concept Development*, Santa Monica, Calif.: RAND Corporation, MR-912-OSD, 1998; John Birkler, Mark V. Arena, Irv Blickstein, Jeffrey A. Drezner, Susan M. Gates, Meilinda Huang, Robert Murphy, Charles Nemfakos, and Susan K. Woodward, *From Marginal Adjustments to Meaningful Change: Rethinking Weapon System Acquisition*, Santa Monica, Calif.: RAND Corporation, MG-1020-OSD, 2010; John Birkler, Giles Smith, Glenn A. Kent, and Robert V. Johnson, *An Acquisition Strategy, Process, and Organization for Innovative Systems*, Santa Monica, Calif.: RAND Corporation, MR-1098-OSD, 2000; Jeffrey A. Drezner, *The Nature and Role of Prototyping in Weapon System Development*, Santa Monica, Calif.: RAND Corporation, R-4161-ACQ, 1992; Jeffrey A. Drezner and Meilinda Huang, *On Prototyping: Lessons from RAND Research*, Santa Monica, Calif.: RAND Corporation, OP-267-OSD, 2009; Jeffrey A. Drezner and Robert S. Leonard, *Innovative Development: Global Hawk and DarkStar: Their Advanced Concept Technology Demonstrator Program Experience*, Santa Monica, Calif.: RAND Corporation, MR-1473-AF, 2002; Jeffrey A. Drezner and Giles K. Smith, *An Analysis of Weapon System Acquisition Schedules*, Santa Monica, Calif.: RAND Corporation, R-3937-ACQ, 1990; Christopher H. Hanks, Elliot Axelband, Shuna Lindsay, Mohammed Rehan Malik, and Brett Steele, *Reexamining Military Acquisition Reform: Are We There Yet?* Santa Monica, Calif.: RAND Corporation, MG-291-A, 2005; Burton H. Klein, Thomas K. Glennan, Jr., and Gustave H. Shubert, *The Role of Prototypes in Development*, Santa Monica, Calif.: RAND Corporation, RM-3467/1-PR, 1971; Mark A. Lorell, Julia F. Lowell, Michael Kennedy, and Hugh P. Levaux, *Cheaper, Faster, Better? Commercial Approaches to Weapons Acquisition*, Santa Monica, Calif.: RAND Corporation, MR-1147-AF, 2000; Isaac R. Porche III, Shawn McKay, Megan McKernan, Robert W. Button, Bob Murphy, Kate Giglio, and Elliot Axelband, *Rapid Acquisition and Fielding for Information Assurance and Cyber Security in the Navy*, Santa Monica, Calif.: RAND Corporation, TR-1294-NAVY, 2012; Giles K. Smith, A. A. Barbour, Thomas L. McNaugher, Michael D. Rich, and William Stanley, *The Use of Prototypes in Weapon System Development*, Santa Monica, Calif.: RAND Corporation, R-2345-AF, 1981; Giles K. Smith and E. T. Friedmann, *An Analysis of Weapon System Acquisition Intervals, Past and Present*, Santa Monica,

Key enablers of agile acquisition include the following:

- a sense of urgency
- conspicuous, informed support of key senior leaders
- tighter alignment and more-frequent interaction among requirements, acquisition, and budget organizations
  - close collaboration between user (warfighter) and developer (industry and government)
- open system or open architecture design
- use of mature technology in planned incremental upgrades
- experimentation, concept refinement, and technological maturity through the use of prototypes and engineering development models (EDMs)
- streamlined decision and approval processes, including
  - delegation of authority to lower levels
  - limited organizational participation (horizontal and vertical oversight)
  - flexible contracting strategies (e.g., other transaction authority)
- flexibility in technical and operational requirements and stability in funding.

An agile acquisition approach can be characterized by several activities or strategies, including

- use of advanced concept technology demonstration or joint concept technology demonstration programs to initiate development and operational test of a new capability
- rapid prototyping to address areas of risk and demonstrate feasibility or practicality before committing to further development or production
- waiving regulations or reporting requirements (e.g., documentation, review, and oversight requirements), which may increase risk to both the user and developer
- relaxing technical or operational requirements that may require more time or money—for example, redefining the performance objectives and threshold values contained in a program's baseline
- evolutionary acquisition, with incremental improvements in either capability (platform or subsystems); a block buy approach is also consistent with the tenants of agile acquisition.

The strategies common to agile acquisition are consistent with the concept of parallel development. Parallel development can be conceived as an approach within the larger context of agile acquisition. In particular, it is intended to address technological and integration risk through incremental development and introduction of new technology, resulting in the accelerated

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Calif.: RAND Corporation, R-2605-DR&E/AF, 1980; Geoffrey Sommer, Giles K. Smith, John Birkler, and James Chiesa, *The Global Hawk Unmanned Aerial Vehicle Acquisition Process: A Summary of Phase I Experience*, Santa Monica, Calif.: RAND Corporation, MR-809-DARPA, 1997; Michael R. Thirtle, Robert V. Johnson, and John L. Birkler, *The Predator ACTD: A Case Study for Transition Planning to the Formal Acquisition Process*, Santa Monica, Calif.: RAND Corporation, MR-899-OSD, 1997; and Shara Williams, Jeffrey A. Drezner, Megan McKernan, Douglas Shontz, and Jerry M. Sollinger, *Rapid Acquisition of Army Command and Control Systems*, Santa Monica, Calif.: RAND Corporation, RR-274-A, 2014.

fielding of new capabilities that is a hallmark of agile acquisition. By decoupling development of components or subsystems (e.g., platform and mission systems) and allowing each to mature and evolve at their own pace, quickly evolving mission systems can be integrated into existing platforms in order to deliver new capabilities with improved speed and responsiveness. Parallel development can be used to simplify execution of large, complex systems by breaking them down into smaller, more-manageable development activities. In general, parallel development approaches enable incremental introduction of new capabilities.

For purposes of this research, we adopt the perspective of a new-start program. That is, our framework assumes that the key management actions that we identify as enabling parallel development can be designed into the acquisition strategy in the early stages.

It is important to note that parallel development is not concurrency in the traditional sense. In the traditional acquisition process context, *concurrency* is defined as the overlap of the development and production phases of a program—that is, initiation of production prior to the completion of development (including initial developmental and operational testing). Under parallel development, technologies are developed at their own pace, largely independent of each other, and those technologies are not transitioned to production and integrated as part of a weapon system until they are fully developed and understood. Examples include the targeting kit at the heart of the Joint Direct Attack Munition and the development of the guidance, rocket motor, and electronic counter-countermeasures subsystems in the Advanced Medium-Range Air-to-Air Missile (AMRAAM) program.

By our definition, modification programs are not strictly parallel development, although they share some characteristics (e.g., incremental development of new subsystem capability). Parallel development is planned from the outset to develop major subsystems and technologies separately on their own timelines, integrating mature technologies across the subsystems to yield an increment of system capability that can be fielded. System of system programs may use a parallel development approach (e.g., developing major subsystems and systems on independent timelines), but such a program is not inherently a parallel development.

We also do not consider co-development to be parallel development. For instance, the F-22 and DDG-1000 programs included co-development of major subsystems at the same time, managed by the same office, under the same integrated schedule. Those co-developed major subsystems included the following:

- F-22: engine, platform, and avionics
- DDG-1000: hull form, propulsion, total ship system computing environment, peripheral launch tubes, advanced gun system and projectile, automated fire suppression system, and other major subsystems.

Although the contracts developing these systems were different, they were managed under a single government program office. More importantly, advances in all major subsystems were planned to be introduced simultaneously, which increases technological risk. Parallel development is intended to reduce technological risk by maturing and introducing major new subsystem technologies on separate timelines, introducing them incrementally one at a time when they are fully mature.

Parallel development is neither a single approach nor a complete acquisition strategy in itself. Rather, the concept encompasses a range of management actions that can be used as part of a program's broader acquisition strategy. It can (and should) be applied differently to programs with different characteristics (i.e., tailoring). We discuss the method we used to identify examples of parallel development and agile approaches below, as well as list the programs from which we draw those examples. We elaborate on those examples in Chapter Two.

Methodology

We initially reviewed a body of RAND literature, U.S. Department of Defense (DoD) policy guidance documentation, and several outside studies on agile and rapid acquisition to ground our analysis of parallel development in a broader acquisition framework. We then identified ten program case studies from previous RAND research that embodied one or more of the following characteristics:

1. The program employed some form or aspect of parallel development in its acquisition strategy (e.g., F/A-18E/F).
2. The program was originally conceived as an agile acquisition program (e.g., B-1B and AMRAAM).
3. The program provided an important contrast or counterpoint to another program featuring parallel development (e.g., DDG-51 versus DDG-1000).

Importantly, we do *not* present any of the programs as perfect examples of parallel development—or even examples of parallel development at all. For instance, the F-22 program applied parallel development techniques only sparingly, thus it is not meant to be treated as an appropriate model of parallel development.[5] The F-22 does, however, provide a useful contrast to the F/A-18E/F, which did employ management actions enabling parallel development. The program sample was designed to identify specific enablers of parallel development. The ten programs we reviewed (and the enablers they exhibited) included the following:

- *F-22 Raptor multi-role stealth fighter* (Air Force): The F-22 program's acquisition strategy included co-development of the engine, airframe, and mission systems to be integrated into full capability. Parallel development was not used, and the highly

[5] The only visible instance of parallel development in the F-22 program occurred in the development of an air-to-ground capability. This does not mean that this is the only example of parallel development in the F-22, but it is the only publicly available example. The active electronically scanned array (AESA) radar and the engine for the F-22 were developed by separate contractors but on essentially the same timeline as the platform with the intent to integrate them all at the same time to produce full capability. Likewise, all systems were managed within the F-22 System Program Office (SPO). Therefore, the F-22 does not meet our definition of parallel development. Although the Air Force initiated multiple F-22 modernization programs, these were conceived well into the production and deployment phase and are therefore not applicable to the narrow framework explored in this report—namely, applying parallel development as an agile acquisition approach.

integrated nature of the platform suggests that parallel development may not have been appropriate. We therefore chose to include the F-22 program as an interesting contrast to the other aircraft development programs we examined.

- *F/A-18E/F Super Hornet* (Navy): The F/A-18E/F was a major modification program, including both the airframe and mission systems, that explicitly used parallel development. Changes to the airframe were introduced first, and mature legacy mission systems were integrated in the initial versions of the system. New mission systems, such as an AESA radar, were integrated as they matured.
- *F-16 Multinational Staged Improvement Program (MSIP)* (Air Force): Like the F/A-18E/F, the F-16 MSIP was expressly conceived as a parallel development process. The program established a clear blueprint for incrementally upgrading the F-16C/D airframe with advanced subsystems developed in parallel. The program office planned to execute the upgrade program in three stages, with mini-block upgrades in each stage. The more-significant technological advances were pushed to the later stages to allow them to fully mature. Parallel development of the major subsystems was managed by separate program offices, but the F-16 SPO collaborated closely with each to incorporate MSIP-specific design elements.
- *B-1B Lancer bomber* (Air Force): Parallel development of key subsystems was critical to the desired agility in the B-1B's acquisition strategy. Planners attempted to achieve significant commonality with the B-1A airframe and incorporate mature propulsion and electronics technologies to minimize technological risk, with the expectation that mature subsystems could be incrementally upgraded as technologies matured in parallel. We included the B-1B program as an example of a parallel development process specifically designed to accelerate fielding of the system. However, the program also reflects the importance of maximizing the number of enabling management strategies used—and, in particular, the potentially negative consequences of employing parallel development in the absence of several such management strategies.
- *Advanced Medium-Range Air-to-Air Missile (AMRAAM)* (Air Force/Navy): Parallel development was not initially pursued in this case, which ostensibly violates the spirit of our conceptual definition (that embedding parallel development approaches into the early planning process is critical to successful implementation). However, the AMRAAM acquisition program was specifically designed to be agile. Parallel development was implemented during the engineering and manufacturing development (EMD) phase and proved a highly effective approach at isolating technological risk, aligning technological maturity levels with fielding timelines, and, ultimately, facilitating rapid fielding of the basic system. Although the program thus does not completely adhere to our definition of a parallel development *acquisition strategy*, it is instructive to view in the context of the management strategies that it did and did not implement, as well as its relative effectiveness as an agile acquisition program.
- *Low Altitude Navigation and Targeting Infrared for Night (LANTIRN)* (Air Force): Like the AMRAAM program, the LANTIRN acquisition program was designed to rapidly field a critically needed capability and did not initially pursue parallel development. Also like the AMRAAM program, parallel development was attempted as a contingency during EMD. In contrast, however, the LANTIRN program limited the use of parallel development to a few critical technologies, such as the Automatic Target Recognition (ATR), with most components developed alongside the platform in the EMD program.

The LANTIRN program thus serves as an interesting counterpoint to the AMRAAM program—that is, similar fielding and acquisition strategies, initial absence of parallel development, and eventual use of parallel development as a contingency, contrasted with significant differences in scope and type of parallel development strategies employed, number of enablers pursued, and program outcomes.

- *F-117 Nighthawk stealth fighter* (Air Force): The F-117 program's primary focus was on pushing the state of the art in stealth technologies, principally the airframe and engine, while still maintaining an emphasis on rapid fielding. Mature mission systems operating on other aircraft were used to accelerate deployment of the basic capability. The F-117 program constitutes one of the few pure examples of parallel development. We include it not only on its own merits as a parallel development program but also as a point of comparison with other pure parallel development programs in the broader context of agile acquisition. That is, although the F-117 acquisition program generally fits our definition of *parallel*, we attempt to identify the extent to which it did or did not exhibit the enabling management strategies outlined in Chapter Two and, in turn, how its use of these enablers contributed to its effectiveness as an agile acquisition program.
- *DDG-51* Arleigh Burke*–class destroyer* (Navy): The ship and its critical Aegis combat system were separate acquisition programs managed by separate program executive offices (PEOs). The DDG-51 was expressly conceived as a parallel development acquisition program, whereby the hull and mature capabilities would be rapidly fielded and incrementally upgraded as subsystems—particularly the Aegis technology—matured in parallel. In addition to the utility the program thus provides as a pure example of parallel development, it further provides a useful contrast to the DDG-1000 program (see below), which initially planned to follow a similar development outline but ultimately diverged.
- *DDG-1000* Zumwalt-*class destroyer* (Navy): Although the original DD(X) program planned multiple hull flights and mission system capability upgrades, a challenging mix of budget constraints and rigorous oversight by the Navy and Office of the Secretary of Defense (OSD) ultimately led to a "single step to full capability" approach. There were ten major subsystems based on new technology that would be integrated together, and, although each had a prototyping program (called an EDM) to reduce risk, all were developed on the same timeline and introduced together. Unlike the DDG-51 program, on which the original acquisition strategy was loosely modeled, all development activities were also organized under one program office.
- *Littoral combat ship (LCS)* (Navy): Two separate hull variants and three unique mission system packages (for mine countermeasures, antisubmarine warfare, and surface warfare) were developed independently, as separate acquisition programs managed by distinct program offices. The LCS program was explicitly conceived to be agile, with the lead ship to be rapidly fielded and equipped with mature mission systems. New mission-module technologies were designed to be modular and introduced incrementally as they matured in parallel. The LCS thus represents another pure example of parallel development, in both program structure and desired agility. However, the LCS program provides an important counterpoint to other pure parallel development programs, because it exhibits far fewer enablers and (we argue, not incidentally) is relatively less effective at employing parallel development than others in our sample.

Our program case studies were primarily grounded in historical RAND research, consisting of detailed explorations of the program histories, acquisition strategies, and development program outcomes. We further attempted, where possible, to substantiate program details and parallel development insights through a review of Selected Acquisition Reports, DoD policy guidance documents, and other outside assessments. However, it is important to note that the case studies in this report do not constitute an exhaustive analysis of each development program. Indeed, we relied primarily on prior RAND research that, in some cases, may be somewhat outdated or incomplete. We also did not conduct primary-source surveys, and actual performance data were generally limited. However, given our limited objective of identifying a set of enablers for parallel development as a jumping-off point for further research, the program details are less important than the overarching lessons that may be gleaned for future potential agile acquisition programs (see below for more discussion of the report's limitations).

We examined each program's development experience to determine whether it exhibited some aspect of parallel development. Using the insights gained from each program's specific application of parallel development techniques, and informed by actual program outcomes (i.e., performance, schedule, and cost) where possible, we refined the list of enablers of parallel development across our program sample. Finally, we detailed the extent to which each program did or did not exhibit each enabler.

Limitations of this Study

This study was designed as an exploratory review of readily available information conducted in a short time frame. It is therefore not a comprehensive or exhaustive analysis of parallel development. It does, however, offer an initial analytical framework that can inform a broader, more complete study of the issue.

Perhaps the greatest limitation to our study is, simply, the dearth of research expressly dedicated to parallel development. There are minimal references to the concept in either RAND literature or DoD policy guidance documentation. Moreover, the research upon which our case studies are based provides only sporadic (if any) discussion of parallel development practices employed by programs in our sample. Our review of the program case studies was limited to identifying likely aspects of parallel development, with few explicit references to the concept. The lack of direct references in prior research thus infuses a significant degree of subjectivity into our analysis.

The size of our program sample poses another constraint. Establishing a robust set of guiding principles for parallel development would ideally entail a much broader program sample in order to test the legitimacy of our findings (and, presumably, identify additional enablers of parallel development not present in our limited sample). We also did not select the programs in our sample with any meaningful rigor, beyond a cursory identification of potential parallel development or agile attributes within the RAND literature.

The lack of discernible references to parallel development in the relevant body of literature and the limited size of our program sample are compounded by the fact that our assessments are based almost entirely on previous RAND research. This has two potentially serious limiting factors. First, given the lack of primary sources upon which we relied, there may be gaps in our data or inconsistencies with actual program experiences. A more formal assessment would obviously require considerably more program-specific source material and methodological rigor. Second, much of the pertinent RAND literature may be somewhat outdated, with many of the programs having undergone development 30 (or more) years ago. During the intervening period, conventional wisdom regarding acquisition practices and principles has evolved. Several issues that are particularly germane to parallel development, such as software complexity, integration, and subsystem modularity, have become considerably more relevant in today's development landscape than in any of the programs we explored. With this in mind, we attempted to fill in any potential gaps in enablers of parallel development to better reflect the full complexity of new warfighting and technological concepts. Nevertheless, further research is required to properly align the notion of parallel development with evolving acquisition practices and technological standards.

In spite of the preceding limitations, we have attempted to develop a first-step set of guiding principles for parallel development. This report is designed to merely establish parallel development as a legitimate practice in an agile acquisition context and is not intended to be exhaustive. In light of the growing importance of strategic agility in acquisition practices and the increasingly constrained nature of development budgets, we recommend that further research be pursued to more comprehensively document the attributes and enablers of parallel development. In order to instill sound acquisition practices as early as possible, it is critical that program managers fully understand the potential benefits—and limitations—of employing parallel development techniques in an agile environment.

Organization of This Report

Chapter Two describes our research results in detail, including specific examples from programs illustrating management actions that enable parallel development and how they can be implemented.

In Chapter Three, we begin to identify the myriad challenges that the Air Force (and DoD generally) may face implementing parallel development, and we suggest possible actions that may mitigate some of these challenges.

Chapter Four presents our conclusions and observations on parallel development in an agile acquisition context.

Chapter Two. Enablers of Parallel Development in an Agile Acquisition Environment

Parallel development is one approach to capability development in defense acquisition. However, neither official DoD acquisition policy guidance documents nor reports in the relevant body of RAND literature have ever formally developed a robust conceptual framework for parallel development. Given the inherent constraints of this study (outlined in Chapter One), we do not attempt to construct such a comprehensive framework here; rather, we merely seek to illuminate parallel development as a viable and potentially enabling strategy in the context of agile acquisition. To this end, we identify a broad set of enablers of parallel development, as well as the potential limitations of parallel development within the broader acquisition framework.

In this chapter, we first provide a brief definition of parallel development and describe the narrow context in which we seek to apply the concept. We then outline and explore *enablers of parallel development* that may contribute to rapidly fielding new capabilities. Finally, we explore in more depth each of the *management actions* that constitute the enablers, presenting evidence from historical program case studies.[1]

As noted earlier, parallel development is a way to manage technological risk in order to accelerate the fielding of new capabilities. We define *parallel development* as an approach that intentionally decouples the development of core elements of a weapon system, including both technological and managerial elements. Examples include decoupling platform development from development of mission system equipment and decoupling development of software architecture from applications that will run in that software environment. In parallel development, the development of new technologies (and associated operational concepts and capabilities) for platforms, mission systems, software, and architecture are on separate paths managed by separate entities, with explicit attention to system integration. Subsystem development, testing, and maturation are happening at the same time, but each subsystem is refined, enhanced, and matured at its own pace. When a subsystem reaches maturity, it can be integrated into the overall weapon system.

There is no single model of parallel development; rather, there are multiple approaches tailored to the unique characteristics of a program and the program's underlying technology. But all models share some basic attributes at a general level.[2] Those attributes include

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[1] In this report, we distinguish between *management actions*, which are specific activities that a program office can perform, and *enablers of parallel development*, which each represent a set of interdependent management actions that can enable parallel development when performed together.

[2] As discussed in Chapter One, constructing an exhaustive set of attributes of parallel development at a granular, engineering-quality level is beyond the scope of this report. Indeed, the purpose of this research is to identify tangible ways in which parallel development can potentially accelerate fielding timelines in order to motivate further

- decomposition of the desired system design into discrete subsystems or components
- an intentional plan to develop, mature, and deploy system capabilities incrementally in parallel (same general time frame) but independent of each other
- separate design, development, and testing of major subsystems or components, allowing subsystem maturation at a pace suitable for that subsystem
- separate management of each subsystem using a tailored development approach specific to that subsystem
- a focus on introducing one new capability or technology at a time, to the extent possible
- modularity and open systems or open architectures as a design feature of the system.

We do not intend this definition of parallel development to be definitive; rather, it is a starting point to facilitate subsequent refinement of the concept. But it does reflect certain basic characteristics of a parallel development approach—planned or intentional, decomposition of technical challenges, separate management and development, and incremental introduction of capabilities—that we use as criteria to identify examples from which lessons can be drawn on how to implement this approach more broadly.

Using our program case studies, and informed by RAND research on agile acquisition principles, we identified the following five *enablers of parallel development*, or *enablers*:

1. effective assessment of technological risk and maturity
2. effective management of system integration risk
3. planned incremental approach to fielding capabilities
4. tight alignment of requirements, acquisition, and budget stakeholders
5. strong contingency planning.

This list is not meant to be exhaustive and obviously entails some degree of subjectivity. Indeed, the limited size of our sample presumably masks other potentially important enablers not present in the programs we examined.[3] However, within our program sample, the above enablers of parallel development were consistently present in programs that effectively used parallel development to facilitate agile acquisition. Each enabler relies, in turn, on interrelated management actions, which we elaborate on in the following sections.

The reader should note that these enablers do not represent specific program characteristics allowing for or precluding the use of parallel development, nor are they necessarily exclusive to the concept of parallel development. A program could conceivably decouple the development of

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policy discussions. Additional research will be required to rigorously identify specific program characteristics that either allow for or rule out parallel development. Likewise, we did not have access to the primary-source data necessary to correlate parallel development implementation with specific program outcomes. Finally, the list of enablers (and the management actions that constitute them) may not be exhaustive, having been informed by a limited sample that was not selected randomly.

[3] In addition to the limited sample size, our data selection process and evaluation may have relied, to varying degrees, on certain forms of bias. We did not attempt to mitigate this in light of our rather limited objectives—namely, to initiate a policy discussion by identifying an initial set of enablers of parallel development. A more formal assessment of the attributes, enablers, and benefits of parallel development would obviously require bias to be effectively eliminated from both the study's construction (i.e., selection bias) and findings (i.e., confirmation bias).

core technological and managerial elements without, for example, effectively assessing technological risk and maturity. Our purpose, therefore, is not to characterize parallel development, per se, but rather to identify specific management actions that enable parallel development to be successful. We define parallel development as one approach to agile acquisition; therefore, parallel development is "successful" in this context if it is able to rapidly field new capabilities. Had we been asked to address a different set of objectives, such as minimizing cost in parallel development, the five enablers and their underlying management actions would presumably have been quite different.[4]

All of the programs in our sample feature some variation of parallel development, ranging in scope from limited technology development activities to full acquisition strategy. No one program fully encompasses all five of the enablers, but each program may use or exhibit some aspect of the individual management actions that constitute the enablers. For instance, the AMRAAM program exhibits two key aspects of *effective management of system integration risk*—namely, it appropriately assigned roles and responsibilities according to organizational capacity, and it effectively isolated subsystem integration risk—but it did *not* effectively conduct early and continual assessments of integration risk. It is important to note that whether a program exhibited a particular management action does not necessarily indicate success or failure either in program outcome (i.e., cost, schedule, performance) or in the program's broad use of parallel development. It also does not indicate the degree to which the program actually exhibited a particular management action. Rather, we impose a simple binary choice—yes or no—on each program, indicating whether its development experience exhibited a given management action. We provide these results in this chapter and include a discussion of relevant program details, when available, to elaborate on the extent to which programs exhibited an enabler or underlying management action.[5]

Although the programs in our sample were chosen because they exhibited some aspect of parallel development, not every program constructed an acquisition strategy fully consistent with

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[4] Because parallel development can be applied continuously throughout a program's life cycle (development, production, and sustainment), the factors that enable it to be successful presumably also vary depending on the particular analytic frame of reference. We were asked to assess parallel development as a specific approach to agile acquisition. Therefore, the enablers we identify reflect ways in which a program can implement parallel development to facilitate agility in fielding a system. Many of the management processes documented in this report therefore tend to be aimed at the development time frame before Milestone (MS) C. However, this does not suggest that parallel development occurs only during that period or that parallel development processes cannot be enabled after MS C.

In this regard, the F-117 program's experience throughout production and sustainment is instructive for programs seeking to employ parallel development. Specifically, significant residual challenges can still remain after MS C in a broadly successful parallel development program if funding and requirements flexibility, an empowered SPO, rapid fielding, limited technological integration risks, and other key enablers are not paired with robust contingency planning.

[5] We also attempt to describe how effectively programs were able to translate each enabler or management action into rapidly acquiring and fielding the basic system. This information was not always readily available. Program details therefore vary in both scope and substance.

the basic attributes of parallel development outlined in Chapter One. For example, the LANTIRN program only began to develop the immature ATR system in parallel as a response to cost and schedule growth during the EMD phase, an action that was not explicitly planned and managed under the initial acquisition strategy. In contrast, the F-16 MSIP was expressly conceived in accordance with a parallel development acquisition strategy. Thus, we argue that merely disaggregating a program's development activities at some point during the acquisition process does not adequately fulfill our definition of parallel development. We use this distinction to distinguish between programs that embody parallel development and those that do not. Similarly, not every program was designed to be agile. The F-22 program, for instance, was never conceived as an agile acquisition program, with development planners prioritizing technological advances and an unprecedented degree of integration among various systems over a rapid fielding schedule. Naturally, it does not exhibit as many enablers of parallel development as the F-117 or B-1B programs, which were explicitly assigned agile acquisition strategies.

In the following sections, we provide a more detailed description of each of the five identified enablers of parallel development, as well as the additional underlying management actions by which to judge the effectiveness of parallel development strategies in agile acquisition programs.

Effective Assessment of Technological Risk and Maturity

One of the most critical enablers of parallel development is an effective assessment of technological risk and maturity in key subsystems.[6] Programs in our sample that successfully implemented parallel development efforts overwhelmingly provided—and acted on—a more accurate evaluation of risk and maturity early and recurrently throughout development. Importantly, the relative effectiveness with which programs are able to parlay risk assessments into successful parallel development strategies depends not only on the *accuracy* of the assessments but also on the *responsiveness* of program managers to the findings. That is, successful examples of parallel development tend to exhibit a willingness by the SPO to continually incorporate findings from technological risk and maturity assessments into a program's acquisition strategy.

Our program sample, informed by prior RAND research, suggests the following two management actions for evaluating the effectiveness of risk and maturity assessments in the context of parallel development:

a. early and continual assessment of technological risk and maturity
b. maximized use of mature systems.

[6] Our program sample suggests that an effective assessment of technological risk and maturity in key subsystems appears to be a necessary (but not sufficient) condition for parallel development to be successfully implemented. This accords with statutory and DoD policy guidance, under which a Technology Readiness Assessment is only one of many program requirements for major defense acquisition programs.

Four programs in our sample (F/A-18E/F, F-16 MSIP, DDG-51, and F-117) exhibited both of these characteristics (see Table 2.1).

Table 2.1. Effective Assessment of Technological Risk and Maturity

Platform	Early and Continual Assessment of Technological Risk and Maturity	Maximized Use of Mature Systems
F-22 Raptor	No	No
F/A-18E/F Super Hornet	Yes	Yes
F-16 MSIP	Yes	Yes
B-1B Lancer	No	No
AMRAAM	No	Yes
LANTIRN	No	No
F-117 Nighthawk	Yes	Yes
DDG-1000 *Zumwalt*	N/A[a]	No
DDG-51 *Arleigh Burke*	Yes	Yes
LCS	No	No

NOTE: N/A = not applicable. "Yes" indicates that a given program exhibited a particular characteristic of parallel development, based on historical RAND case studies. "No" indicates that a given program did not exhibit that characteristic. If there is insufficient evidence in the case studies to demonstrate that a given program either exhibits or does not exhibit a particular characteristic, it is labeled "Unknown." We elaborate below on the relative effectiveness with which a program executed each characteristic to rapidly field the basic platform. Some part of each program listed reflected what we define as parallel development. With the exception of the F/A-18E/F program and F-16 MSIP, the term *parallel development* was not explicitly used; rather, one or more elements of a program's acquisition strategy incorporated some aspect of parallel development (as defined in this report).

[a] The initial DD(X) acquisition strategy properly characterized the technological risks involved in integrating an array of immature technologies and planned to mitigate risks by spiraling in new capabilities. However, extreme budget cuts and OSD-directed program restructures propelled the program into EMD without adhering to the initial risk-management plan. As a result, major subsystems were incorporated into the lead ship design with questionable technology readiness levels at MS B. Coupled with an inadequate appraisal of integration risk, this caused significant risks to remain throughout the EMD phase. Certain capabilities—most notably the dual-band radar and propulsion system—were ultimately jettisoned in order to ameliorate the extreme cost and schedule growth. For further reading, see John F. Schank, Giles K. Smith, John Birkler, Brien Alkire, Michael Boito, Gordon T. Lee, Raj Raman, and John Ablard, *Acquisition and Competition Strategy Options for the DD(X): The U.S. Navy's 21st Century Destroyer*, Santa Monica, Calif.: RAND Corporation, MG-259/1-NAVY, 2006; and Irv Blickstein, Michael Boito, Jeffrey A. Drezner, James Dryden, Kenneth Horn, James G. Kallimani, Martin C. Libicki, Megan McKernan, Roger C. Molander, Charles Nemfakos, Chad J. R. Ohlandt, Caroline R. Milne, Rena Rudavsky, Jerry M. Sollinger, Katharine Watkins Webb, and Carolyn Wong, *Root Cause Analyses of Nunn-McCurdy Breaches*, Vol. 1: Zumwalt-*Class Destroyer, Joint Strike Fighter, Longbow Apache, and Wideband Global Satellite*, Santa Monica, Calif.: RAND Corporation, MG-1171/1-OSD, 2011.

Manifold approaches are available to program managers seeking to assess and optimize technological risk and maturity. These approaches include, but are not limited to, extensive and focused prototyping and experimentation; early and frequent testing; realistic cost and schedule estimates; consistency between technical requirements, operational need, and available technologies; and harmonization between the SPO and independent assessments of technological maturity. The preceding techniques are all critical to providing an effective assessment of technological risk and maturity; however, no single approach is, in itself, a sufficient precondition for parallel development.[7] In determining the appropriateness of parallel development, program managers should therefore seek to maximize the number and variety of such techniques used to facilitate an accurate evaluation of risk and maturity—and, consequently, to develop an acquisition strategy that is responsive to the results of that evaluation.

Below, we discuss in greater detail the two management actions for judging the effectiveness of risk and maturity assessments. As noted earlier, the presence of a particular management action does not necessarily indicate success or failure; rather, it indicates whether the program's development experience appears to have exhibited that characteristic. In addition, we provide a more granular exploration of the relative success with which individual programs in our sample parlayed these assessments into an appropriate parallel development strategy.

Early and Continual Assessment of Technological Risk and Maturity

A Technology Readiness Assessment is required for all major defense acquisition programs prior to MS B.[8] There is, however, significant variation in the accuracy of such assessments among individual programs. Parallel development in an agile context presupposes the ability to rapidly transition from EMD into production, with any major outstanding technology development or risks isolated in parallel efforts. The effectiveness of parallel development, then, is inextricably linked to the accuracy of the technological risk and maturity assessments. Failing to thoroughly identify, document, and respond to potential technological risk and maturity concerns can lead to critical performance deficiencies, cost growth, and schedule delays. This, in turn, can affect the SPO's ability to rapidly field the basic system and can delay the introduction of new technology increments.

As noted elsewhere, parallel development is a continuous, iterative process that is not limited to activities occurring before initial operational capability (IOC). Because parallel development is a fundamentally agile approach, the basic rapidly fielded capability will initially be fitted with mature subsystems that must be incrementally upgraded as the desired technologies mature in parallel. This suggests that much of the parallel development process may actually occur

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[7] Although prototyping and testing, for instance, are essential to demonstrating technological readiness, they are not sufficient in and of themselves. Prototyping can be a useful tool to demonstrate individual capabilities, but it should be applied in tandem with other strategies to demonstrate maturity of all major subsystems (as well as of the total system). Moreover, the concept of prototyping encompasses a range of different design and development activities, from experimentation to technology demonstration to more production-ready testing, and can be conducted at both the system and subsystem levels. (For a good introduction to various forms of prototyping, see Birkler et al., 2010, Chapter 5.) Technology development phases can be successful at pushing the state of the art for individual capabilities without adequately addressing overall system maturity. In addition, novel platform or subsystem configurations—even those employing mature subsystems—can entail considerable risk.

[8] See DoD, *Operation of the Defense Acquisition System*, DoD Instruction 5000.02, January 7, 2015; Public Law 111-23, Weapon Systems Acquisition Reform Act (WSARA) of 2009, May 22, 2009; and United States Code, Title 10, Section 2366b, Major Defense Acquisition Programs: Certification Required Before Milestone B Approval, 2010.

throughout the production and sustainment phases. It is therefore important for risk and maturity assessments to not only be conducted early and throughout the pre–MS C development periods but also updated and reassessed as long as major subsystems continue to be developed in parallel. Formal risk assessments should ideally be overseen by a Risk Management Board and validated by a panel of independent subject-matter experts, and they should be verified through repeated prototyping, experimentation, and developmental testing. Moreover, *responsiveness* of the SPO to risk assessments is essential to effectively managing technological risk.

Four programs in our sample—F/A-18E/F Super Hornet, F-16 MSIP, F-117 Nighthawk, and DDG-51 *Arleigh Burke*—conducted early and continual assessments of technological risk and maturity, and were responsive to the findings:

- F/A-18E/F Super Hornet: The F/A-18E/F SPO strongly emphasized risk assessments as key to program success and managed risk through the oversight of a risk-assessment board. Planners conducted extensive trades during the technology maturation and risk reduction (TMRR) and demonstration and validation (Dem/Val) phases to cull design proposals entailing significant technological risk. Several novel configurations were considered during concept validation and Dem/Val, but they were ultimately discarded. Effective risk-management planning, coupled with SPO responsiveness to periodic risk and maturity assessments, enabled the initial platform to be fielded with minimal deficiencies, which contributed to relatively stable cost and schedule outcomes.[9]
- F-16 MSIP: Planners conducted a thorough risk assessment following the TMRR phase, emphasizing both a heavy reliance on mature technologies and extensive planning for integration risk. The program's evolutionary design approach across three "stages" enabled planners to diffuse risk among different technologies and between phases of development. Projections of low, moderate, and moderate-high levels of technological risk in each of the three respective stages proved highly accurate.[10]
- F-117 Nighthawk: The F-117 program minimized technological risk by explicitly limiting the scope of technological advances to a stealthy airframe design. Developers correspondingly mitigated risk in the airframe design through the Have Blue demonstrator. Pre-EMD risk assessments of airframe development enabled the Air Force to accelerate fielding of the platform, with deficiencies or execution challenges primarily limited to reliability and maintainability. However, this was anticipated and accepted in the acquisition strategy.[11]

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[9] Obaid Younossi, David E. Stem, Mark A. Lorell, and Frances M. Lussier, *Lessons Learned from the F/A-22 and F/A-18E/F Development Programs,* Santa Monica, Calif.: RAND Corporation, MG-276-AF, 2005. Also see Robert V. Johnson and John Birkler, *Three Programs and Ten Criteria: Evaluating and Improving Acquisition Program Management and Oversight Processes Within the Department of Defense*, Santa Monica, Calif.: RAND Corporation, MR-758-OSD, 1996, pp. 38–39.

[10] Frank Camm, *The F-16 Multinational Staged Improvement Program: A Case Study of Risk Assessment and Risk Management,* Santa Monica, Calif.: RAND Corporation, N-3619-AF, 1993.

[11] Giles K. Smith, Hyman L. Shulman, and Robert S. Leonard, *Application of F-117 Acquisition Strategy to Other Programs in the New Acquisition Environment,* Santa Monica, Calif.: RAND Corporation, MR-749-AF, 1996, pp. 10, 12, 21.

- DDG-51 *Arleigh Burke*: Development planners effectively assessed the Aegis combat system, previously developed for the CG-47-class cruiser, as a mature technology that imposed limited risk on overall DDG-51 development. Technological risk was also monitored and addressed throughout development, with planners scrapping an advanced propulsion system prior to MS B in favor of a more mature mechanical drive to minimize technological risk. Only the hull design entailed significant risk, given the major planned improvements in stealth and survivability. However, development of the hull was successfully executed according to a clear risk management plan, and initial cost growth on the lead ship was due primarily to concurrency rather than poor risk assessments.[12]

Conversely, five programs in our sample—F-22, B-1B, AMRAAM, LANTIRN, and LCS—did not effectively conduct or respond to early and continual assessments of technological risk and maturity:

- F-22 Raptor: The F-22 SPO did not conduct separate risk management approaches outside of designated integrated product team activities. Although initial risk assessments did identify significant technological risks, institutional pressure and poor contingency planning propelled the F-22 into EMD without adequately addressing technological maturity or integration risks, particularly in the integrated avionics suite. Moreover, initial risk assessments did not identify any high-risk areas, which ultimately proved inaccurate. Technology development efforts were pursued prior to EMD in the state-of-the-art AESA radar; electronic warfare suite; and communications, navigation, and identification system, but each required considerably more development before reaching the desired level of operational capability.[13]
- B-1B Lancer: Technological risks were duly assessed early in development. The SPO, however, pursued the final B-1B design without having prototyped any of the proposed technological advances, and the office failed to recognize the immaturity of capabilities previously developed under the B-1A program. While the SPO correctly chose to separate development of certain mission systems from that of the platform because of the inherent technological risk, it failed to acknowledge the level of immaturity in the mission systems it subsequently developed in-house.[14]
- AMRAAM: The AMRAAM Joint SPO (JSPO) conducted rigorous risk assessments, prototyping, and contingency planning prior to EMD. The JSPO also planned for a second source as a hedge. Nevertheless, important design tasks were slipped from Dem/Val into EMD—including satisfactory flight testing, development of the solid-state transmitter (SST), and stability of the missile design—in order to adhere to the accelerated schedule. Independent organizations at the time assessed significant unaddressed risk in the JSPO's development plan.[15]

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[12] Schank et al., 2006, pp. 73–75.

[13] Younossi et al., 2005, pp. 40–41. Also see Johnson and Birkler, 1996, pp. 38–42.

[14] Susan J. Bodilly, *Case Study of Risk Management in the USAF B-1B Bomber Program,* Santa Monica, Calif.: RAND Corporation, N-3616-AF, 1993a.

[15] Kenneth R. Mayer, *The Development of the Advanced Medium-Range Air-to-Air Missile: A Case Study of Risk and Reward in Weapon System Acquisition,* Santa Monica, Calif.: RAND Corporation, N-3620-AF, 1993.

- LANTIRN: Design specifications called for a mixture of mature and immature technologies, with the feasibility of many systems having not yet been demonstrated. The SPO provided hedging strategies for the immature ATR system, but it did not provide contingencies elsewhere. Appraisals of technological maturity in most subsystems proved to be flawed, with substantial risk remaining in the EMD program even after riskier technologies were isolated. SPO planners sought to mitigate the risk through contractor competition, prototyping, and testing. However, an accelerated acquisition strategy ensured that initial testing and a fully integrated prototype would not be completed until well into EMD and that the Dem/Val phase would be eliminated altogether.[16]
- LCS: The LCS program office formally established a Risk Management Board, which was tasked with identifying and mitigating potential areas of risk (technical, schedule, and cost) in development and production. However, the Navy did not perform risk analyses in its cost estimation efforts—an OSD and U.S. Government Accountability Office (GAO) best practice. GAO also found that development planners had developed insufficiently robust plans to address the immaturity of various mission package technologies being developed in parallel and had failed to acknowledge the extent of configuration changes required for some of the more mature technologies. A majority of critical technologies for both the seaframe and mission packages were deemed mature, which proved (in the latter case) to be inaccurate. This was, in part, because the program was initiated without having fully resolved the scope of the planned mission packages, which precluded developers from conducting thorough risk analyses for some technologies. Although the LCS program conducted brief TMRR phases for several mission-module technologies, the absence of a comprehensive mission package development plan injected uncertainty into the program's understanding of technological risk. Finally, the Navy neglected to develop a comprehensive test schedule for both initial seaframes and critical mission package technologies, leading critical test events to be delayed and risk assessments to be deferred.[17]

Maximized Use of Mature Systems

The extent to which a program maximizes the use of mature systems has a profound effect on the technological risk, integration challenges, and effectiveness of parallel development strategies. The rapid fielding expectations embedded within parallel development require the

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[16] Susan J. Bodilly, *Case Study of Risk Management in the USAF LANTIRN Program,* Santa Monica, Calif.: RAND Corporation, N-3617-AF, 1993b. The LANTIRN development experience reinforces the notion that individual mitigation strategies, such as prototyping and testing, are not sufficient in and of themselves. Exogenous factors—such as budget environment, operational need, and political will—can have a profound impact on the effectiveness of parallel development efforts, even when planners do attempt to assess and implement risk mitigation strategies. The LANTIRN example further illustrates the inadequacy of risk assessments alone: Failing to fully execute prototyping and testing phases can critically hamper an agile acquisition program.

[17] GAO, *Littoral Combat Ship: Actions Needed to Improve Operating Cost Estimates and Mitigate Risks in Implementing New Concepts*, Washington, D.C., GAO-10-257, February 2010, pp. 9–16, 27–28. Also see GAO, *Defense Acquisitions: Plans Need to Allow Enough Time to Demonstrate Capability of First Littoral Combat Ships*, Washington, D.C., GAO-05-255, March 2005, p. 4; Ronald O'Rourke, *Navy Littoral Combat Ship (LCS) Program: Background, Issues, and Options for Congress*, Congressional Research Service, RL33741, April 29, 2011, pp. 26–28; and Ronald O'Rourke, *Navy DD(X) and LCS Ship Acquisition Programs: Oversight Issues and Options for Congress*, Congressional Research Service, RL32109, October 28, 2004, pp. 41–42.

initially fielded system to meet minimum operational performance thresholds in order to provide the warfighter with an acceptable level of capability. If the maturity of critical subsystems is not initially maximized, the program may encounter performance deficiencies, integration challenges, or shortfalls in operational testing, which may lead to delays in the fielding schedule. Likewise, technologies developed in parallel may face cost and schedule growth if they are not sufficiently mature prior to being integrated.

It is important to note that some programs, such as the B-1B and LCS, attempted to employ mature subsystems but ultimately fell short. This is an essential distinction because it is the successful maximization of mature systems—rather than merely the presumption of such—that enables parallel development. Maximizing the use of mature subsystems is not always sufficient to eliminate risks associated with parallel development. This is particularly true of highly immature platforms or of complex or novel configurations. However, maximizing the use of mature subsystems reduces aggregate technological risks and can channel developers' focus into a limited set of challenges.

Five programs in our sample—F/A-18E/F, F-16 MSIP, AMRAAM, F-117, and DDG-51—effectively maximized the use of mature systems:

- F/A-18E/F Super Hornet: Developers achieved sufficient technological maturity in all major F/A-18E/F subsystems prior to EMD by maximizing commonality with the legacy F/A-18C/D models—including approximately 90-percent commonality in the various electronics components—and limiting TMRR efforts that required significant technological advances. The avionics and propulsion systems were also derived from C/D variants. Although the airframe design entailed significant modifications, it was aerodynamically similar to the C/D variant.[18]
- F-16 MSIP: The initial Stage I design incorporated combat capabilities almost exclusively from the existing F-16A/B models, focusing instead on structuring the airframe for subsystem modularity (e.g., wiring provisioning for electronic countermeasure, fire control, and radar altimeter upgrades). Stages II and III integrated considerably more capabilities, but the highest-risk technologies were phased in incrementally. Only Stage III featured relatively immature subsystems, such as LANTIRN pods and APG-68V fire-control radars.[19]
- AMRAAM: Neither the missile design nor the critical SST technology had been sufficiently demonstrated prior to EMD, and assumptions regarding maturity initially proved inaccurate. The configuration required for multiple-aircraft compatibility was also new and risky. However, the SPO chose mature replacements for the SST and integrated circuitry to minimize technological risk. Immature subsystems necessary to meet operational requirements were ultimately developed in parallel. All in all, the SPO's responsiveness to address immature technologies contributed to the program's overall effectiveness with respect to technological risk and maturity.[20]

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[18] Younossi et al., 2005, p. 43.

[19] Camm, 1993.

[20] Mayer, 1993.

- F-117 Nighthawk: The F-117 EMD program relied heavily on mature subsystems—for example, the engine, inertial navigation system, and flight control—to isolate risk in design and integration of the airframe. Air Force planners adapted the F404 engine and cockpit head-up display from the F-18, the inertial navigation system from the B-52, and multiple flight control components from the F-16. The infrared acquisition and designation system was the only subsystem that required major technological advances.[21]
- DDG-51 *Arleigh Burke*: Pursuant to the rigorous risk management strategy described earlier, development planners deliberately sought to couple major technological advances in the hull with a mature set of mission systems to rapidly field the lead ship. Immature subsystems were relegated to subsequent DDG-51 baseline upgrades. The Aegis combat system technology, which had previously been matured for the CG-47-class cruiser, was the centerpiece of developers' plans to rapidly field a lead ship with mature subsystems.[22]

Five programs in our sample—F-22, B-1B, LANTIRN, DDG-1000, and LCS—did not effectively maximize use of mature systems:

- F-22 Raptor: The airframe, engine, and integrated avionics all entailed considerable technological advances. Neither platform nor mission systems were judged sufficiently mature following MS B. The acquisition strategy acknowledged that the Air Force's desire to push the state of the art in several areas would likely require the program to enter EMD with immature subsystems, and Air Force leadership willingly accepted the risk. However, the effort required to bring all mission-critical capabilities up to an acceptable level of maturity prior to fielding, particularly the immature airframe and avionics designs, contributed to extreme cost growth and a prolonged development time frame.[23]
- B-1B Lancer: Planners assessed a low degree of technological risk at MS B because of the presumed level of maturity in major systems, projecting 80-percent commonality in the airframe structure with the B-1A. However, these assessments failed to properly acknowledge the residual immaturity in the B-1A design, flight test issues, and required design changes.[24] The SPO planned to maximize mature components in the offensive and defensive avionics packages by leveraging advances made on the B-52 and F-16, but neither sufficiently addressed the required capability improvements or acknowledged the substantial configuration and integration risks.[25]
- LANTIRN: The LANTIRN development program involved certain unproven critical subsystems; the ATR and CO_2 laser, in particular, were purely conceptual. Moreover, the configuration and integration of the environmental control unit, terrain-following radar, and targeting pods were entirely new, despite the relative maturity of those components.[26]

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[21] Smith, Shulman, and Leonard, 1996, pp. 12, 20.

[22] Schank, Smith, et al., 2006, pp. 74–75.

[23] Younossi et al., 2005, pp. 34–37.

[24] One notable exception was the YF101-GE-102 engine, which was derived from the B-1A design but had already been thoroughly tested and required few modifications.

[25] Bodilly, 1993a.

[26] Bodilly, 1993b.

- DDG-1000 *Zumwalt*: Half of the featured EDMs were assessed at a technology readiness level less than 6 by MS B. Among the least-mature systems at MS B were the integrated power system, the dual-band radar, and advanced gun system, and during EMD, all of these systems generated cost and schedule overruns related to technology development and integration.[27]
- LCS: The acquisition strategy emphasized rapidly acquiring and fielding a basic hull with mature combat systems, and associated mission packages would be spiraled in as they matured. However, the assessed maturity level of the aluminum trimaran structure of one of the two LCS variants was downgraded following initial fielding and survivability testing. Combat system component performance was likewise judged unsatisfactory following initial developmental testing. Other novel design elements, such as using automation technologies to support a small crew and provisioning for subsystem modularity, added considerable complexity to the basic platform. Moreover, the Navy accepted multiple increments of different mission packages without having demonstrated threshold requirements in the first mine countermeasures package. Although the SPO attempted to employ rapid prototyping practices and subject-matter expertise to reassess and validate the technological maturity of mine countermeasure technologies prior to fielding, several of the technologies, such as the remote minehunting system and autonomous vehicles, had still not been tested or demonstrated when the LCS was fielded. As a result, reliability deficiencies in the mine countermeasure technologies repeatedly delayed successful integration onto the platform.[28]

Effective Management of System Integration Risk

Even if program managers effectively identify and mitigate technological risks, maximize the use of mature subsystems, and isolate risky technology development efforts, considerable risks may still remain. Indeed, by concentrating mature technologies in a potentially novel configuration and staggering the integration of immature technologies, parallel development can paradoxically *increase* a program's integration risks. It is therefore essential that planners thoroughly identify and manage system integration risk. Successful examples of parallel development in our program sample tended to actively plan for and monitor integration risks.[29] Our program case studies further offer the following three management actions for evaluating the effectiveness of system integration risk management plans in the context of parallel development:

a. early and continual assessment of integration risk

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[27] Schank, Smith, et al., 2006. Also see Megan P. McKernan and Jeffrey A. Drezner, *A History of Phase IV and Lessons Learned from the DDG-1000 Acquisition Program,* Santa Monica, Calif.: RAND Corporation, 2012, not available to the general public; and Blickstein et al., 2011, pp. 24–27.

[28] O'Rourke, 2011, pp. 26–29. Also see GAO, "Littoral Combat Ship (LCS)," *Defense Acquisitions: Assessments of Major Weapon Programs*, Washington, D.C., GAO-04-248, March 2004, pp. 81–82; O'Rourke, 2004, pp. 55–56; and GAO, 2005, pp. 21-27.

[29] As with technological risk, integration risk management also appears to be a necessary (but not sufficient) condition.

b. roles and responsibilities appropriately assigned according to organizational capability
c. isolated subsystem integration risk

Roughly half of the programs in our sample exhibited at least two of these management actions, with three programs (F/A-18E/F, F-16 MSIP, and DDG-51) strongly conforming to all three (see Table 2.2).

Table 2.2. Effective Management of System Integration Risk

Platform	Early and Continual Assessment of Integration Risk	Roles and Responsibilities Appropriately Assigned According to Organizational Capability	Isolated Subsystem Integration Risk
F-22 Raptor	No	No	No
F/A-18E/F Super Hornet	Yes	Yes	Yes
F-16 MSIP	Yes	Yes	Yes
B-1B Lancer	No	No	No
AMRAAM	No	No	Yes
LANTIRN	No	No	No
F-117 Nighthawk	Unknown	Yes	Yes
DDG-51 *Arleigh Burke*	Yes	Yes	Yes
DDG-1000 *Zumwalt*	No	No	No
LCS	No	No	No

NOTE: "Yes" indicates that a given program exhibited a particular characteristic of parallel development, based on historical RAND case studies. "No" indicates that a given program did not exhibit that characteristic. If there is insufficient evidence in the case studies to demonstrate that a given program either exhibits or does not exhibit a particular characteristic, it is labeled "Unknown." We elaborate below on the relative effectiveness with which a program executed each characteristic to rapidly field the basic platform. Some part of each program listed reflected what we define as parallel development. With the exception of the F/A-18E/F program and F-16 MSIP, the term *parallel development* was not explicitly used; rather, one or more elements of a program's acquisition strategy incorporated some aspect of parallel development (as defined in this report).

As with technological risk and maturity assessments, the relative effectiveness with which programs are able to parlay integration risk evaluations into successful parallel development efforts depends as much on program managers' responsiveness and attention to detail as on the quality of the evaluations themselves. Effective integration risk management is particularly critical given the potential for parallel development to actually increase integration risk. By decoupling platform development from that of the major subsystems, the SPO responsible for total system integration will, by necessity, no longer be responsible for development of each constituent component. Failure to maintain a close working relationship among program offices, contractors, and users, coupled with insufficient integration planning and testing, can substantially increase the degree of integration risk.[30]

[30] This is true even when the subsystems being integrated are appropriately mature.

Measuring integration risk can be considerably more complex than other forms of risk, such as technological risk or immaturity. Indeed, development planners have fewer tools at their disposal with which to concretely estimate integration risk, a challenge that is compounded by the uncertainty associated with integrating new technologies or new configurations that have never been rigorously tested. To this end, program managers may pursue a range of strategies to mitigate integration risk, including focused prototyping and testing for integration risk; early collaboration both among developers and between the SPO and contractors to identify potential integration risks; contingency planning for subsystem and total system integration; clear identification of the respective integration roles between the SPO and contractor team, with system integration driven by a prime contractor with relevant expertise; and demonstration of integration readiness and maturity of manufacturing and assembly processes.[31]

Early and Continual Assessment of Integration Risk

MS B validation requires "final demonstration that all sources of risk have been adequately mitigated. This includes technology, engineering, *integration*, manufacturing, sustainment, and cost risks."[32] However, as with technological risk, the relative effectiveness of integration risk assessments varies widely by program. A thorough and accurate assessment of system integration risk early in development, updated and reassessed continually throughout development, is therefore vital to constructing a sound parallel development strategy. Decoupling subsystem development from that of the platform inherently expands the potential for unexpected integration challenges. Consequently, parallel development demands particularly rigorous integration planning and risk mitigation through such actions as prototyping, testing, and contingency planning.

Thorough and ongoing testing for integration risk is not sufficient in and of itself; rather, the program office must be actively invested in the process and responsive to the findings. Upgrade increments subject to high integration risk should be appropriately rephased, and the SPO should explore possible contingencies. While properly characterizing integration risk early in development can help developers lay the groundwork for future integration efforts by provisioning the platform and designing in subsystem modularity, each successive increment will entail some degree of risk. Parallel development is a continuous process, whose upgrade increments can extend well into the production phase. Program managers should therefore remain continually engaged in assessing integration risk throughout the entire development process—not merely until the basic platform is initially fielded.

Three programs in our sample—F/A-18E/F, F-16 MSIP, and DDG-51—conducted early and continual assessments of integration risk and were responsive to the findings:

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[31] Use of open systems and open architectures is another technique to mitigate system integration risk; however, none of the programs in our sample explicitly used this technique.

[32] See DoD, 2015, emphasis added.

- F/A-18E/F Super Hornet: Planners conducted extensive trades throughout development to monitor integration risk. The SPO's selective focus on mature technologies and compatibility with the expected platform design modifications ensured limited integration risk during EMD.[33]
- F-16 MSIP: Planners recognized potential integration risks early in the development cycle, which allowed the SPO to conduct early coordinated test and integration efforts with subsystem developers. The development plan explicitly acknowledged both the need for compatibility between subsystems and platform and the potential risks associated with integrating progressively more-complex technologies in stages. The F-16 SPO actively engaged with subsystem developers early and consistently in order to embed integration strategies into the actual development process. The SPO also regularly employed rigorous "test-fix-analyze" processes aimed at identifying and mitigating integration risks.[34]
- DDG-51 *Arleigh Burke*: Naval Sea Systems Command explicitly planned for potential integration challenges, given the likely risks associated with its desired parallel development structure. Developers conducted early in-house feasibility studies and reviews of potential hull configurations, specifically addressing the subsystem modularity required to conduct multiple flight upgrades of the hull and baseline upgrades of the combat systems.[35]

Six programs in our sample—F-22, B-1B, AMRAAM, LANTIRN, DDG-1000, and LCS—did not conduct early and continual assessments of integration risk, or the SPO was not responsive to the findings:

- F-22 Raptor: Air Force planners did not adequately address the significant integration risks—particularly the integrated avionics suite—at either the platform or subsystem levels. Although the SPO conducted a competitive prototyping phase during Dem/Val, resulting in dual technology demonstrator prototypes (YF-22 and YF-23), the integrated avionics suite requirement called for remarkable advances in the AESA radar; electronic warfare; and communications, navigation, and identification components. Formal efforts to assess the true integration risk of such advanced technologies prior to MS B were minimal, as was any effort to assess the unprecedented challenges associated with developing a truly integrated avionics set.[36]
- B-1B Lancer: The B-1B's new configuration significantly increased integration risks, which were inadequately recognized or addressed by B-1B developers. The presumption of limited risk by the SPO and senior DoD leadership, coupled with an accelerated fielding schedule, further compelled the SPO to proceed without developing a fully integrated prototype.[37]
- AMRAAM: The initial development plan explicitly acknowledged integration and producibility risks by requiring competitive prototyping and extensive testing during the

[33] Younossi et al., 2005, pp. 21–22.

[34] Camm, 1993, pp. 3, 49–50.

[35] Schank, Smith, et al., 2006, pp. 74–75, 83.

[36] Younossi et al., 2005, pp. 16–19, 40–41.

[37] Bodilly, 1993a, pp. 13–14, 24–25.

Dem/Val phase. However, cost and schedule requirements forced the contractors to not only delay development and integration assessments of critical technologies—particularly the SST and integrated circuitry—until EMD but also cut the number of test-fired prototypes in half.[38]

- LANTIRN: The LANTIRN development program's greatest persistent challenge was integration risk because the various subsystems (e.g., fire control pod) had never previously been integrated in the desired configuration. SPO planners acknowledged the integration risk that the platform's unique configuration would naturally entail and sought to mitigate the risk through contractor competition, prototyping, and testing. However, the accelerated acquisition strategy ensured that initial testing and a fully integrated prototype would not be completed until well into EMD. Final testing was also delayed by unaddressed software integration issues, which created cost and schedule growth.[39]
- DDG-1000 *Zumwalt*: Exit criteria at MS B were generally structured around the successful maturation, testing, and demonstration of new subsystem technologies, such as the dual-band radar and advanced gun system. Most integration-related concerns were deferred until EMD so that the SPO and contractors could focus on the rigorous demands of the technology development efforts. Although the initial TMRR contractual arrangement was structured around a single prime integrator (in recognition of the extensive integration risks), the DDG-1000 program proved inadequately equipped to deal with integration challenges during EMD.[40]
- LCS: The initial acquisition strategy called for the four "Flight 0" lead ships to promote testing and experimentation between the seaframe and various mission package technologies, including assessing potential integration challenges for subsequent Flight 1 ships. However, the accelerated fielding schedule required Flight 1 ships to begin detail design and construction concurrently with Flight 0 testing.[41] Concurrency in design, testing, and construction across various flights compounded an incomplete planning and design phase, contributing to significant weight growth in both the seaframe and mission packages that created additional integration challenges. GAO found that inadequate attention was paid to assessing integration risk and contingency planning, resulting in a sharp increase in integration challenges. This was, in part, because the original memorandum of agreement between the LCS program office and other program offices responsible for developing mission package technologies was insufficient in scope to compel a comprehensive and iterative process for assessing integration risk. Finally, although the program featured an Integrated Test Team that developed plans for "Post-Delivery Tests and Trials," as well as developmental and operational testing, the volume of deficiencies discovered during fielding of both seaframes and mission packages had a

[38] Mayer, 1993, pp. 34–35.

[39] Bodilly, 1993b, pp. 8–10, 14–15, 43–44.

[40] Schank, Smith, et al., 2006, p. 47. Also see McKernan and Drezner, 2012, pp. 7–8.

[41] This concurrency was later somewhat mitigated when Congress mandated a "gap year" between Flight 0 and Flight 0+ ship construction.

cascading effect on integration testing, which was delayed well into construction of subsequent hulls.[42]

Roles and Responsibilities Appropriately Assigned According to Organizational Capability

The challenges associated with system integration are particularly germane to parallel development, given both the diffusion of responsibilities between contractors and program offices and the explicit decoupling of platform from subsystems. Programs in our sample that appropriately assigned integration roles and responsibilities according to organizational capability generally followed a few common approaches, including clearly establishing responsibilities during the planning process; delegating the system integrator role to a prime contractor, with the SPO providing limited oversight;[43] and ensuring relevant system integration experience and technical expertise in the integration organization.

Four programs in our sample—F/A-18E/F, F-16 MSIP, F-117, and DDG-51—appropriately assigned roles and responsibilities according to organizational capability:

- F/A-18E/F Super Hornet: Developing higher-risk mission systems in parallel empowered the program manager to focus on the limited-risk platform development and not be distracted by potential integration challenges. The F/A-18E/F EMD program assigned a clear delineation of responsibilities, with one contractor acting as system integrator. The prime contractor built on previous design experiences with its subcontractors on the F/A-18C/D development programs and enjoyed a close working relationship with the SPO. The program employed integrated product teams early in development, which promoted effective system integration management and collaboration.[44]
- F-16 MSIP: The management structure of the F-16 MSIP was derived from existing relationships between the F-16 SPO and the General Dynamics–led industry team. Although actual SPO management oversight vacillated between specific directorates, the continuity of experience, technical expertise, and government-industry relationships produced a stable integration team during early development. The prime contractor was named lead system integrator, whose responsibilities under the Total System Performance Responsibility and Integrated System Performance Responsibility contractual requirements included integration testing and evaluation at the contractor's

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[42] GAO, "Littoral Combat Ship—Mission Packages (LCS MP)," *Defense Acquisitions: Assessments of Major Weapon Programs,* Washington, D.C., GAO-15-342SP, March 2015, pp. 109–110. Also see GAO, 2005, pp. 26–27; and Usher L. Barnum, *Business Process Re-Engineering: Application for Littoral Combat Ship Mission Module Acquisition*, thesis, Monterey, Calif.: Naval Postgraduate School, 2006, pp. 31–32.

[43] Although delegating system integration responsibilities to a single prime contractor is often considered a best practice in the development of aircraft and other platforms, the *opposite* is frequently true of Navy shipbuilding programs, in which a combat system prime contractor and platform prime contractor retain distinct integration responsibilities, and the Navy provides significant oversight. This was, indeed, the case with the DDG-51 program. Additionally, further research will need to be conducted to determine whether traditional roles and responsibilities remain appropriate for next-generation concepts, such as complex systems-of-systems, families-of-systems, and modular open systems architectures.

[44] Younossi et al., 2005, pp. 24–27. Also see Johnson and Birkler, 1996, p. 70.

system integration lab. The SPO and contractor developed formal relationships with other program offices and contractors early in the development of various subsystems to facilitate integration testing, including providing government-furnished equipment.[45]

- F-117 Nighthawk: A small and experienced SPO staff worked in close collaboration with the prime contractor, which was delegated total system integration responsibilities. The contractor possessed technological expertise and was afforded considerable contractual flexibility. Moreover, the SPO and contractor continually maintained robust communications.[46]
- DDG-51 *Arleigh Burke*: The program manager delegated specific areas of responsibility to the lead system integrator, whose role was to assess the integration readiness level of the combat system and carefully manage integration with the ship. Although the SPO was heavily involved in the integration management process, its role was generally limited to delegating broad areas of responsibility and providing the combat systems as government-furnished equipment. The experience, technical expertise, and close working relationships between the SPO and contractors—as well as the carefully managed and thoroughly planned parallel development structure—enabled a novel integration arrangement. The Aegis combat system was managed by an entirely separate program office, reflecting a truly parallel development process.[47]

Six programs in our sample—F-22, B-1B, AMRAAM, LANTIRN, DDG-1000, and LCS—did not appropriately assign roles and responsibilities according to organizational capability:

- F-22 Raptor: Industrial-base concerns led to an artificial workshare allocation among the contractor team, with minimal consideration given to the highly complex system integration process. Although the prime contractor was named lead system integrator, the contractor's desire to optimize its facility workloads led it to delegate design and integration responsibilities to a team with insufficient technical expertise. The F-22 SPO retained integrated weapon system manager responsibilities, which established oversight over day-to-day program management through use of integrated product teams but ultimately ceded significant control over the development process to the prime contractor. Additionally, the patchwork workshare arrangement neglected the inherently integrated nature of the F-22's advanced subsystems. The contractor teams also maintained only limited continuity and working relationships with the SPO.[48]
- B-1B Lancer: The Air Force SPO assumed the role of system integrator, accepting all major integration management decisions despite failing to properly anticipate integration risks. Given the SPO staff's limited expertise with integration management, coupled with

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[45] Camm, 1993, pp. 18–24, 44–55.

[46] Smith, Shulman, and Leonard, 1996, pp. xii, 14–18, 47.

[47] Schank, Smith, et al., 2006, pp. 74, 77–82. Also see Martin M. Ferber, "Navy Shipbuilding: Cost and Schedule Problems on the DDG-51 AEGIS Destroyer Program," testimony before the House Armed Services Committee, Subcommittee on Seapower and Strategic and Critical Materials, Washington, D.C.: U.S. Government Accountability Office, January 24, 1990, p. 1.

[48] Younossi et al., 2005, pp. 18–21. Also see Johnson and Birkler, 1996, p. 22.

the resulting decrease in the SPO's oversight of other development areas, existing technological and integration risks were significantly compounded.[49]

- AMRAAM: The AMRAAM EMD program initially suffered from several factors relating to integration roles and responsibilities. The Air Force–led JSPO did not have much experience building air-to-air missiles; earlier management oversight and relationships resided with the Navy. Considerable turnover in the JSPO further compounded a relative lack of overall staff experience. Ambiguities in the technical requirements and the relationship with the prime contractor also hampered communication among team members. Finally, the unique configuration and desired multiple-aircraft compatibility of the missile design created unanticipated integration challenges with other aircraft SPOs.[50]
- LANTIRN: The SPO possessed a lack of continuity and personnel familiar with LANTIRN concept development, not to mention the technical expertise required to undertake robust integration management and contingency planning. Additionally, the flexible contractual strategy did not establish strict objectives or tie contractor performance to program outcomes, which created inherent uncertainty regarding the contractor's responsibilities.[51]
- DDG-1000 *Zumwalt*: Competing priorities and visions between the SPO and OSD, coupled with persistent requirements flux, budget instability, and technological uncertainty, caused the DDG-1000 organizational and contractual framework to be restructured several times. Although initially envisioned to function with a design prime contractor responsible for overall system integration, the SPO was ultimately forced to act as system integrator by acquiring the subsystems as government-furnished equipment to limit cost growth.[52]
- LCS: At program initiation, no unified LCS program office existed, with responsibilities dispersed across various SPOs. The LCS Program Office (PMS-501), under the direction of PEO Ships, was responsible for developing the hull and final system integration, while the LCS Mission Modules Program Office (PMS-420), under the direction of PEO Littoral Mine Warfare, was responsible for developing the three mission packages.[53] PMS-420 was responsible for coordinating with the five different resource sponsors that actually developed the mission systems, as well as the prime mission package integrator and the total system integrators. The authorizing memorandum of agreement neither established a standardized system of interagency communication nor delegated sufficient authority to PMS-420 to create a streamlined flow of communications between program offices. The LCS program offices thus frequently did not have "direct communication with or oversight of most mission systems being developed" and lacked a "working relationship and physical proximity to both operational end users and systems design

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[49] Bodilly, 1993a, pp. 17–18.

[50] Mayer, 1993, pp. 48–50.

[51] Bodilly, 1993b, pp. 12–13, 19–20.

[52] Schank, Smith, et al., 2006, p. 47. Also see McKernan and Drezner, 2012, pp. 7–8.

[53] The three LCS mission packages are for mine countermeasures, antisubmarine warfare, and surface warfare.

teams."[54] Therefore, the LCS platform did not appropriately assign roles and responsibilities according to organizational capability.[55]

Isolated Subsystem Integration Risk

The ability to decompose complex systems into more-manageable pieces and then integrate the pieces after they have been suitably tested (i.e., they are mature) is fundamental to parallel development. Programs in our study that effectively demonstrated this concept were generally more successful at isolating subsystem integration risk through a range of strategies, including developing a full prototype or EDMs to demonstrate system integration prior to low-rate initial production (LRIP), comprehensive provisioning of the platform for modular subsystem upgrades, and the design and test of assembly or manufacturing processes.

Five programs in our sample—F/A-18E/F, F-16 MSIP, AMRAAM, F-117, and DDG-51—effectively isolated subsystem integration risk:

- F/A-18E/F Super Hornet: Limited technological advances in the initial design specifications significantly constrained the scope of challenges the SPO faced during initial integration and testing. Manageable manufacturing processes and producibility were an important consideration during the Dem/Val phase, enabling a relatively smooth transition from EMD to LRIP. Importantly, developers incorporated provisioning for modular subsystem upgrades into the design, which correspondingly isolated integration risk in future modification efforts.[56]
- F-16 MSIP: The program structure isolated integration risk by minimizing platform development risk, dedicating Stage I almost entirely to provisioning for future subsystem integration and placing greater emphasis on SPO and contractor integration management. Extensive and iterative testing at both the subsystem and total system levels effectively isolated integration risk. The SPO's collaborative relationship with other program offices, including a mutual exchange of test articles and equipment, provided additional mitigation of integration risk.[57]

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[54] Barnum, 2006, p. 31. Although the LCS program's organizational structure and delegation of responsibilities generally matched those described in this report as optimal for parallel development, the lack of interagency relationships, streamlined communications, and clear delineation of authority created a suboptimal institutional environment for parallel development—and, indeed, contributed to the serious integration challenges the program faced during fielding. In response to these organizational challenges, the Navy formed a stand-alone PEO-LCS in 2011, which merged all LCS-related program offices. This allowed all mission package integration efforts to be streamlined under a single umbrella agency. However, we argue that the Navy's initial decision to decouple management responsibilities for the hull and mission systems was not, in itself, a primary cause of the program's integration issues and, to the contrary, was probably appropriate given the parallel structure of mission system development. Rather, the program's challenges appear to have stemmed from a range of other sources, including poorly defined roles and responsibilities, inadequate technological and integration risk assessments, insufficient reliance on mature technologies, and unstable funding and requirements.

[55] GAO, *Littoral Combat Ship: Need to Address Fundamental Weaknesses in LCS and Frigate Acquisition Strategies*, Washington, D.C., GAO-16-356, June 2016, p. 41. Also see O'Rourke, 2004, pp. 54–55; and Barnum, 2006, pp. 20–35.

[56] Younossi et al., 2005, pp. 24–27.

[57] Camm, 1993, pp. 51–53, 60–62.

- AMRAAM: Although the JSPO did not sufficiently account for integration risk prior to MS B, it subsequently underwent extensive restructuring to isolate ongoing risks in the EMD program. The AMRAAM Producibility Enhancement Program (APREP) placed design changes to certain components—including the guidance, rocket motor, and integrated circuits—into parallel development to be incrementally upgraded. This restructure successfully isolated the risks associated with integrating some of the more challenging subsystems, which enabled the JSPO to accelerate testing and fielding of the basic missile platform.[58]
- F-117 Nighthawk: The Have Blue demonstrator was not a full prototype and was explicitly designed to demonstrate a limited capability—namely, a stealthy airframe design. However, this limited capability set was intentionally written into the aircraft's technical requirements to enable rapid fielding. Deficient capabilities were deferred to incremental upgrades. Although producibility and manufacturing challenges emerged because of new materials and fabrication processes related to the low-observable design, coupled with the relative immaturity of the platform configuration, the program's deliberate decoupling of platform and subsystem development did effectively limit integration issues to the platform itself.[59]
- DDG-51 *Arleigh Burke*: Developers structured the design concept around subsystem modularity from early in the development process. The combination of effective configuration design planning and the initial specification of highly mature subsystems effectively limited the integration risk during fielding of the first hull flight. The SPO likewise isolated integration risk in future combat system baselines and hull flights by designing and provisioning modularity into the configurations, which was facilitated by the close working relationships between program offices and among contractors.[60]

Five programs in our sample—F-22, B-1B, LANTIRN, DDG-1000, and LCS—did not successfully isolate subsystem integration risk:

- F-22 Raptor: The technological advances required by the development of an integrated avionics suite were largely deferred to EMD. Unaddressed risks in testing and integration ultimately contributed to extended schedule delays. Moreover, the artificial workshare arrangement led the industry teams' manufacturing and assembly capabilities to be misaligned with the F-22's unique integration challenges.[61]
- B-1B Lancer: A flying prototype with all newly developed subsystems, particularly the defensive avionics package, was never constructed. Due to a presumption of limited technological risk, most key subsystems were untested following MS B. Of particular concern, the offensive and defensive avionics—both critical to the aircraft's survivability requirements—were not planned to undergo flight testing until after MS C. Although the SPO chose to develop certain components not deemed essential to initial mission-capability requirements in parallel (which did isolate some degree of integration risk), its

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[58] Mayer, 1993, pp. 25–27.

[59] Smith, Shulman, and Leonard, 1996, pp. 8–9, 14, 21–22.

[60] Schank, Smith, et al., 2006, pp. 82–86.

[61] Younossi et al., 2005, pp. 18–21, 40–43.

failure to isolate the risk of integrating the defensive avionics and terrain-following components led to extensive execution challenges.[62]

- LANTIRN: Effective contingency planning for the ATR technology development, which posed the greatest integration risk, allowed the SPO to restructure it into a parallel development effort early in EMD. However, when the Dem/Val phase was eliminated to preserve an agile fielding schedule, other subsystems were precluded from rigorous testing, and risk management planning was not conducted for potential residual integration risks. OSD repeatedly criticized the SPO for deficiencies in its test plan. The SPO's failure to isolate integration risk through rigorous testing manifested itself through ongoing integration challenges in the terrain-following radar, targeting pods, and software. Insufficient planning and testing also created manufacturability issues that lasted well into production.[63]
- DDG-1000 *Zumwalt*: Unrealistic assumptions at MS B regarding subsystem integration led to cost and schedule growth, as well as ongoing integration challenges. Integration risk assessments further underestimated the challenges associated with integrating an unprecedented number of automated functions. Although the SPO attempted to mitigate technological risk by conducting lengthy technology development phases for the advanced technologies (ultimately resulting in ten major EDMs), the scope of technological risk across platform and subsystems prevented robust integration risk management planning. Integration testing was delayed until well into lead-ship construction. Finally, the unique manufacturing requirements were largely underestimated in order to artificially satisfy industrial base concerns.[64]
- LCS: Two contractor teams, led by Lockheed Martin and General Dynamics/Austal, were ultimately downselected to construct alternate variants. Each team was composed of a shipbuilder and prime integrator, while Northrop Grumman was selected to serve as the mission package integrator. The Navy encouraged competing industry teams to maximize suppliers with experience building "smaller ships, ships with non-traditional hull forms, and ships incorporating new technologies."[65] The Navy also attempted to incorporate lessons from analogous research and development programs that developed prototypes of small, fast ships featuring unconventional hull forms, such as the X-Craft program. However, the number of new technologies, accelerated fielding schedule, and degree of modularity in the LCS's mission systems varied significantly from previous surface combatants. As a result, the Congressional Research Service determined that it was "very difficult for the Navy (or anyone else) to fully understand the technological risk involved in developing and building the LCS."[66] The accelerated fielding schedule limited the amount of prototyping and EDMs of major mission systems conducted prior to initial fielding. The ad hoc nature of the program's planning for mission package integration also prevented the hull design from completely designing in modularity for future upgrade increments. Ultimately, a lack of robust contingency planning, inadequate

[62] Bodilly, 1993a, pp. 13–14, 24–25, 33–37.

[63] Bodilly, 1993b, pp. 22–25, 27–28, 31–37.

[64] McKernan and Drezner, 2012, pp. 47–48; and Blickstein et al., 2011, pp. 24–27.

[65] O'Rourke, 2004, p. 45.

[66] O'Rourke, 2004, p. 45.

assessments of technological and integration risk, a patchwork approach to modularity, and delays to integration testing yielded a concentration—rather than isolation—of integration risk in the mission systems.[67]

Planned Incremental Approach to Fielding Capabilities

A key objective of parallel development is isolating integration risk from the initially fielded platform. As previously discussed, however, parallel development can paradoxically increase integration risk if improperly applied. The most common strategy employed by programs in our sample to overcome this obstacle was simply to decouple technology development efforts and spiral in subsystems that were developed in parallel using carefully planned and executed incremental upgrades. This approach mirrors other acquisition practices, such as evolutionary acquisition, in the sense that capabilities are introduced in phases rather than all at once. However, we emphasize that the phases in which new subsystems are introduced should generally not overlap.[68] Indeed, allowing the SPO and prime integrator to focus on a limited set of integration challenges and minimizing integration risk are two of the principal ways in which a phased technology introduction can enable parallel development. The more subsystems that a program attempts to integrate simultaneously, the higher the integration risk, leaving the SPO less flexibility to apply to program execution. Decoupling technology development efforts and introducing new technologies one subsystem at a time can foster agile acquisition and rapid fielding of the initial system by diffusing risk, sharpening SPO and contractor focus, limiting development challenges during EMD, and allowing risky components to be fully matured at their own pace in parallel.

In practice, this is not always possible. Development programs involving complex or highly integrated technologies that inherently push the state of the art frequently require extensive technology development of both platform and mission systems (e.g., the F-22), or both hardware and software.[69] Operational need and fielding schedule may also dictate that successive integration phases overlap one another in order to accelerate the delivery of capability to the

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[67] GAO, 2016, p. 41. Also see O'Rourke, 2004, pp. 54–55; and Barnum, 2006, pp. 20–35.

[68] As we discuss in Chapter One, some degree of conceptual overlap may exist between the principles of parallel development discussed in this document and other strategies, such as subsystem designation, block upgrades, and capability increments, that are formally described in DoD acquisition guidance documents. What distinguishes the former from the latter, however, is the explicit decoupling of platform from subsystems. Under parallel development, the SPO may not be directly responsible for managing the subsystems developed in parallel. In contrast, typical block upgrades or software increments of a system are often still managed as part of the same EMD program (DoD, 2015; United States Code, Title 10, Section 2430, Major Defense Acquisition Program Defined, 2006).

[69] For programs featuring more-sophisticated or integrated hardware and software development, this may also be difficult to apply in principle. In the case of the Navy's Acoustic Rapid Commercial-off-the-Shelf Insertion (A-RCI) program, for example, new hardware upgrades are always accompanied by a new software upgrade. For a good discussion of the A-RCI program, see Michael Boudreau, *Acoustic Rapid COTS Insertion: A Case Study in Spiral Development*, Monterey, Calif.: Naval Postgraduate School, NPS-GSBPP-06-016, 2006.

warfighter. However, we contend that this very notion is at odds with the potential for success in a parallel development—and, more broadly, agile—framework. As laudable as boundary-pushing technological advances undoubtedly can be, we argue that successfully applying parallel development to rapidly field the basic system demands that the introduction of new technology development be limited to one subsystem at a time.

Prior RAND research and our program sample suggest the following two management actions for evaluating the effectiveness of incremental subsystem upgrades in the context of parallel development:

a. capability increments planned early in development and updated continually based on new information
b. intention to accelerate fielding of initial capability improvements, even if less than full capability.

Eight out of ten programs in our sample exhibited at least one of these two management actions, with three programs (F-16 MSIP, AMRAAM, and DDG-51) displaying both (see Table 2.3).

Table 2.3. Planned Incremental Approach to Fielding Capabilities

Platform	Capability Increments Planned Early in Development and Updated Continually Based on New Information	Intention to Accelerate Fielding of Initial Capability Improvements, Even If Less Than Full Capability
F-22 Raptor	No	No
F/A-18E/F Super Hornet	Yes	N/A[a]
F-16 MSIP	Yes	Yes
B-1B Lancer	No	Yes
AMRAAM	Yes	Yes
LANTIRN	No	Yes
F-117 Nighthawk	Unknown	Yes
DDG-51 *Arleigh Burke*	Yes	Yes
DDG-1000 *Zumwalt*	N/A[b]	No
LCS	N/A[c]	Yes

NOTE: N/A = not applicable. “Yes” indicates that a given program exhibited a particular characteristic of parallel development, based on historical RAND case studies. “No” indicates that a given program did not exhibit that characteristic. If there is insufficient evidence in the case studies to demonstrate that a given program either exhibits or does not exhibit a particular characteristic, it is labeled “Unknown.” We elaborate below on the relative effectiveness with which a program executed each characteristic to rapidly field the basic platform. Some part of each program listed reflected what we define as parallel development. With the exception of the F/A-18E/F program and F-16 MSIP, the term *parallel development* was not explicitly used; rather, one or more elements of a program’s acquisition strategy incorporated some aspect of parallel development (as defined in this report).

[a] Navy planners did not explicitly structure the F/A-18E/F development program to be agile. Rather, the decision to use mature subsystems with built-in modularity for future upgrades was conceived as a preventive measure against cost and schedule growth. Although the F/A-18E/F followed a normal aircraft development schedule—that is, not agile—the effectiveness of its parallel development blueprint did, indeed, contribute to minimal schedule slippage. Note that while the F/A-18E/F program was not expressly conceived as an agile program, the acquisition strategy did intend to acquire the initial system at less than full capability. Because of this discrepancy, we do not assess this criterion for the F/A-18E/F program.

[b] The DDG-1000 SPO had initially planned to integrate immature technologies through multiple hull flights and spiral upgrades. However, the program was restructured several times by both Navy and OSD leadership, cutting the envisioned fleet size from 32 to three. The radically altered production plan made the notion of planned upgrades uneconomical. The array of demanding technology developments was thus retained in-house and aligned with total ship integration. Therefore, because initial plans for incremental upgrades were planned but ultimately discarded under a new, OSD-directed acquisition strategy, we do not attempt to assess this criterion for the DDG-1000 program.
[c] LCS planners developed a fielding and upgrade schedule early in development, in which hulls and combat systems would be designed, constructed, and fielded in multiple flights, while the mission packages would be developed in parallel and integrated through multiple spiral increments. Although concurrency between hull flights and among the various mission package spirals (compounded by fielding schedules that were already compressed) generated a variety of deficiencies and ultimately contributed to cost and schedule growth, the incremental upgrade plan constituted an important part of the overall acquisition strategy. Moreover, the SPO responded to early technological challenges during Flight 0 sea trials by restructuring Flight 1 into "Flight 0+" to better reflect the test-oriented nature of early flights. However, the program officially planned only two initial test flights, the outcome of which would be used to inform later acquisition strategies. Planners thus did not initially construct a comprehensive upgrade schedule for the full acquisition program, leaving lingering uncertainty in the mission package capability plan. We therefore judge the LCS program as not applicable, reflecting the partial and early, but ultimately incomplete, nature of its upgrade increment planning. For a discussion of the acquisition timeline, see GAO, 2005.

Successful examples of parallel development practices in our program sample actively planned for and implemented incremental capability enhancements or spiral development phases. Common methods utilized by program managers to facilitate successful incremental upgrade regimes—and, consequently, enable parallel development efforts and rapid fielding of the platform and mature subsystems—include early planning; close collaboration between the SPO, other program offices, and users; sufficient maturation of components prior to fielding; iterative testing; and a clear statement of mission-critical capabilities.

Capability Increments Planned Early in Development and Updated Continually Based on New Information

Carefully planned incremental upgrades allow program managers to tie fielding of immature subsystems to a more appropriate schedule while minimizing technological and integration risk. When a specific upgrade plan is built into the parallel development strategy early in development planning, the SPO can potentially concentrate more freely on rapidly fielding the platform and mature subsystems. Components developed in parallel should be allowed to mature prior to fielding in order to minimize execution challenges. In addition, the SPO should maintain close collaboration with other program offices, as well as the user. Iterative testing and constant feedback between stakeholders are critical to smoothly integrating a mature subsystem into a rapidly fielded platform.

Four programs in our sample—F/A-18E/F, F-16 MSIP, AMRAAM, and DDG-51—planned early in development for incremental upgrades, updating continually based on new information:

- F/A-18E/F Super Hornet: The initial F/A-18E/F configuration employed mature subsystems, with development of major avionics technologies (e.g., AESA radar, forward-looking infrared imaging, and electronic countermeasure) occurring in parallel with the actual EMD phase. Moreover, oversight of the upgrade programs resided in separate program offices. Mission system integration occurred through incremental upgrades, once they had sufficiently matured. The SPO's successful incorporation of subsystem modularity effectively isolated risk for the initially fielded platform, while the SPO's effective collaboration with other responsible program offices enabled the F/A-18E/F to receive capability upgrades relatively on cost and on schedule.[70]

- F-16 MSIP: The MSIP established a clear blueprint for incrementally upgrading the F-16C/D with advanced subsystems developed in parallel. The SPO planned to execute the upgrade program in three stages, with mini-block upgrades in each stage. The more-significant technological advances were pushed to the later stages to allow them to fully mature. Stage I focused on developing the airframe structure and provisioning it for modular upgrades, and Stages II and III concentrated on individual subsystems. Additionally, the platform was largely common to the existing F-16A/B models in order to isolate development risk in a few key subsystems and, principally, in the system integration. Parallel development of the major subsystems was managed by separate program offices, but the F-16 SPO collaborated closely with each to incorporate MSIP-specific design elements, engage in extensive equipment transfer, and facilitate iterative testing.[71]
- AMRAAM: Development planners did not initially embed parallel development strategies within the AMRAAM program's acquisition strategy, which envisioned integrating all capabilities at once during EMD rather than incrementally. However, ongoing cost and schedule problems, coupled with insufficient maturation in key capabilities, forced the Air Force to restructure the AMRAAM EMD program. Several technologies, including electronic counter-countermeasures and the APREP's guidance and rocket motor systems, required parallel development efforts. Developing the major subsystems in parallel enabled the SPO to concentrate on achieving a stable missile design and a configuration that was compatible with multiple aircraft. The parallel development efforts established during EMD ultimately isolated development of the guidance, rocket motor, and integrated circuits from that of the platform. Integration involved a pre-planned product improvement phase during LRIP, plus a revised testing schedule. The restructured efforts enabled the AMRAAM capability to resume its rapid fielding schedule, albeit following significant initial schedule delays.[72]
- DDG-51 *Arleigh Burke*: The SPO planned for the DDG-51 acquisition program to encompass at least three flights of hulls and nine combat system baselines. Incremental baseline combat system upgrades were expected to continually integrate technological advances into the DDG-51 fleet's capability. These included hangar decks for MH-60 helicopters, extended-range guided munitions, an advanced air and missile defense radar, and state-of-the-art electronics and electronic warfare technologies. The program office effectively employed mission system modularity from early in development to facilitate subsequent capability upgrades and maintained a close working relationship with external program offices responsible for developing the desired capabilities in parallel.[73]

Three programs in our sample—F-22, B-1B, and LANTIRN—did not plan for incremental upgrades early in development or continually update plans based on new information:

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[70] Younossi et al., 2005, pp. 23, 43.

[71] Camm, 1993, pp. 34–39, 43–52.

[72] Mayer, 1993, pp. 25–28.

[73] Schank, Smith, et al., 2006, pp. 73–74, 83–86.

- F-22 Raptor: Although the SPO did effectively respond to the unexpected addition of an air-to-ground requirement by placing it in parallel development and planning for it to be upgraded incrementally, the platform and major subsystems were not designed to be modular. Indeed, the highly-integrated nature of the F-22 configuration, coupled with the state-of-the-art technological advances in all major subsystems, effectively tied integration and fielding of all major subsystems to initial fielding of the platform. This design reality inherently constrained the SPO's ability to upgrade components incrementally. The F-22 program subsequently received a series of modernization efforts and capability block upgrades. However, we were unable to find any incremental upgrade schedules built into the initial development planning processes. It could be argued that the notable absence of the latter ultimately led to a need for the former—at considerable additional cost, and several years after the platform was initially fielded.[74]
- B-1B Lancer: Given the urgency of need built into the B-1B's fielding schedule, the SPO had always planned to rapidly field the platform and retrofit key subsystems developed in parallel. However, developers' inadequate assessment of technological maturity in the subsystems resulted in upgrades of technologies that had not sufficiently matured. This created significant testing and integration challenges.[75]
- LANTIRN: The SPO recognized during EMD that the new ATR technology was not nearly mature enough and placed it into parallel technology development, but the absence of contingency planning and coordination between program offices ultimately failed to produce a mature ATR capability. Moreover, development challenges in other key components, such as the navigation and targeting pods, coupled with a lack of hedging strategies embedded in early contingency planning, led to schedule, testing, and production delays in fielding critical capabilities.[76]

Intention to Accelerate Fielding of Initial Capability Improvements, Even If Less Than Full Capability

Parallel development, when effectively deployed through incremental upgrades, can accelerate the fielding of a partial capability. However, the relative success of this strategy depends on several factors, including designing modularity into the platform, limiting the number of technical requirements in the initially fielded system (while planning for requirements for future versions of the system), limiting the SPO management's focus to a constrained set of objectives, and carefully planning the upgrades for mature subsystems. An equally important enabler of parallel development in the broader context of agile acquisition is the intention to accelerate fielding of initial capability improvements, even if less than the full capability is present. Although ensuring a satisfactory level of technological risk and maturity is essential to the stability of fielding timelines, program managers and operators must be willing to accept a lower level of capability in the initially fielded platform. This is a fundamental principle of parallel development as an agile approach.

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[74] Younossi et al., 2005, pp. 34–37, 42.

[75] Bodilly, 1993a, pp. 31–37.

[76] Bodilly, 1993b, pp. 31–35, 39–40, 49–50.

It is important to reiterate that, in this context, we do not judge programs as successes or failures. Not all programs are designed to be agile (e.g., F/A-18E/F, F-22), so the lack of intention to rapidly field the platform is not necessarily a bad thing. The presence or absence of this intent in a program merely reflects the extent to which that program successfully enabled parallel development to rapidly field the basic system.

Seven programs in our sample—F-16 MSIP, B-1B, AMRAAM, LANTIRN, F-117, DDG-51, and LCS—exhibited the intention to accelerate fielding of the initial capability:

- F-16 MSIP: The staged upgrade schedule envisioned by the F-16 MSIP plan allowed initial platform design modifications to be incorporated into new F-16 aircraft in less than two years. Although these fielded F-16s added minimal combat capability to the existing F-16A/B aircraft, the modularity and provisioning designed into the first MSIP-capable F-16s accelerated the fielding of not only the initial platform but also the first "true" F-16C/D aircraft equipped with the Stage II MSIP upgrades.[77]
- B-1B Lancer: Political pressure from the White House and OSD for the Air Force to counter the Soviet threat with a multi-role bomber generated an artificially conceived and optimistic IOC for the B-1B. Despite significant concurrency, relegating subsystem integration to future upgrades enabled the SPO to achieve first flight less than two years after program initiation, with IOC just three years later.[78]
- AMRAAM: Development planners estimated an accelerated development schedule, from Dem/Val through MS C, of 90 months—including an EMD phase of only three years. Budget pressures caused the Air Force to compress this schedule to only 73 months, eliminating or delaying several activities from Dem/Val and LRIP. Until the AMRAAM JSPO instituted parallel development efforts for some of the more challenging technologies, the EMD program experienced serious delays. Ultimately, MS C was delayed by almost three years, and IOC was delayed by almost six years. However, successful implementation of the APREP upgrade did effectively curb additional cost and schedule growth.[79]
- LANTIRN: The urgency of need expressed by senior leadership led to an accelerated five-year development schedule, from program initiation to MS C. Although the concentration of technological risk within the EMD program (coupled with budget pressures) led to schedule growth of more than three years for MS C and more than five years for IOC, the program office maintained the intention to accelerate fielding timelines. Moreover, following technological and other challenges and schedule slippage, DoD restructured the EMD program, placing the navigation pod and the targeting pod into more-appropriate incremental upgrade schedules.[80]
- F-117 Nighthawk: Program planners envisioned the F-117 acquisition as agile, with first flight expected only 20 months after MS B and the first operational delivery expected ten

[77] Camm, 1993, pp. 34–35.

[78] Bodilly, 1993a, pp. 11–12, 14–16, 33–34.

[79] Mayer, 1993, pp. 16–27.

[80] Bodilly, 1993b, pp. 14–15, 56.

months thereafter.[81] Heavy concurrency was built into the program's schedule assumptions. By limiting initial system specifications and pushing non–mission-critical capabilities to future increments, the SPO achieved rapid fielding of the platform.[82]

- DDG-51 *Arleigh Burke*: The combination of urgency of need with the planned incremental hull flights and combat system upgrades allowed the DDG-51 to reach MS C from program initiation in only six years and IOC six years thereafter. It was, indeed, the intention of development planners to speed delivery of the platform to users at less-than-full capability in order to be more responsive to a quickly changing environment, with the expectation of incrementally improving capabilities according to operational need.[83]
- LCS: The accelerated fielding schedule of the first LCS seaframe was a key objective in the acquisition strategy. Indeed, the lead ship was launched only four years after program initiation, with IOC less than three years thereafter. The acquisition strategy further planned to field the lead ship with mature combat and mission systems that would be upgraded through multiple spiral increments. However, a compressed technology development phase and a lack of effective technological and integration risk assessments yielded serious technological deficiencies in the first hull flight, ultimately leading the Navy to cancel hull procurements in multiple years and restructure the acquisition strategy. Although the misalignment between fielding timelines and technological readiness thus contributed to cost and schedule growth, the LCS program was expressly conceived as an agile acquisition program and accepted the trade-off between lower initial capability and rapid fielding schedule of the basic seaframe.[84]

Two programs in our sample—F-22 and DDG-1000—did not exhibit the intention to accelerate fielding of the initial capability:

- F-22 Raptor: The considerable technological challenges associated with development of both the F-22 platform and major subsystems led the EMD phase to exceed its original schedule estimate by more than 52 months (as of 2001), including slippage of more than two years for the initial operational test and evaluation phase. This resulted in a total EMD length of more than 14 years. However, the F-22 program was not conceived as an agile acquisition program and, to the contrary, prioritized technological advances and providing the full capability at fielding over an agile fielding schedule.[85]
- DDG-1000 *Zumwalt*: The rigorous demands associated with developing a new, cutting-edge hull form, along with several advanced subsystems, led to a development schedule of more than 20 years from program initiation, including nearly ten years for pre-EMD technology development activities alone. The decision not to separate subsystem development from that of the initially fielded platform resulted in numerous cost and

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[81] In practice, these assumptions proved optimistic, with the first flight slipping by 11 months (to 31 months after MS B) and the first operational delivery slipping by 13 months (to 43 months after MS B).

[82] Smith, Shulman, and Leonard, 1996, pp. 9–10, 14–23.

[83] Jeffrey A. Drezner, Mark V. Arena, Megan McKernan, Robert Murphy, and Jessie Riposo, *Are Ships Different? Policies and Procedures for the Acquisition of Ship Programs,* Santa Monica, Calif.: RAND Corporation, MG-991-OSD/NAVY, 2011, p. 35.

[84] GAO, 2016, p. 41. Also see O'Rourke, 2011.

[85] Younossi et al., 2005, pp. 5–10.

> schedule overruns, delayed testing, and slipped platform fielding. As in the F-22 program, however, the DDG-1000 concept entailed furnishing the lead ship with full operational capability, rather than rapidly acquiring the system at partial capability.[86]

Tight Alignment of Requirements, Acquisition, and Budget Stakeholders

Regardless of the relative effectiveness of a program's risk assessments and contingency planning, the relationship between various stakeholders can have a profound effect on program outcomes. For example, programs that institute well-conceived parallel development strategies can still be victims of budget cuts; misalignment among technical requirements, available technologies, and operational need; or artificially imposed constraints by external actors. Exogenous forces, such as budget environment and leadership priorities, may constitute a program's greatest source of uncertainty and the greatest challenge to a program manager's responsiveness. A tight alignment of requirements, acquisition, and budget stakeholders is therefore critical in any program seeking to employ parallel development.

Prior RAND research establishes three management actions for evaluating the effectiveness of stakeholder alignment:

a. close collaboration between the user (warfighter) and developer (industry and government)
b. flexible technical requirements and stable funding[87]
c. sufficiently empowered program office management.

Only three of the programs in our sample (F/A-18E/F, F-16 MSIP, and F-117) encapsulated all three management actions (see Table 2.4), with no other programs clearly exhibiting even two of the three.

[86] Drezner et al., 2011, pp. 35–40. It could be justifiably argued that the initial acquisition strategy entailed incremental capability upgrades. However, the program itself was not designed to be developed in an agile environment, hence the ten major EDMs prior to MS B.

[87] We refer here to *technical requirements* (i.e., design specifications), as opposed to *operational requirements* (i.e., approved by the Joint Capabilities Integration and Development System). Not only are these two types of requirements under the purview of two entirely distinct communities, but the notion of requirements flexibility carries vastly different connotations for each. Flexible *operational* requirements might be taken to mean requirements "creep," or an evolving or unstable statement of operational needs. This can add significant flux to a development program's cost and schedule assumptions. Conversely, flexible *technical* requirements describe the ability of the SPO to tailor technical specifications to balance cost, schedule, and performance concerns with operational needs (i.e., trade-offs).

Table 2.4. Tight Alignment of Requirements, Acquisition, and Budget Stakeholders

Platform	Close Collaboration Between the User (Warfighter) and Developer (Industry and Government)	Flexible Technical Requirements and Stable Funding	Sufficiently Empowered Program Office Management
F-22 Raptor	No	No	No
F/A-18E/F Super Hornet	Yes	Yes	Yes
F-16 MSIP	Yes	Yes	Yes
B-1B Lancer	No	No	No
AMRAAM	Unknown	No	No
LANTIRN	No	No	No
F-117 Nighthawk	Yes	Yes	Yes
DDG-51 *Arleigh Burke*	Unknown	Yes	Unknown
DDG-1000 *Zumwalt*	No	No	No
LCS	No	No	No

NOTE: "Yes" indicates that a given program exhibited a particular characteristic of parallel development, based on historical RAND case studies. "No" indicates that a given program did not exhibit that characteristic. If there is insufficient evidence in the case studies to demonstrate that a given program either exhibits or does not exhibit a particular characteristic, it is labeled "Unknown." We elaborate below on the relative effectiveness with which a program executed each characteristic to rapidly field the basic platform. Some part of each program listed reflected what we define as parallel development. With the exception of the F/A-18E/F program and F-16 MSIP, the term *parallel development* was not explicitly used; rather, one or more elements of a program's acquisition strategy incorporated some aspect of parallel development (as defined in this report).

This somewhat conservative outcome reflects the unpredictability and sheer magnitude of the impact associated with stakeholder alignment. Indeed, exogenous forces can have a profound effect on the success of a parallel development program, completely irrespective of the relative efficacy of a SPO's risk management, contingency planning, and acquisition strategy. Stakeholders should therefore be particularly sensitive to the vagaries of intergovernmental power dynamics by pursuing a range of enabling strategies, including a tight alignment among concept developers, requirements developers, the SPO, oversight agencies, operational users, and industry; alignment of technical requirements, available technologies, and operational need; stable funding; limited or no arbitrary cost caps or schedule deadlines; flexibility in acquisition strategies; the ability to relax unrealistic or challenging requirements; and frequent input from independent observers (e.g., review teams, advisory boards).

Close Collaboration Between the User (Warfighter) and Developer (Industry and Government)

A close working relationship between user and developer can benefit parallel development in several respects.[88] Perhaps most critically, the warfighter provides feedback regarding

[88] Other stakeholder relationships within government (program offices, various levels of service decisionmakers, the acquisition community, budgeteers, testing organizations, OSD, the White House, Congress, and so on) between

performance of the initially fielded system. This feedback not only assesses the technological readiness of the system and potential integration risks but also informs schedule planning for subsystem upgrade increments. The user-developer dynamic most favorably affected the programs in our sample when it was developed early (i.e., during concept development, requirements definition, early testing, and prototyping) and was maintained throughout testing, fielding, and production.

Three programs in our sample—F/A-18E/F, F-16 MSIP, and F-117—maintained close collaboration between user (warfighter) and developer (industry and government):

- F/A-18E/F Super Hornet: The technical requirements, acquisition strategy, and contractual arrangements were all largely initiated by the same program managers and contractor teams that had previously been responsible for the F/A-18C/D. This continuity of relationships and responsibilities fostered a close collaboration between relevant government and industry stakeholders from concept development through production. The F/A-18E/F was also a proof-of-concept for the Navy's use of integrated product teams as a management tool. The close collaboration among all interested stakeholders enabled program managers to quickly identify potential problems and make effective adjustments during testing and fielding.[89]
- F-16 MSIP: MSIP staff maintained a close collaboration with other F-16 directorates and F-16A/B users. The mini-block upgrade structure fostered an iterative process of industry-SPO subsystem development and user testing. Additionally, the MSIP was conceived as a development effort capable of flexibly addressing the evolving operational needs of multiple distinct users—both the Air Force and partner nations. This required program managers and the contractor team to maintain an unusually close working relationship with users through iterative subsystem testing and continual feedback regarding operational need.[90]
- F-117 Nighthawk: The Have Blue demonstrator forged initial relationships among industry, developers, and users that continued throughout development and fielding. Indeed, RAND research identifies a pattern of strong communication among these groups. The limited number of F-117 performance specifications led to significant SPO and contractor autonomy and, ultimately, an organic collaboration among key stakeholders. Even following MS C, the SPO maintained a stable flight test program and ongoing user feedback in order to inform a series of incremental configuration upgrades.[91]

Five programs in our sample—F-22, B-1B, LANTIRN, DDG-1000, and LCS—lacked a close collaboration between user (warfighter) and developer (industry and government):

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government and industry (integrated product teams, the prime contractor, subcontractors, industry teams responsible for pertinent subsystem development, and so on) and with independent advisory boards (independent review teams, Defense Science Board, Defense Business Board, and so on) are equally critical. Here, we focus exclusively on the user-developer dynamic.

[89] Younossi et al., 2005, pp. 21–27. Also see Johnson and Birkler, 1996, p. 21.

[90] Camm, 1993, pp. 18–21, 34–35, 39–43.

[91] Smith, Shulman, and Leonard, 1996, pp. 8–9, 16–17, 24, 29–34, 47.

- F-22 Raptor: Although the F-22 program's use of integrated product teams to foster close collaboration among users, developers, and industry was unprecedented, the stakeholders that emerged had neither the preexisting working relationship nor technical expertise to effectively identify challenges in engineering, manufacturing, or user performance. This was exacerbated by the artificially constructed contractual relationship, which emphasized industrial base concerns over continuity through a well-defined, existing supply chain.[92]
- B-1B Lancer: The B-1B concept and requirements were originally promulgated through high-profile negotiations between the White House and Congress, rather than through organic explorations among developers, users, and industry. Consequently, the assessed level of technological risk became misaligned from realistic cost estimates. B-1B developers neither collaborated closely enough with users early in concept development to recognize the risks associated with incorporating previous B-1A capabilities nor planned for adequate user feedback prior to initial fielding. Indeed, the program's test plan was nearly concurrent with the expected IOC deadline, and testing for key subsystems was deferred entirely until after initial fielding. This fundamental disconnect between developer and user caused aircraft early in production to be fielded without being fully mission-capable.[93]
- LANTIRN: Following program initiation, the incipient SPO developed a program definition that diverged from that formulated by Air Force, OSD, and combatant command leadership. SPO management subsequently acknowledged to RAND researchers that this created a disconnect between developers and users in terms of technical requirements and available technologies. A bid protest following the EMD contract award also distracted the SPO from collaborating with industry and users to develop a fairly unrefined concept definition. Finally, the dearth of simulation and testing planned for the EMD program, coupled with minimal user input, led to serious user concerns of technological risk through production.[94]
- DDG-1000 *Zumwalt*: The original DD-21 program was envisioned as a next-generation platform capable of meeting myriad future operational needs. Technical requirements were organically conceived through collaboration among user, developer, and industry. However, a stream of program restructurings from the Navy, OSD, and Congress, as well as serious budget cuts, resulted in a misalignment between technical requirements and operational need. Moreover, the SPO vacillated between "hands-off" and "hands-on" in its collaboration with other stakeholders—particularly industry. Finally, plans for ongoing system testing and user feedback were delayed indefinitely to focus on the considerable technology development remaining in EMD.[95]
- LCS: In 2014, the Secretary of Defense initiated a task force to assess the concept of operations (CONOPS), which involved consulting with fleet operators. Although this sort of CONOPS exploration was conducted prior to program initiation, the focus was on restarting a Streetfighter-like capability—*not* on the full scope of LCS missions. The

[92] Younossi et al., 2005, pp. 13–21.

[93] Bodilly, 1993a, pp. 2, 14–16, 25–26.

[94] Bodilly, 1993b, pp. 12–13, 24–25, 29–31, 43–44.

[95] McKernan and Drezner, 2012, pp. 9–12, 19–23, 43–47.

loose organizational structure between mission system program offices and the program manager responsible for total system integration led to a disconnect between developers and users, with weak lines of communication undermining operator feedback. This was compounded by significant delays in both developmental and operational testing, which ensured that developers would not receive user feedback until well into construction of later ships. As of fiscal year (FY) 2014, the Director of Operational Test and Evaluation found that many *Independence*-variant combat system technologies had not been tested because of reliability-driven availability shortages and initial deployment obligations. Developmental testing was not completed for the *Independence* variant until well into FY 2015, nearly seven years after initial fielding.[96]

Flexible Technical Requirements and Stable Funding

The relative stability of the budget environment and flexibility of technical requirements can likewise dramatically influence the trajectory of parallel development programs. A tight budgetary environment or artificially imposed cost caps can delay or eliminate critical enablers of parallel development, such as early testing and validation activities; create unrealistic expectations; or misalign technical requirements with technological availability and operational need. Resources available for contingency tools, such as management reserves, can also be curtailed. Conversely, flexible requirements afford developers the opportunity to foster a close relationship with users and industry, generate requirements around technological availability rather than arbitrary technical wish lists, and conduct the necessary planning for implementing a comprehensive parallel development strategy.

Four programs in our sample—F/A-18E/F, F-16 MSIP, F-117, and DDG-51—maintained flexible requirements and stable funding:

- F/A-18E/F Super Hornet: Conceived as a capability improvement to the existing F/A-18C/D platform, planners deliberately limited the F/A-18E/F's mission requirements and initial technical specifications in order to minimize cost and schedule burdens. This enabled program managers to flexibly employ parallel development by constructing the desired capabilities around suitable technologies rather than arbitrary technical wish lists. Although Navy leadership imposed a strict ceiling for the average unit flyaway cost, the combination of accurate cost estimates, an unprecedented use of the cost-as-an-independent-variable analytic framework, close collaboration between the SPO and contractors, substantial management reserves, and flexible requirements allowed parallel development to succeed in spite of the cost constraints. Effective cost management likewise enabled the program to weather temporary congressional funding constraints and OSD's eventual direction to reduce the acquisition program from 1,000 to 548 total aircraft.[97]
- F-16 MSIP: The MSIP specifications were, by their very essence, designed to be flexible. The concept was envisioned to provide the SPO with relatively loose requirements and

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[96] GAO, 2016, p. 14. Also see O'Rourke, 2004, pp. 39, 55; and Barnum, 2006, pp. 27, 31.

[97] Younossi et al., 2005, pp. 2–3, 21–23. Also see Johnson and Birkler, 1996, p. 49.

build subsystem modularity into the design in order to flexibly incorporate new desired capabilities through parallel development as they became available.[98]

- F-117 Nighthawk: RAND research identifies "relatively high stability in program objectives and availability of funding" as critical enablers of the F-117 program's agile acquisition strategy. The decision to "set an absolute minimum number of design and performance specifications as hard requirements, leaving the remainder as goals," further provided the SPO with "considerable freedom . . . in system design." Only three strict parameters were established in the system specifications—mission profile, ordnance loads, and takeoff and landing distances—with all other specifications left as "goals." In particular, the SPO deferred development, testing, and integration of reliability and maintainability capabilities until after initial fielding of the platform as a series of configuration upgrades. Planners accepted a certain envelope of risks as a tradeoff for an accelerated schedule.[99]
- DDG-51 *Arleigh Burke*: The DDG-51 program's stable funding and procurement plan, coupled with highly accurate cost estimates, yielded a perennially consistent unit cost. The final congressionally appropriated funds were remarkably close to both SPO and independent cost estimates. A major reason for this cost stability was the Navy's competitive acquisition strategy, whereby all construction contracts for hulls following the lead ship were to be competed between two shipyards. The program's multiyear procurement funding mechanism added further stability to the industrial base. Initial requirements were generally limited to a new survivable hull. Advances in the various subsystems were expected to be developed in parallel as operational need and technological availability dictated, which enabled requirements to remain optimally flexible across multiple flight upgrades.[100]

Six programs in our sample—F-22, B-1B, AMRAAM, LANTIRN, DDG-1000, and LCS—did not maintain flexible requirements and stable funding:

- F-22 Raptor: The Air Force adamantly specified the need for a stealthy multi-role fighter, whose technical requirements would necessitate a range of significant technological advances—airframe, propulsion, integrated avionics, and eventually an air-to-ground capability. Independent advisors, most notably the Defense Science Board, recommended that the Air Force relax its requirements in order to meet potential challenges posed by cost, schedule, and technological risk. However, institutional pressure caused the program to proceed with rigid specifications, which impacted not only the technological immaturity of major subsystems but also the SPO's ability to undertake a successful parallel development program. The challenging budget climate further restricted the SPO to allocate only a small portion of its budget to management reserves, which may have impacted its responsiveness to technical challenges.[101]
- B-1B Lancer: High-level requirements for a multi-role bomber were preordained by Congress and the White House, inherently constraining developers' ability to organically

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[98] Camm, 1993, pp. 2–3.

[99] Smith, Shulman, and Leonard, 1996, pp. 14–23, 34–35.

[100] Schank, Smith, et al., 2006, pp. 73–74, 85–87, 90–94.

[101] Younossi et al., 2005, pp. 1–2, 48–50.

formulate appropriate specifications. To address leadership concerns about the potential for cost and schedule growth, OSD imposed a strict cost cap and firm IOC deadline. Likewise, Congress exercised close scrutiny over the program, often instituting significant budget cuts as a punitive response to program execution challenges. These factors limited the SPO's ability to address risks through flexible management and contingency planning, and they constrained the potential efficacy of the parallel development program. The Air Force's subsequent decision to incorporate a multiyear procurement plan into the production schedule, before EMD had even concluded, forced the SPO to concentrate its efforts on fixing technical problems instead of executing the critical incremental upgrades.[102]

- AMRAAM: Requirements established by the Joint Service Operational Requirement were designed to provide flexibility, but according to RAND researchers, the SPO and industry misinterpreted them as rigid. Unrealistic cost and schedule estimates further limited the SPO's flexibility and budget. Congress repeatedly cut early-development AMRAAM funding, including zeroing-out the FY 1978 Dem/Val budget. This caused several key development and testing activities to slip into EMD, which had a direct impact on the technological immaturity of the system. Finally, the artificially imposed IOC deadline increased technological and integration risks. Following several high-profile technological challenges and schedule delays, Congress tied future funding to strict performance, cost, and schedule requirements.[103]
- LANTIRN: Technical requirements were highly rigid and exceeded the operational needs statement. The SPO further pursued a program definition that was inherently dissociated from that of early planners. The divergence among the SPO, early program planners, and users ultimately led to "poor program definition," according to RAND researchers. Inflexible budget expectations by senior OSD and congressional leadership also appear to have compelled the SPO and contractor to severely underestimate expected development costs.[104]
- DDG-1000 *Zumwalt*: The DDG-1000 program incurred at least three separate unit cost growth breaches against the baseline, including a significant average procurement unit cost breach of more than 25 percent and a critical program acquisition unit cost breach of 86 percent of the baseline. The program's Nunn-McCurdy breach has been explicitly linked to OSD's budgetary decision to cut planned ship quantities from an MS B baseline of ten to only three. Unrealistic cost estimates further curtailed the SPO's ability to constrain cost growth. Initial design specifications recommended that immature subsystems be developed in parallel to isolate EMD development risks in the novel platform design. The decision to pursue an array of major technology development efforts during EMD was influenced in large part by high-level Navy, OSD, and congressional leadership mandates. To the credit of the DDG-1000 SPO, however, program management was responsive to the development and integration challenges

[102] Bodilly, 1993a, pp. 7–8, 11–12.

[103] Mayer, 1993, pp. 15–16, 24–30, 37–39, 42–43.

[104] Bodilly, 1993b, pp. 4–7, 13, 28–30.

presented by such a high concentration of immature technologies, ultimately scaling down technical requirements and jettisoning some of the more immature capabilities.[105]

- LCS: In addition to initiating the development program without having conducted an analysis of alternatives, established requirements, or fully defined CONOPS and concepts of employment, design deficiencies discovered during testing led to redesign and restructure efforts, including reworking the platform to accommodate a larger crew. Moreover, the LCS program sought to implement the new set of construction standards set out by the American Bureau of Shipping, called the Naval Vessel Rules, which were not published in a fully approved form until after contracts for the lead LCS ships were awarded and were subsequently modified by the Navy. This flux in construction standards has been identified by RAND researchers as a major source of cost growth in the LCS program. The full scope of mission-module technologies was not set at program initiation, leaving significant residual uncertainty well into development. Finally, the program has consistently experienced instability in the acquisition strategy and in funding. The program has vacillated between single- and dual-variant downselect approaches, with uncertainty regarding combat and mission system commonality between the variants persisting even following the announcement of a block buy of ten ships in 2010. Moreover, extreme schedule delays and cost growth caused the Navy to cancel the procurement of four hulls in FY 2008, and the Secretary of Defense announced in 2015 that the Navy would transition into a mixed LCS-frigate fleet and reduce the total acquisition by 12 ships because of survivability and lethality concerns.[106]

Sufficiently Empowered Program Office Management

A recurring theme in prior RAND research is the importance of empowering SPO management to flexibly adapt to challenges through a combination of planning for contingencies, relaxing unrealistic technical requirements, and managing the contractual relationship with industry partners. Programs in our sample that featured strong, experienced, and empowered SPO staff tended to be better equipped to handle the unique challenges of parallel development. Just as successful implementation of various risk-mitigation strategies (e.g., prototyping and testing) can be undermined by negative exogenous factors, the presence of *positive* exogenous factors, especially strong program management, can enable a parallel development program to overcome potential challenges, such as a concentration of risky technology development efforts.

Three programs in our sample—F/A-18E/F, F-16 MSIP, and F-117—sufficiently empowered SPO program managers:

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[105] Blickstein et al., 2011, pp. 20–24. Also see Ronald O'Rourke, *Navy DDG-51 and DDG-1000 Destroyer Programs: Background and Issues for Congress*, Congressional Research Service, RL32109, March 10, 2016, pp. 15–18.

[106] John Schank, Mark V. Arena, Kristy N. Kamarck, Gordon T. Lee, John Birkler, Robert Murphy, and Roger Lough, *Keeping Major Naval Ship Acquisitions on Course: Key Considerations for Managing Australia's SEA 5000 Future Frigate Program*, Santa Monica, Calif.: RAND Corporation, RR-767-AUS, 2014, pp. 19–20, 95–96. Also see O'Rourke, 2011, p. 9; and GAO, 2016, p. 2.

- F/A-18E/F Super Hornet: The F/A-18E/F requirement largely evolved out of existing relationships among F/A-18C/D program managers, contractors, and users. This afforded the SPO tremendous leeway in defining system specifications. The parallel development framework envisioned by planners provided the SPO with additional flexibility to define subsystem requirements incrementally, as technological availability caught up to operational need. In spite of the strict budget and cost scrutiny imposed by Navy leadership, the SPO was generally afforded considerable flexibility in concept definition and strategic planning.[107]
- F-16 MSIP: Although the MSIP directorate underwent some degree of organizational flux as the program matured, it maintained a strong working relationship with both the F-16 SPO as a whole and other program offices charged with managing individual subsystem development. Moreover, MSIP program managers were empowered to identify promising technologies that could be developed in parallel and incorporated into a future MSIP upgrade.[108]
- F-117 Nighthawk: The limited number of F-117 performance specifications led to significant SPO and contractor autonomy. The F-117 program's status as a special access program also may have shielded it from oversight by external stakeholders—particularly Congress and the public.[109] The stability in funding and requirements enabled the SPO to focus on a correspondingly stable set of technical objectives and challenges. Finally, the SPO was given considerable autonomy to manage the schedule for its planned subsystem development and upgrades.[110]

Six programs in our sample—F-22, B-1B, AMRAAM, LANTIRN, DDG-1000, and LCS—did not sufficiently empower SPO program managers:

- F-22 Raptor: Rigid technical requirements, coupled with a strong vested interest from senior Air Force leadership, created institutional pressure to maintain a very specific design concept, which limited the options available to the SPO to address technical challenges. The SPO delegated design and integration responsibilities to a prime contractor without sufficient relevant experience, expertise, supplier base, or existing relationships with SPO staff, further hindering the SPO's responsiveness to unanticipated technological challenges.[111]
- B-1B Lancer: From the start, the B-1B program was an unusually high-profile program with interested stakeholders ranging from Congress to the White House. This subjected the program to an equally unusual degree of oversight from several external actors. The SPO was thus deprived of the ability to adapt to technological challenges, with Congress and OSD frequently instituting dramatic program restructures, cost caps, and schedule requirements. Although the SPO had planned to mitigate an accelerated acquisition schedule through a series of parallel development and upgrade efforts, its ability to

[107] Younossi et al., 2005, pp. 2–3, 21–27.

[108] Camm, 1993, pp. 2–3, 20–26.

[109] This is not to say that adequate transparency and public oversight do not have their own merits; however, we do not consider such issues here.

[110] Smith, Shulman, and Leonard, 1996, pp. 1–2, 13–17, 47.

[111] Younossi et al., 2005, pp. 1–2, 14–20.

execute these efforts was nonetheless curtailed by external budget and schedule pressures.[112]

- AMRAAM: A demanding and expedited schedule, coupled with strict performance requirements, inherently limited the SPO's flexibility. In response to the program's execution challenges during EMD, Congress instituted more-formal cost and schedule constraints. RAND researchers contend that these limitations "eliminated all flexibility within the SPO to engage in any sort of cost-performance trade-offs." Recurring cost estimates and testing requirements were also deemed unrealistic. Even the relatively successful parallel development structure was imposed by OSD as a remedy to technological challenges rather than pre-planned by the SPO early in development.[113]
- LANTIRN: The LANTIRN SPO was created only after requirements and concept development had been finalized, and it lacked a connection to concept planners and the relevant industrial base. Moreover, Congress and OSD continually restructured the program and imposed budget and schedule constraints. Although the SPO was empowered to undertake parallel development efforts for immature technologies (such as the ATR), external stakeholders imposed strict cost, schedule, and performance requirements.[114]
- DDG-1000 *Zumwalt*: The DDG-1000 requirements entailed a slew of complex and immature technologies, which was complicated by the Navy and OSD leadership's significant investment in the capability from early in development. The SPO was not empowered to relax the myriad technical requirements until severe budget cuts, technological challenges, and a critical Nunn-McCurdy breach necessitated a change (at which point the advanced propulsion system and dual-band radar were both descoped). Early SPO development planning initially propounded an acquisition strategy more akin to that of the DDG-51, but a series of restructurings and budget cuts mandated by OSD ultimately made an optimally conceived parallel development strategy infeasible.[115]
- LCS: The diffusion of responsibilities across program offices, unclear delineation of authority as defined in the original memorandum of agreement, and loose interagency communication system acted in concert to minimize the SPO's control of program efforts. This was somewhat mitigated by the creation of a stand-alone PEO-LCS in 2011, which allowed a single agency to establish oversight and communication lines between program offices. Nonetheless, the program has retained significant interest from senior Navy, OSD, and congressional leadership since its inception. The program came into being as a loosely defined concept with no assessed alternatives as a result of personal involvement by the Chief of Naval Operations, and ongoing technological challenges, schedule delays, and cost growth have led leaders (including the Chief of Naval Operations and the Secretary of Defense) to intervene in the program's acquisition strategy, culminating in a sharp reduction in program scope.[116]

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[112] Bodilly, 1993a, pp. 7–8, 11–12.

[113] Mayer, 1993, pp. 5, 15–16, 24–30, 37–39, 42–43.

[114] Bodilly, 1993b, pp. 4–7, 13, 28–30.

[115] McKernan and Drezner, 2012, pp. 9–12, 19–23, 43–47.

[116] GAO, 2016, p. 41. Also see O'Rourke, 2004, pp. 54–55; and Barnum, 2006, pp. 20–35.

Strong Contingency Planning

Planning for unexpected contingencies is an essential part of any development program, and it is particularly vital to a program employing parallel development. Indeed, the built-in modularity necessary to upgrade capabilities over time generates intrinsic uncertainty. Deferring combat capability—perhaps indefinitely—has a direct and immediate impact on the warfighter. The decision to introduce capabilities incrementally via parallel development, in order to facilitate rapid fielding of the platform, thus entails a trade-off. Programs in our sample that conducted relatively more-effective contingency planning tended to navigate this trade-off with greater success. Our program sample suggests two management actions for evaluating the effectiveness of contingency planning in parallel development:

a. rigorous contingency planning conducted early in development
b. effectively restructured development program according to contingency plans.

Only one program in our sample (F-16 MSIP) conformed to both management actions (see Table 2.5).

Table 2.5. Strong Contingency Planning

Platform	Rigorous Contingency Planning Conducted Early in Development	Effectively Restructured Development Program According to Contingency Plans
F-22 Raptor	No	Unknown[a]
F/A-18E/F Super Hornet	Yes	N/A[b]
F-16 MSIP	Yes	Yes
B-1B Lancer	No	No
AMRAAM	No	Yes
LANTIRN	No	Yes
F-117 Nighthawk	No	No
DDG-51 *Arleigh Burke*	Unknown	N/A[b]
DDG-1000 *Zumwalt*	Yes	No
LCS	No	No

NOTE: N/A = not applicable. “Yes” indicates that a given program exhibited a particular characteristic of parallel development, based on historical RAND case studies. “No” indicates that a given program did not exhibit that characteristic. If there is insufficient evidence in the case studies to demonstrate that a given program either exhibits or does not exhibit a particular characteristic, it is labeled “Unknown.” We elaborate below on the relative effectiveness with which a program executed each characteristic to rapidly field the basic platform. Some part of each program listed reflected what we define as parallel development. With the exception of the F/A-18E/F program and F-16 MSIP, the term *parallel development* was not explicitly used; rather, one or more elements of a program’s acquisition strategy incorporated some aspect of parallel development (as defined in this report).

[a] While the F-22 program did effectively adapt to the added air-to-ground requirement by placing the capability in parallel development, the overwhelming majority of its technological challenges centered on the platform and avionics development. The RAND research that we consulted does not provide any details on the management strategies used to address ongoing development challenges.

[b] The F/A-18E/F and DDG-51 programs are designated “N/A” because each enjoyed a relatively short or uneventful development phase. This is not to say that challenges did not arise in these programs but that any technological, integration, or testing challenges generally appear to have been manageable and easily remedied by SPO management.

Programs that conducted relatively more-effective contingency planning—including using parallel development as a contingency tool—tended to navigate cost, schedule, and performance trades with greater success. Among the contingency-planning strategies employed by program managers to enable parallel development are flexibility to cancel or relax technical requirements, sufficient capacity designed into the configuration to accommodate new or unanticipated technologies and capabilities, the ability to quickly deploy a temporary fix to a technical challenge arising from concurrency or an accelerated schedule, the ability to deploy future capability upgrades to achieve the desired performance, and insulation of program contingency planning from budget or requirements flux.

Rigorous Contingency Planning Conducted Early in Development

Thorough contingency planning conducted early in development not only enables programs to design sufficient modularity into the platform configuration to accommodate new, unanticipated capabilities but also allows the SPO to identify acquisition "off-ramps" when it encounters insurmountable challenges. Even effective contingency planning can, however, be unraveled by budgetary or requirements flux, poor risk assessments, or poor collaboration between key stakeholders.

Three programs in our sample—F/A-18E/F, F-16 MSIP, and DDG-1000—conducted effective contingency planning early in development:

- F/A-18E/F Super Hornet: Several novel configurations were considered during concept validation and Dem/Val but were ultimately discarded. Indeed, an empowered SPO was able to responsively address technological risk and maturity concerns by following appropriate technology off-ramps. Moreover, the modular configuration and parallel development strategy adopted were the most-successful examples of contingency planning in the F/A-18E/F program. The SPO also planned for realistic cost estimates and a comfortable management reserve, which minimized the impact of unexpected challenges and enabled the SPO to adapt quickly.[117]
- F-16 MSIP: Acknowledging the potential for residual risk in subsystems prior to MS B allowed the SPO to successfully employ contingency planning. Additionally, the developers viewed parallel development as a form of contingency planning, whereby new capabilities could be explored and tested for potential integration without committing to a specific requirement. The SPO worked closely with industry and other program offices to assess operational need, potential modular configurations and expected subsystem candidates for incremental upgrades, and test compatibility with the F-16C/D.[118]
- DDG-1000 *Zumwalt*: The initial acquisition strategy envisioned by the SPO was radically different from the program outcome. The SPO conducted rigorous risk assessments, technology development phases, and contingency-planning efforts. Initially, the program

[117] Younossi et al., 2005, pp. 19–23, 49–56.

[118] Camm, 1993.

office recognized the need for enabling parallel development (including incorporating modularity into the configuration and planning for incremental upgrades), relaxing the requirements, and empowering the SPO. Although a combination of budget cuts, program restructurings, and directives from external stakeholders ultimately undid early planning efforts, the contingency planning appears to have been meticulous and realistic.[119]

Six programs in our sample—F-22, B-1B, AMRAAM, LANTIRN, F-117, and LCS—did not conduct effective contingency planning early in development:

- F-22 Raptor: During the concept validation phase, independent observers, such as the Defense Science Board, argued that the F-22 should relax some of its extensive requirements as a contingency-planning measure. However, institutional pressure from within the Air Force protected the fighter's multi-role status and all of the proposed technological advances. The lack of serious pre-EMD contingency planning and willingness to pursue technology off-ramps appears to have been a major contributing factor to the EMD program's schedule overrun of nearly five years.[120]
- B-1B Lancer: Top-down control over requirements, schedule, and cost limited the SPO's ability to address risks through flexible management and contingency planning and further misaligned the assessed level of technological risk with realistic cost estimates. Although the SPO incorporated a parallel development framework into the acquisition strategy, a lack of robust contingency planning disconnected the built-in modularity from some of the subsystems that could have benefited the most from parallel development.[121]
- AMRAAM: As in the JSPO's unsatisfactory attempts to identify technological risk early in development, early attempts at contingency planning ultimately proved inadequate. For instance, the JSPO prepared contingencies for the SST—considered an important capability for the AMRAAM—but a poor assessment of the transmitter's maturity led developers to overestimate its technological readiness. Contingency planning was further confounded by inputs from external stakeholders, such as the Air Force leadership's premature insistence on a second source (which RAND researchers contend detracted from the team's collaboration).[122]
- LANTIRN: Contingency-planning and hedging strategies were not appropriately followed during concept validation, which was compounded by the lack of prototypes or technological alternatives developed prior to EMD. This omission was due to three primary factors: the SPO was created only after a decision to enter EMD and LRIP had been made, precluding any rigorous contingency planning; the Dem/Val phase was skipped to accommodate an accelerated schedule; and contingency-planning and hedging strategies were explicitly jettisoned in order to minimize cost. The result was an ad hoc management response to technological, schedule, and cost challenges.[123]
- F-117 Nighthawk: The F-117 acquisition strategy emphasized agility, limited requirements, and flexible management. This framework resulted in a rapidly fielded

[119] Schank, Smith, et al., 2006, p. 47. Also see McKernan and Drezner, 2012, pp. 7–8.

[120] Younossi et al., 2005, pp. 1–2, 7–8, 49–56.

[121] Bodilly, 1993a, pp. 1–3, 8–16.

[122] Mayer, 1993, pp. 31–45.

[123] Bodilly, 1993b, pp. 10–17.

platform with an effective emphasis on one particular performance specification (stealth) and an appropriate use of parallel development for the subsystems. However, the emphasis on agility, SPO responsiveness and flexibility, and minimum documentation caused the SPO to forgo contingency planning for capabilities not deemed "mission-critical." As a result, secondary requirements, such as reliability and maintainability, were not explicitly planned for, and the SPO took a "test-and-fix" approach once the platform had already been fielded. This created performance flaws and generated cost growth.[124]

- LCS: No formal analysis of alternatives was conducted leading into development, nor were CONOPS fully fleshed out. The Congressional Research Service has argued that this led the analysis of alternatives, when it was eventually conducted, to essentially be a self-fulfilling prophecy in favor of continuing with LCS development. The accelerated development schedule caused the program to enter detail design and construction of the lead ship prior to having fully validated the scope of mission-package technologies. The parallel development schedule of the first mission package was equally rigorous, leading developers to accept a set of technologies without having conducted thorough contingency planning for potential alternatives. The absence of contingency planning meant that the program's discovery of a significant number of deficiencies during developmental testing necessarily led to major additional development efforts and cost and schedule growth.[125]

Effectively Restructured Development Program According to Contingency Plans

Even if program developers do not adequately plan for contingencies or properly assess risks early in development, a sufficiently empowered and experienced SPO can still meaningfully affect the trajectory of a program. This may entail anything from placing struggling subsystems in parallel technology development to relaxing or eliminating technical requirements. However, parallel development strategies should not be considered a catch-all contingency for failing subsystems.[126] The benefits of placing a component in parallel development should be weighed against the potential integration risks and criticality of that component to immediate mission requirements. Parallel development may not always be the optimal—or even feasible—solution. Likewise, the relative success with which the SPO adapts to a particular challenge may have little bearing on overall program outcomes (i.e., performance, schedule, and cost). SPO responsiveness to challenges should ideally be paired with other parallel development enablers, such as risk management, early planning, and flexible budget and requirements.

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[124] Smith, Shulman, and Leonard, 1996, pp. 26–27, 47–53.

[125] GAO, 2010, pp. 9–16, 27–28. Also see GAO, 2005, p. 4; O'Rourke, 2011, pp. 26–28; and O'Rourke, 2004, pp. 41–42.

[126] Indeed, we contend that placing a component into parallel development as a contingency measure rather than as a strategically conceived step in the initial acquisition strategy can create serious challenges to the program's ability to successfully enable parallel development. As we argue throughout this report, parallel development should be thoughtfully integrated into the early planning stages of an acquisition program, with desired capabilities carefully aligned with fielding timelines and weighed against expected risks.

The ability to restructure a program according to contingency plans appears to be particularly important—and sometimes overlooked—in agile acquisition programs. Program offices responsible for rapidly delivering a capability to the warfighter may view an agile fielding schedule as an overriding concern, often at the expense of initial operational performance and the potential for cost and schedule growth in capability upgrades. This was true of at least three explicitly agile programs in our sample—B-1B, F-117, and LCS. While fielding schedule considerations are obviously germane to parallel development—and agile acquisition in general—a program manager's willingness to pursue contingencies and adapt to challenges can pay dividends in later capability outcomes.

Three programs in our sample—F-16 MSIP, AMRAAM, and LANTIRN—effectively restructured the development program according to contingency plans:

- F-16 MSIP: The parallel development framework constructed by MSIP developers functioned as the most effective form of contingency planning. Several of the capabilities identified as potential candidates for integration during Stage III of the MSIP, such as the AN/APG-68 fire-control radar, AMRAAM, and LANTIRN, experienced unexpected technological challenges during their parallel development phases. Fortunately, the modularity designed into the MSIP concept enabled the SPO to integrate mature alternatives into earlier increments of the F-16C/D aircraft, allowing the desired capabilities to continue to mature in parallel and be retrofitted during subsequent increments.[127]
- AMRAAM: Cost and schedule problems, coupled with insufficient maturation in key capabilities, forced a restructure in the EMD program. The APREP placed design changes to certain components, including the guidance, rocket motor, and integrated circuitry, into parallel technology development to be incrementally upgraded. This restructuring isolated technological and integration risks and allowed the SPO to focus on achieving a stable missile design. The redesign lowered cost estimates by $2 billion and accelerated fielding of the platform while still meeting performance requirements.[128]
- LANTIRN: Following significant schedule delays, the LANTIRN program underwent a major restructuring that included placing the ATR Dem/Val project into parallel technology development. This cut down significantly on the technological and integration risks to the platform but left several other technological challenges unaddressed. The program underwent two additional restructurings, which enabled the SPO to relax the schedule and certain functionality (e.g., A-10 compatibility), mitigate the effects of concurrency, and develop the immature targeting pod in parallel to the production-ready navigation pod. These targeted stakeholder (Congress, OSD, and Air Force) interventions effectively stabilized the EMD program, although final performance and production volume standards were well below initial specifications.[129]

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[127] Camm, 1993, pp. 69–102.

[128] Mayer, 1993, pp. 48–50.

[129] Bodilly, 1993b, pp. 15–16, 33–41, 47–55.

Four programs in our sample—B-1B, F-117, DDG-1000, and LCS—did not effectively restructure the development program according to contingency plans:

- B-1B Lancer: The B-1B's rigid schedule and tight congressional cost cap had a deleterious impact on the SPO's ability to adapt to technological challenges, as demonstrated by its inability to effectively hedge at the component level. As in the F-117 program, the accelerated schedule prevented the SPO from identifying potential technological challenges during EMD and efficiently restructuring the program accordingly. As a result of delayed subsystem testing and integration, technological challenges did not become apparent until after the platform had been fielded. Fixes were costly, with initial deficiencies requiring at least $2 billion to correct, and problems lingered well into production. Moreover, overall system performance measured well below the promised mission capability. Strong contingency planning may have enabled the SPO to better apply its parallel development efforts.[130]
- F-117 Nighthawk: Given the accelerated schedule and limited technical requirements associated with initial fielding of the platform, the F-117 EMD program appears to have encountered few significant challenges. A theoretical restructure to the program may therefore not have even been appropriate. However, the performance challenges—particularly in reliability and maintainability—that afflicted the program well into production should arguably not have been ignored. Agile acquisition and desired technological advances notwithstanding, the F-117 program's lack of robust contingency planning and the limited ongoing focus of its parallel development activities created performance challenges for which the SPO was ill-equipped to quickly resolve.[131]
- DDG-1000 *Zumwalt*: The restructuring fixes proposed by OSD during EMD were a necessary, but ultimately insufficient, solution to the DDG-1000 program's myriad challenges. Moreover, the program's biggest challenges were largely self-imposed, with budget cuts, requirements flux, and technological immaturity overwhelming early contingency-planning efforts. Although the restructure relaxed some of the more burdensome requirements (especially the dual-band radar and volume-search radar) and extended the schedule, the EMD program retained most of the demanding technology development projects without pursuing additional mitigation tools. The unabated presence of most of the DDG-1000 program's challenging technology developments throughout EMD has allowed ongoing technological challenges in the subsystems (notably the integrated power system) to persist. Nevertheless, the SPO's ability to pursue off-ramps for some of the more challenging technologies should be acknowledged as a (partially) effective response.[132]

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[130] Bodilly, 1993a, pp. 33–45.

[131] Smith, Shulman, and Leonard, 1996, pp. 14–18, 26–27, 47. The F-117 program's experience throughout production and sustainment serves as a cautionary lesson for programs seeking to employ parallel development. Specifically, significant residual challenges can still remain in a broadly successful parallel development program if funding and requirements flexibility, an empowered SPO, rapid fielding, limited technological integration risks, and other key enablers are not paired with robust contingency planning.

[132] Schank, Smith, et al., 2006, p. 47. Also see McKernan and Drezner, 2012, pp. 30–32, 39–40; and O'Rourke, 2016, pp. 15–18.

- LCS: In light of persistent technological and integration challenges, the Navy made several attempts to restructure the program, ranging from reorganizing the program office to placing a gap year between lead-ship fielding events and even canceling the procurement of four LCS hulls to better accommodate testing and technological fixes. However, the absence of rigorous contingency planning left the SPO with minimal flexibility to respond to challenges. The Navy considered dropping the mine countermeasure requirement—a mission-critical capability—altogether because of the extent of technological deficiencies and few alternatives. Eventually, the Secretary of Defense determined that the best course of action was to introduce a more suitable platform concept.[133]

Summary

While it is critical that program developers adhere as closely as possible to well-established engineering and acquisition principles to optimize program outcomes, the enablers of parallel development enumerated in this chapter are not intended to be exhaustive. However, our program sample suggests at least five key enablers of parallel development. Perhaps the two most critical preconditions for a successful parallel development program are an effective assessment of technological risk and maturity in key subsystems and effective management of system integration risk. These both appear to be necessary—but not sufficient—conditions in any parallel development program. Parallel development is also relatively more successful when applied incrementally through block upgrades. Even effective development planning and risk management, however, can be undermined by unforeseen exogenous factors, such as tight budgets or requirements flux. Proper alignment of all relevant stakeholders is therefore critical. Finally, effective contingency planning—including parallel development itself as a contingency tool—can enable the SPO to navigate any areas of uncertainty generated by parallel development programs.

Parallel development can be applied to a program in multiple ways, depending on identified needs. When deciding which parallel development strategies may be appropriate—or whether parallel development should be used at all—it is essential to not only pursue the sorts of broad approaches detailed in this document but also consider whether there are enablers that are both applicable to the given program and capable of meaningfully facilitating parallel development. More generally, we contend that program managers can appreciably affect a parallel development program's chances of success (i.e., rapidly fielding the basic weapon system at less-than-full capability) merely by faithfully executing sound acquisition principles—from early prototyping and testing to minimizing the number of immature technologies integrated onto the platform.

An important takeaway from our research is that no single enabler is sufficient to ensure successful implementation of parallel development. On the contrary, programs in our sample that

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[133] O'Rourke, 2011, p. 9. Also see GAO, 2016, p. 2.

were relatively more successful at leveraging parallel development strategies tended to exhibit a greater number of the enablers. Maximizing the use of management actions described in this report can have a considerable enabling effect on the effectiveness of parallel development and can facilitate a more rapid fielding of a basic level of capability. Employing multiple enablers in tandem may also mitigate the potential impact of exogenous forces, such as a constrained budget environment and requirements flux. These types of exogenous forces can make or break a parallel development program, completely irrespective of risk management, contingency planning, or acquisition strategy. Stakeholders should therefore seek to optimize the chances of success by pursuing the full range of enabling strategies.

Under the right circumstances, parallel development can enable the basic platform to be rapidly fielded while facilitating future capability upgrades. Effectively employing parallel development can minimize risks and foster strong collaboration among stakeholders. However, parallel development is not appropriate for every development program, nor is it a panacea for defense acquisition in general. Programs featuring highly integrated subsystems, for example, may not be appropriate, given the added challenges to integration planning. Likewise, programs seeking to push the state of the art in multiple major systems would probably not conform to the maturity considerations required for parallel development to be successful. Development planners should take care to assess the potential viability of a parallel development strategy early in the development process and should continually reevaluate the strategy's appropriateness as the program evolves. Further research is needed to properly characterize program attributes that are either conducive or aversive to parallel development.

Furthermore, the scope of this report was limited to a handful of specific program case studies, which has presumably masked other potentially important enablers of parallel development. The Navy's A-RCI program, for instance, is an excellent example of parallel development that was not explored in this report. In the A-RCI development approach, hardware and software development were explicitly decoupled, with the hardware consolidated with commercial-off-the-shelf solutions. For program managers seeking to employ parallel development in a more modern context, the A-RCI example raises critical issues, including the use of modular open systems and open architectures, the relationship between hardware and software, the relationship between the total system integrator and combat system integrator, the importance of well-defined boundaries or interfaces between the platform and combat system, and the importance of establishing sensible contractual incentives.[134] These sorts of issues tend to be more relevant to contemporary programs than to the more traditional acquisition programs explored in this report, which accentuates the need for further analysis—particularly in light of the Air Force's impending development of several next-generation families of systems.

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[134] For additional insights on the use of parallel development in the A-RCI program, see Boudreau, 2006. For a discussion of considerations for command, control, communications, computers, and intelligence, see John F. Schank, Christopher G. Pernin, Mark V. Arena, and Susan K. Woodward, *Controlling the Cost of C4I Upgrades on Naval Ships*, Santa Monica, Calif.: RAND Corporation, MG-907-NAVY, 2009.

Chapter Three. Implementation Considerations

At one level, the management actions we have identified as enabling parallel development can also be considered good program management practice. Our review suggests that many programs commonly include one or more of these actions, and although that does not meet our definition of a parallel development program (which requires implementing all the identified management actions together), it does allow us to derive lessons on practical applications of such actions from past experiences of programs that have successfully implemented them.

We have examined enablers of parallel development at the program level. The fact that so few programs can be characterized as using a complete parallel development approach (e.g., F/A-18E/F, F-117, and DDG-51 come closest in our small sample) suggests that broader and more-widespread use of this approach constitutes a significant change from traditional acquisition strategies, particularly for major weapon system programs. Transition to widespread use of parallel development in an agile acquisition context should be viewed as a multiyear, continuous process. This applies at the individual program level and to portfolios of weapon systems and their subsystems and components.

The single most important issue is performing and acting on an honest assessment of technological risk and maturity. This requires an independent, unbiased assessment of that risk, including system integration risk. Only technologies that are mature—that is, well understood—should be incorporated into the design of new systems. One relatively objective measure of maturity is performance demonstrated through rigorous testing. Advances in technology should be pursued and matured to the maximum extent possible through robust initiatives for science and technology and for prototyping, not as part of major system development.

While not explored here, DoD experience with development of modular systems also offers a model of how parallel development can be implemented. Modularity is designed into a system or family of systems through the expected use of common subsystems or components. Historical experience suggested mixed success with this approach. The UH-60 variants can be viewed from this perspective as a success, while the family of armored vehicles program in the 1980s and the Future Combat System's manned vehicle systems in the 2000s were less than successful, illustrating the risks and challenges of this kind of approach.[1]

Implementing agile acquisition and parallel development on a large scale (i.e., above a single program level) is particularly challenging because it requires a fundamentally different way of conceiving of system design and capability development and fielding. Organizational change

[1] For a good discussion of modularity, see Jean M. Dasch and David J. Gorsich, "Survey of Modular Military Vehicles: Benefits and Burdens," *Defense ARJ*, Vol. 23, No. 1, January 2016.

management strategies offer useful guidance.[2] This literature identifies several strategies that can enable large organizations to change business processes and associated cultural elements. Specific elements of these change management strategies relevant to implementing parallel development in an agile acquisition context include the following:

- *Provide senior leadership support*: Leaders need to establish and communicate a compelling need for change and articulate a specific plan to accomplish it. As they implement change, leaders need to issue new policies, institute workforce training, and establish metrics and other systems to measure the change's progress and effectiveness. And to sustain change, they must pursue activities necessary to institutionalize it and make it the new day-to-day routine.
- *Establish a sense of urgency*: Along with senior leaders establishing a compelling need for change, experience suggests that significant change typically does not succeed unless there is also a sense of urgency. This helps stakeholders solve problems and overcome the challenges involved in following nontraditional processes. Because organizations are typically deliberately structured to preserve the status quo—that is why they exist—serious change raises basic existential issues about processes and procedures that current personnel have often created and committed themselves to (again, often unconsciously) emotionally.
- *Create a coalition of relevant stakeholders*: Individuals change organizations and must change their behaviors in specific ways for organizational change to succeed. An early task of any major change effort is to determine who must change their behaviors for organizational change to succeed and who represents those people's interests or has authority to direct their behaviors in the organization. These stakeholders must sign on to the change if it is to overcome their resistance. Again, organizations are mainly designed to preserve the status quo, and each stakeholder has a current role to play in doing that. The primary stakeholders have been around for a long time and know how to exploit the current system to their own advantage. Change often fails when stakeholders that oppose change hunker down and wait out the advocates of change.

  Large change efforts benefit from formalizing coalitions at two levels. The executive level (political appointee, general/flag officer, and Senior Executive Service level) provides top cover for the change effort and monitors it regularly to ensure that it continues to advance the broader goals of the organization. If the change is not achieving the gains promised, this executive group has the authority to change its direction or shut it down. The management level (the O-6/GS-15 level) works the details. It ensures effective day-to-day coordination among the services and defense agencies. It designs the details of the change, oversees its execution, and reports on progress to the executive level. Both levels must remain active, intact, and functional for the duration of any successful major change.

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[2] See John P. Kotter, *Leading Change*, Boston: Harvard Business School Press, 1996; Frank Camm, Laura Werber, Julie Kim, Elizabeth Wilke, and Rena Rudavsky, *Charting the Course for a New Air Force Inspection System*, Santa Monica, Calif.: RAND Corporation, TR-1291-AF, 2013; and National Defense Research Institute, *Sexual Orientation and U.S. Military Personnel Policy: An Update of RAND's 1993 Study*, Santa Monica, Calif.: RAND Corporation, MG-1056-OSD, 2010, Chapter 11.

- *Build on incremental successes*. Significant change takes time. As a practical matter, in private industry, leaders are often judged against quarterly goals or other relatively short-term metrics. Throughout DoD, leaders turn over often, making it difficult for them to take credit for anything that takes more than a year or so to achieve. Bite-size increments can scale a large change down into pieces small enough so that information about progress can be generated every few months. Successful change efforts track their performance at short intervals and trumpet news of success to those they rely on for continuing leadership attention and resource support. Such efforts start with modest resources on relatively easy tasks and, as a change team builds experience, confidence, and success, take on increasingly challenging tasks made possible by increasingly large commitments of resources.
- *Consolidate and institutionalize changes*: Formal change managers have differing views on how to manage the transition from the old to the new. Some advocate maintaining old and new side by side (so-called “scaffolding”) until the organization is absolutely sure the new systems will work. They promote this even if it creates duplication, confusion about which is the official system at any point, or ambiguity about the depth of the leadership’s commitment to real change. Others see rapid dissolution of legacy processes as a way to heighten individuals’ sense of being on a burning platform or to convey the leadership’s dedicated commitment to the future.

  This potential problem can be mitigated if sufficient pilot testing in the planning phase has demonstrated that the change is both feasible and beneficial to the organization and if sufficient knowledge has been gained to make adjustments and fine-tune the change. Under these conditions, dissolution of legacy processes should occur as soon as the new process is up and running.

Over time, new participants come to an activity with no knowledge of what it looked like before formal change management had taken place. The new approach is fully internalized and taken for granted; it becomes routine. As noted earlier, that does not mean that change ceases to occur. It means only that, when personnel in the activity today happen to stumble across the language spoken in the activity before the change management exercise, it sounds archaic and nonsensical to them. Change is truly complete when the new policies and practices have been fully adopted and become standard operating procedure.

Chapter Four. Conclusions

Although the sample size was small, our review of programs exhibiting one or more management actions that enable parallel development suggests that this approach is applicable under certain conditions. Successful application of management actions that enable parallel development can help address technological risk and accelerate the delivery of new capabilities through incremental fielding, one of the goals of agile acquisition.

The taxonomy of management actions enabling parallel development appears to capture many of the key elements of an acquisition strategy based on parallel development. As outlined earlier in the report, the five enablers of parallel development, along with each enabler's underlying management actions, are as follows:

1. effective assessment of technological risk and maturity
    a. early and continual assessment of technological risk and maturity
    b. maximized use of mature systems
2. effective management of system integration risk
    a. early and continual assessment of integration risk
    b. roles and responsibilities appropriately assigned according to organizational capability
    c. isolated subsystem integration risk
3. planned incremental approach to fielding capabilities
    a. capability increments planned early in development and updated continually based on new information
    b. intention to accelerate fielding of initial capability improvements, even if less than full capability
4. tight alignment of requirements, acquisition, and budget stakeholders
    a. close collaboration between the user (warfighter) and developer (industry and government)
    b. flexible technical requirements and stable funding
    c. sufficiently empowered program office management
5. strong contingency planning
    a. rigorous contingency planning conducted early in development
    b. effectively restructured development program according to contingency plans.

While this is not a complete list of enablers and management actions, it can provide the foundation for further refinement of the parallel development approach to capability development and fielding, including identification of additional enablers and management actions.

Two general observations about this list of enablers help characterize parallel development in relation to other development approaches. Perhaps the most important difference from other approaches is that a successful parallel development approach requires all five of these enablers to be implemented. It is the synergistic effect of these enablers working together that leads to successful application of parallel development in any one case. Our review of historical examples suggests that when most of these enablers and their management actions are present at the same time, programs appear to better manage risk and often accelerate capabilities to the field. On the other hand, this list of enablers is not very different from a list of common sense program management best practices for managing risk. This suggests that while there are few examples (at the major defense acquisition program level) of historical application of parallel development, the individual activities that constitute such an approach are known to the acquisition community.

Accurate assessment of technological risk and maturity in key subsystems is critical in the successful application of parallel development. System integration must be explicitly managed, and technological risk must be fully understood. The roles and responsibilities of and within the government and contractor teams must be laid out as part of program planning, with particular emphasis on integration and test functions. Finally, parallel development is relatively more successful when applied incrementally, focusing on introducing one major new subsystem at a time. A block upgrade strategy can enable this, focusing on an element of either a mission system or the platform, but not both in the same increment.

However, parallel development is not always appropriate, and it can be quite detrimental if it is applied in a program to which it is not well-suited or if it does not broadly conform to the enablers described in this report. Certain classes of development programs, such as a platform with highly integrated subsystems (e.g., F-22) or a platform with overly advanced technical requirements (e.g., DDG-1000), may be ill-suited for parallel development. Sound acquisition principles dictate that development programs strictly adhere to certain key practices, including using mature technologies, minimizing technological risks, and limiting the introduction of new technologies to one major subsystem at a time. Thus, a successful parallel development program should follow naturally from a few basic preconditions. More broadly, we contend that program managers can enable agile acquisition simply by adhering to sound acquisition principles, as illustrated by the experience of our program sample in implementing enablers of parallel development. The challenge is that successful application of parallel development requires that all five of the enablers we have identified be implemented together. This paradigm is very different from including one or two of these enablers in the context of a traditional single step to full capability acquisition strategy.

Given our limited sample, there are likely important enablers of parallel development and agile acquisition that we have not identified. For instance, the use of open systems or open architectures is thought to be a key enabler, particularly for managing integration risk. To the extent that open architectures (both hardware and software) provide a "plug-and-play" capability, new capabilities can be fielded more rapidly.

In the context of parallel development, mature (specifically, very mature) technologies are strongly preferred. There is a rationale for including one or two less-mature technologies in system design—as long as there is a contingency plan and the increased risk is accepted. We also note that mature does not exclude new; the point is to mature new technologies thoroughly before including them in system design. Of course, traditional single step to full capability strategies, which are not consistent with parallel development, commonly use immature technologies.

Parallel development can be applied to a program in multiple ways, depending on identified needs. It can enable flexibility and focus on specific elements of a design or a system by decomposing large, complex programs into more-manageable pieces. Similarly, it allows a program to plan for and adapt to changes in threat or requirements. It can also be employed as a strategy to mitigate the effects of concurrency or as a contingency tool by isolating problematic elements of a program.

Parallel development can be an element of an acquisition strategy within an agile process. The attributes that enable successful application of agile acquisition also enable parallel development. While parallel development allows increased focus on a narrower set of issues, it also increases the importance and risk of system integration. That is the paradox of parallel development. Decoupling subsystems allows a narrower focus on a more limited set of technical challenges, but because the subsystems are designed and developed separately, integration risk may increase. Such risk can be mitigated by managing software and hardware interfaces through specifications and standards. From a management perspective, it is useful to think of system integration risk as its own subsystem for purposes of risk assessment, planning, and mitigation strategies. The integration challenge, and the strategy for addressing it, must be highly visible throughout the government and industry chain of command.

Parallel development has the potential to reduce the time from technology development to the fielding of new capabilities, but it is not a panacea for the persistent acquisition challenges that affect complex system development. It must be carefully and wisely applied, and it may not always be an appropriate development approach. For instance, parallel development may have more-limited application for fully integrated systems requiring unique interfaces.

A Path Forward

This research was limited in both scope and time. Given these constraints, our limited objective was to identify an initial list of management actions that, when implemented together, enable parallel development and agile acquisition. Our intention was to begin the discussion by establishing a framework that can then be refined through further research.

This begs the question of where further research efforts could be usefully applied. The following possibilities occur to us:

- Review additional programs to identify other important enablers, such as open systems and open architectures.
- Determine how many of the management actions enabling parallel development need to be present to ensure successful application. With this quick look, we are only able to say that all are required; we suspect that a more thorough analysis could better identify interdependencies and thus refine the range of parallel development approaches.
- Provide more depth to the analysis by diving deeper into the details of each program. This could identify important nuances to consider when transferring lessons from one program to another.
- Derive the characteristics of a program and environmental factors that define when a parallel development approach would be appropriate.

Future research should also adopt a more rigorous methodological approach, addressing the three main limitations of the current work. The minimal reference to the concept of parallel development in program case studies could be mitigated by using a much broader survey of the literature, including broadening the program sample to programs below the major defense acquisition programs used here. The size of the program sample should be significantly increased along several dimensions—size, commodity type, time frame—to better capture the full range of management actions that may enable parallel development. Finally, a more rigorous study would include extensive interviews with program office and industry personnel and original research on specific programs, drawing on a much wider range of published reports and official program documentation.

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