An Innovative Approach to Schedule Management on the F/A-22 Major Defense Acquisition Program (MDAP): Demonstration of Critical Chain Project Management

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ABSTRACT

This multiple-case-based dissertation contributes to the stream of literature on the organizational innovation process by examining Critical Chain Project Management (CCPM) as an innovation with the potential to address an important schedule planning and execution performance gap in DOD weapon system development programs. The contextually different Integrated Product Team case studies in DOD's F/A-22 fighter aircraft weapons system acquisition program are: manufacturing assembly, manufacturing process, test operations, and supplier product development. Rich descriptions of the case studies are developed by the author, a senior Lockheed Martin Aeronautics Company systems engineer in a role that merged participant, observer, change agent and champion (POCAC). Analysis distinguishes between Program and Operational levels of organizational structure and focuses on the innovation process through use of the author-designed Casey Hybrid Innovation Process (CHIP) model based on Rogers' stages heuristic.

Substantively, research demonstrates that in key areas of the F/A-22 program, proper application of the innovative Critical Chain Project Management process can generate and achieve development schedules sometimes substantially better than traditional approaches; improper application will lead to mixed results or rejection.

The research contributes to knowledge in the field of organizational innovation by demonstrating use of the CHIP model in the huge, geographically dispersed and extremely complex organization of the largest DOD weapon system acquisition program of the late 20th and early 21st centuries. The research reflects Program leadership's important role in the top-down initiation and support of an innovation, even while choosing (by policy) not to force use at the Operational level. At the Operational level, details show that IPT implementations and results of the CCPM innovation vary.

DEDICATION

To my family. To Mary Frank, my best friend, soul mate and wife, for her love, support, inspiration and patience during this 15-year odyssey. Far from the "surprised woman" behind the successful man she married, she has always been more responsible than she'll know for any success I've enjoyed through the 39 years of the Air Force, industry, educational and family adventures we've pursued together. And to two fine sons, RJ and Quinn, who have emerged from our family's vagabond, multi-move life-style to motivate completion of this effort through their demonstrated ability to set and achieve high goals in their academic and civilian exploits as well as active/reserve-duty Army and Air Force military assignments. And finally to the Air Force family I still serve, with the hope that this product provides payback to the operators in the form of more quickly developed and delivered major weapons system that deter conflicts or quickly win them.

ACKNOWLEDGEMENTS

I thank my chair, Professor Phil Kronenberg, without whose guidance, mentoring, motivating confidence, endurance, professional equanimity and personal friendship, this effort surely would have foundered. He has my most sincere appreciation for his support throughout my studies at Virginia Tech's Center for Public Administration and Policy, but especially for his valued counsel vital to transforming untold scores of short notes, think-pieces and a nearly 450-page draft into this final dissertation. I also want to thank committee members and Professors John Dickey, Gary Wamsley and Jim Wolf, for their teaching and encouragement during prior course work and throughout this dissertation effort. Especially appreciated and essential to closure was a probing, constructive review of an early draft of this work by Dr. Michael Badawy. Professor Rohr will always be an inspiration and Adjunct Professor Carole Neves' initial and continuing support during course work and dissertation efforts have been appreciated.

Almost completely paralleling this academic journey has been my full-time, professional employment with the Lockheed Martin Aeronautics Company. After an Air Force career flying some of the most awesome fighters ever produced, it has been a privilege to appreciate and participate in the dedicated efforts that assure our nation's fighter pilots can fly the finest, most revolutionary fighter in the world for decades to come. The integrated government (civilian and military) and industrial F/A-22 team surely rivals any development team ever assembled. At the risk of important omissions, I must acknowledge some of the many colleagues on that team who have provided me learning and leadership opportunities in executing their important duties. Among the top pros who patiently supported, educated, assisted and mentored me in their own and important ways are: David Lloyd, Paul Schlein, Paul Metz, Tom Burbage, Ralph Smith, John Smith, Greg Krohn, Jim Bailey, Chris Pelletier, Bob Braeutigam, Mike Hanna, and Jim Cox.

Particularly important to the professional and academic Critical Chain Project Management efforts documented in this dissertation have been John Summerlot, Chris Blake, Bob Rearden, fellow change agents Jim Pitstick and Kevin Calame, as well as Rick Ochoa, David Christ, and Ross McNutt. Supportive in myriad ways have been original teachers Dee and Bob Jacob, Jackie and Gerry Kendall (whose review of early drafts helped immeasurably), Dave Spencer (who also pinch-hit as editor), Bill Dougherty, Ed Baker, Larry McPeak, Ken Seeling, Michelle Choi, Randy Miller, Bruce Peet, Lorenzo Valone, Greg Staley, Dave Kaser, Mark Levin, Vincent Batteur, Mark Stout, Rob DeVenuto and Mike Lawrence.

Life's preparation for this effort was largely the forming, norming, hardening and sometimes chaotic experience of an Air Force career in fighter operations interspersed with staff and professional education assignments. Wingmen and leaders too numerous to mention were the centerline of a 24-year career that included "slipping the surly bonds of earth" in fighters from the F-102, F-105, F-106, and F-4 to the F-15. During those tours, the exemplary leadership of senior officers like Jim Ahmann, Paul Albritton, Butch Viccellio and George Schulstad and close working-level friendships with fellow-aviators— from pilot training buddies Bunny Talley and Jack Addison to John Perkins, Jim Alder, Frank Graham, Roger Chesson, John Bode, Sam Cottrell, Mal Gleave, Max Marosko, Tom Mahan, and Don Davie— remain memorable and motivating sources of my core being. Of course, the ultimate foundation for all of this was the opportunity to learn life's values and the importance of personal integrity and drive as a member of a modest, mid-western, Irish-American family parented by a loving mother and best-friend father whom I still miss, along with Ruby Lee Fry, the very special mother of my bride. Among three brothers and two sisters, older brother Pat has been most important as a fellow fighter pilot, mentor, and most fun friend who led me to engineering and Air Force fighters.

To all, my most sincere thanks.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1: OVERVIEW

Purpose of the Study

The purpose of this inductive, multiple-case-based dissertation employing a unique participant-observer approach is to examine Critical Chain Project Management (CCPM) as an organizational innovation with the potential to address an important gap between schedule management objectives and schedule execution performance in the development of a major weapon systems acquired by the Department of Defense (DOD). Besides implications for development of DOD policy regarding acquisition schedule management, the research contributes empirical evidence to the literature on the organizational innovation process and ways of viewing it. In addition, in terms of research and practice, the study reinforces some case study research protocols and generates proposed refinements of a well-established framework for the study of organizational innovation that will strengthen future research projects of a similar nature.

The origin of this effort was direction from key leaders within the F/A-22 fighter development program to the author, an employee of the Lockheed Martin Aeronautics Company (LM Aero), prime contractor for the F/A-22, to address urgent schedule management challenges on the program. Almost immediately it became obvious that the tasking presented a fortuitous opportunity to simultaneously conduct research "from the inside" on the potential of CCPM as an innovation to solve the schedule management problems faced by the F/A-22 organization.

Despite somewhat foreboding methodological problems, there were several factors that became compellingly overriding reasons for taking advantage of this opportunity. Given the author's considerable professional background in the bureaucracy of DOD and the aerospace industry, but operating within the public administration academy, there was great appeal in the chance to conduct research that responds to Stever's call for efforts to shatter the "glass wall between military and civil administration" (1999). Indeed, it is possible that solutions to the program and organizational challenges faced by the complex multi-organizational government-military-corporate team responsible for the F/A-22 program have potential in other complex public organizations beyond the "glass wall" such as the recently formed Department of Homeland Security and its myriad organizations. Personally, as a combat-experienced fighter pilot and career Air Force officer with sons who continue to deploy in support of combat operations, there is compelling motivation to help solve the broader DOD problem of constantly increasing weapon system development cycle time so that the nation provides necessary military equipment to the operators at the grass roots level as quickly as possible. As a result of these reinforcing sources of motivation, the research was undertaken and closely integrated with the company effort. The dissertation documents the process and results of the multiple applications of the innovation that developed as a result of the originally tasked project.

In this chapter, the context for the study is provided by brief descriptions of the development span within the total life-cycle of a major weapon system and the F/A-22 program from which the case studies originate. The substantive focus of the dissertation, Critical Chain Project Management, has shown very positive schedule planning and execution success in public and private sector applications outside of weapon system development. However, before initiation of use on the F/A-22 program, CCPM had not previously been employed to arrest or reverse unacceptably long cycle times for the development phase of Major Defense Acquisition Programs (MDAPs).[1]

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[1] Aircraft programs constitute one of several MDAP categories that focus on weapon system programs. Others are Helicopters, Missiles, Munitions, Ships, and Other Systems. According to the Defense Department's Instruction 5000.2, "Operation of the Acquisition System", the F/A-22 is an MDAP designated Acquisition Category (ACAT) I, defined as one that is estimated to require an eventual total expenditure for research, development, test and evaluation of more than $365 million in fiscal year (FY) 2000 constant dollars or, for procurement, of more than $2.190 billion in FY 2000 constant dollars.

Besides supporting efforts to transform the Advanced Tactical Fighter concept originated in 1981 into the F/A-22 Raptor air dominance tactical fighter of the 21st century, the use of CCPM is examined in an organizational setting relatively new to acquisition programs. In 1990, DOD mandated use of Integrated Product Teams (IPTs) as the central organizing principle for the first time in acquisition history, tasking which affected virtually every aspect of the program at all the development and manufacturing locations and companies across the country. Later on, DOD extended this mandate to all acquisition programs as one of several acquisition reform initiatives taken by the Secretary of Defense to reduce the cost and cycle time for major weapon system acquisition (Perry, 1994).

Programs, Projects and the Ubiquity of Schedule Management Problems

In the broadest context, the DOD weapon system acquisition community's use of the word program to describe weapon system developments like the F/A-22 is close to the standard definitions for a project given in *A Guide to the Project Management Body of Knowledge (PMBOK® Guide*) [Project Management Institute (PMI)[2] Standards Committee, 2001]: "any undertaking with a defined starting point and defined objectives by which completion is identified," and "in practice, most projects depend on finite or limited resources by which objectives are to be accomplished." Just as any large non-DOD project can represent a hierarchy of projects encompassed within the worldwide reach of PMI, so also do DOD programs represent or require the integration of what can be treated as a sometimes huge number of projects. This dissertation addresses a subset of those myriad projects within the F/A-22 program.

It is worth noting that though the catalyst for this dissertation was the difficulty delivering the products of DOD weapon system programs on time, on schedule, and with

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[2] Founded in 1969, PMI has over 100,000 members worldwide and is a leading nonprofit professional association for project managers. Besides establishing project management standards and the PMBOK guide, PMI provides seminars, educational programs and professional certification (Kenny, 2003).

the capabilities established by war fighter requirements, these difficulties are by no means restricted to DOD, nor is DOD the worst. Biery (1992) reviewed 23 types of large public and private programs/projects in the United States, including both government and commercial projects. Public project types included weapon system development and transportation projects (e.g., airports and air traffic control systems); private sector projects types included new drugs, power plants and refineries. Comparing the start of development (public) or project go-ahead (private) to delivery of the first operational system, average actual delivery span schedule growth for all systems was 75 percent beyond planned. While private sector schedule growth was 84 percent, schedule growth for military weapon systems from 1960 to 1980 averaged 33 percent (Biery, 1992). By the 1990s, the military development schedule performance had worsened considerably. In 1996, Kausel reported that a Defense System Management College survey of major weapon system development showed schedule overruns averaging 63 percent.

Beyond large aerospace or civil construction companies, often acknowledged as comprising the “roots” of project management (Lyneis et al 2001, Yasin et al, 2000), the success or failure in other industries, such as automotive, electronics and software industries, also depends on product development and delivery on time. In general, one can find substantial evidence that schedule problems exist across all environments.

- The Standish Group summarized a survey of 365 Information Technology (IT) executive managers of over 8000 applications in small, medium and large companies and governmental organizations across major industry segments from banking to securities to manufacturing, health care, insurance and services. Only 16.2 percent of the projects successfully delivered fully functional products on time and within budget. Of the remainder, two-thirds experienced schedule overruns of 50 percent or more, and overruns for half of those projects were between 200 and 300 percent. (The Chaos Report, 1994).

- Reichelt and Lyneis (1999) found that schedule overruns in a sample of 10 projects, were 55 percent and cost overruns were as much as 86 percent (depending on assumptions).
- Roberts (1992) surveyed corporate R&D projects and concluded that less than half met their time-to-market and budget objectives.
- The World Bank (1992) found that among its recent projects, only 70 percent had been rated “satisfactory”, with only one-third substantially achieving institutional development objectives and delays in completion averaging 50 percent beyond that originally planned.
- Morris and Hough (1987) reviewed 3500 projects and concluded that “overruns are the norm, being typically between 40 and 200 percent” (p. 7).
- In a 1996 review of Department of Energy (DOE) projects between 1980 and 1996 the Government Accounting Office (GAO) found that of 80 major system acquisition projects, 15 were completed (most late and over budget), 31 were terminated prior to completion after spending over $10 billion, and cost overruns and schedule slippages continue to occur on many of the ongoing projects (GAO/RCED-97-17, reported in Newbold, 1998).

The larger context of these myriad examples provides appreciation for the ubiquity of the cycle time and associated schedule planning and execution problem. In that light, the research, analysis and conclusions focusing on the F/A-22 program may provide useful insight and a value-added contribution to the research literature for those working with similar problems in other contexts beyond the DOD acquisition environment that provides the environmental backdrop for this research

The Defense Acquisition System and the F/A-22 Program

"The Defense Acquisition System is the management process by which the Department of Defense provides effective, affordable, and timely systems to the users" (DOD Directive 5000.1, p.2, 2003). This process, depicted in Figure 1, encompasses activities from the establishment of the mission need, usually prompted by emergence of the threat, to the design, development, production, fielding and sustainment of the system developed to respond to the threat. Within the overall arena, the development cycle time represents the span from the formal milestone decision initiating a program to the first production delivery.

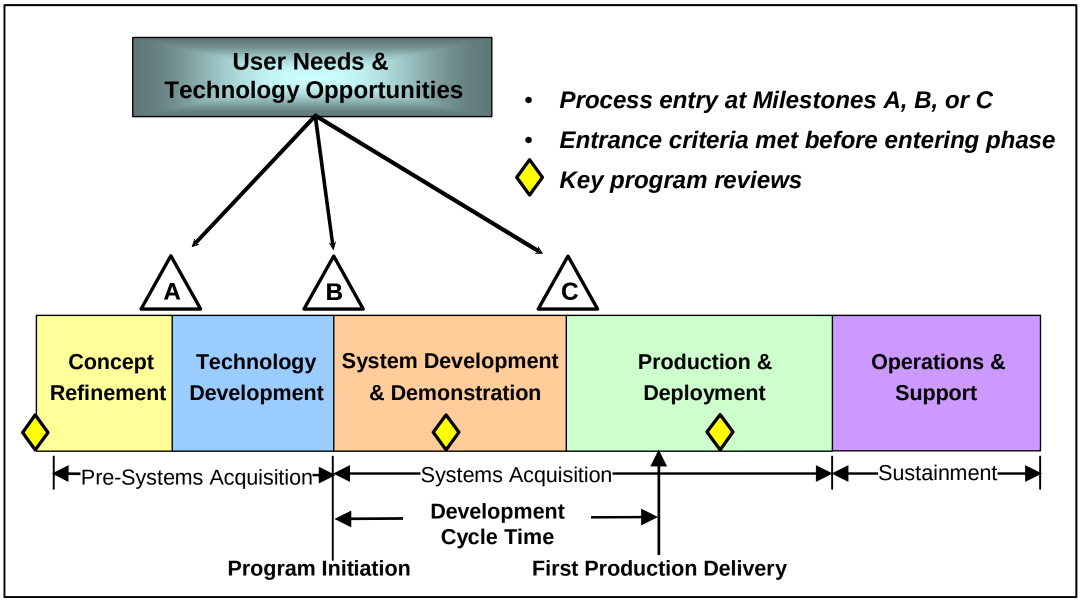

Figure 1. Traditional "development cycle time" within the Defense Acquisition Management Framework (based on information from DODI 5000.2).

Figure 2 provides a top level view of the overall F/A-22 program from inception of the Demonstration/Validation phase of the program, to the Engineering and Manufacturing Development (EMD) phase and, finally to the Production phase. Overlaid on Figure 2 is the span of time encompassed by the several case studies that describe and analyze the applications of the CCPM process in various settings over varying time periods.

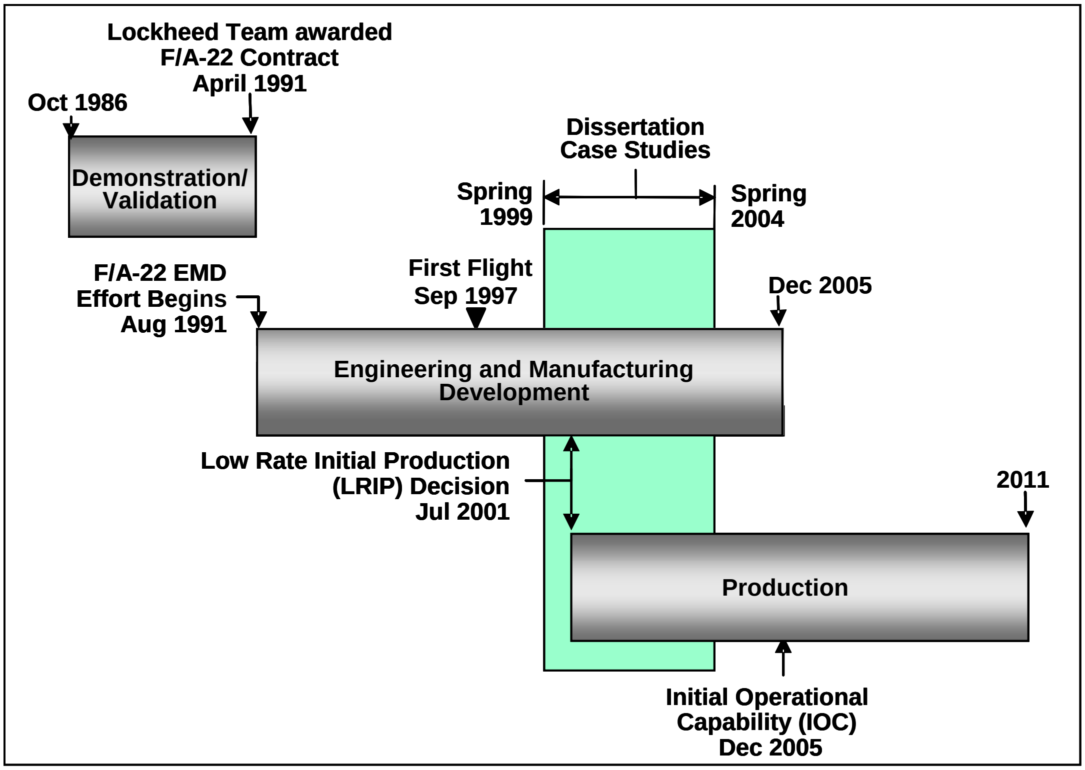

Figure 2. Top-level overview of F/A-22 program.

Consistent with the overall defense management framework, the F/A-22 System Program Office (SPO), Wright Patterson AFB, Ohio, headed by a general officer, the System Program Director (SPD), is the Air Force organization responsible for development and production of the air dominance F/A-22 fighter for employment by the USAF Air Combat Command when it is scheduled to become operational at the end of 2005. Essentially, the value that the F/A-22 will contribute to national security capability is best described in the term “force enabler,” that is, a system with the capability to “kick the door down”--sanitize the battle area by eliminating or denying use of crucial enemy weapon systems. The Raptor will contribute to “intense shock value” so that the rest of the total combat force can achieve objectives more quickly and effectively with fewer losses (Tirpak, 2001).

As the prime contractor, LM Aero, headquartered at Ft Worth, Texas is funded to develop and produce F/A-22s that add this valued capability to the total force. The primary subcontractor and major partner is the Boeing Company (Boeing), Seattle, Washington. Within the overall program depicted, total program funding for EMD and Production of $69.2B (F/A-22 Single Acquisition Management Plan, 2003) is shared under a cost-based teaming agreement between LM Aero and Boeing. After 1993 when Lockheed acquired one of its original F/A-22 team partners, the Fort Worth Division of General Dynamics, Lockheed's share of the F/A-22 contract became 67.5 percent and Boeing's share the remaining 32.5 percent. Most work for which the partners are responsible is accomplished by over 1100 first tier[3] suppliers in 48 of the 50 states, who outsource approximately half the work to second tier and lower tier suppliers (King and Driessnack, forthcoming, 2005).

In all, some 480,000 parts, from thousands of tiny fasteners to the world's largest and most complex titanium castings, fit together in subsystems and systems that comprise the F/A-22. As shown in Figure 3, these parts and systems are integrated into major structural components and assembled in several LM Aero plants across the country as well as Boeing's plant in Seattle, WA. All the major structural components depicted are then assembled into a complete F/A-22 aircraft at LM Aero's final assembly plant in Marietta, Georgia. There the completed airplanes are flown for the first time by contractor and government pilots before delivery to Edwards Air Force Base (AFB), California, for testing or to other Air Force bases for training and operational employment.

Attention to Development Cycle Time

Pragmatically, the need to assure accountability for DOD budgets of $100 billion for research, development and procurement of new weapon systems is a sufficient catalyst to focus in this public policy area. More important than fiscal concerns,

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[3] "Tier" is a reference to a level in a hierarchy. For suppliers, "first tier" means that the supplier is under direct contract to either LM Aero or Boeing. "Second tier" suppliers have no direct contractual link to LM Aero of Boeing, but are under contract to the first tier suppliers. The same logic pertains to lower tiers.

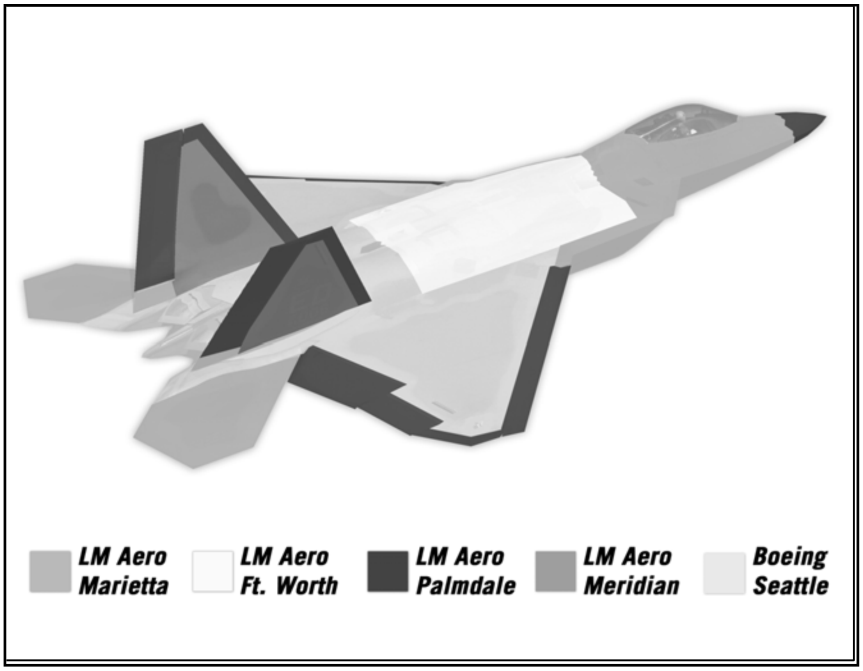

Figure 3. F/A-22 with major structural components and manufacturing sites (LM Aero, January, 2004).

however, the devastating events of 11 September 2001 and the intense conflicts in Afghanistan and Iraq remind us that the clear imperative is to assure US forces have—in the shortest schedule span possible—the best and most effective weapons to take on whatever operational combat challenges face the country. This is true whether the weapon system concerned is a fighter aircraft like the F/A-22 or new technology weapons for the foot soldier or whether the situation concerned ranges from worldwide terrorism to all-out war.

In fact, although terrorism and active conflicts have given new urgency to that objective, the lengthy spans for weapon system development have long been the subject of study (Peck and Scherer, 1962; Fox, 1974), and have been addressed in several high visibility studies and statements. The most heralded study of the acquisition process in the last 25 years was known as the Packard Commission[4] of the mid-1980s, named for its chairman David Packard, then Deputy Secretary of Defense. Its final report stated

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[4] Named for the chairman of the study, David Packard, then Deputy Secretary of Defense and former founder of the Hewlett-Packard Corporation.

that the “unreasonably long acquisition cycle…is a central problem from which most other acquisition problems stem. We believe that it is possible to cut this cycle in half” (President’s Blue Ribbon Commission on Defense Management, p. 8-1, 1986). The introduction to the Federal Acquisition Streamlining Act (FASA) of 1994 agreed, stating the Congressional belief that the development cycle could be cut by 50 percent. Since then others have echoed the Packard commission, calling for reductions of at least 25 percent and as much as 50 percent in weapon system development cycle time (National Performance Report, 1996; Perry, 1995; Gansler, 2000). Also in 1994, Secretary of Defense William Perry stated his belief that the needed reduction of 50 percent could be achieved by the year 2000. Besides recognition as one of the Executive branches most aggressive responses to the *National Performance Report* released by the Vice President, Secretary Perry’s statement initiated a decade of acquisition reform that involved several efforts to improve the acquisition process, together often referred to under the rubric of “better, faster, cheaper” (Beck et al, 1997).

In the face of the operational imperative and repeated calls for action, the time for development of weapon systems has been constantly *increasing*. Figure 4 shows that the average time for development of major acquisition programs has realized what was projected by a 1989 Rand Corporation study: an increase in development spans by more than double over the 40-year span into the first decade of the 21st century. Ironically, nearly one-fourth of the almost 120 percent increase in development span has occurred since the mid-1980s when the high-level sources were calling for major development cycle-time reductions of up to 50 percent. The aircraft data inserted in Figure 4 shows the same malady of increasing development times also affected fighter aircraft.

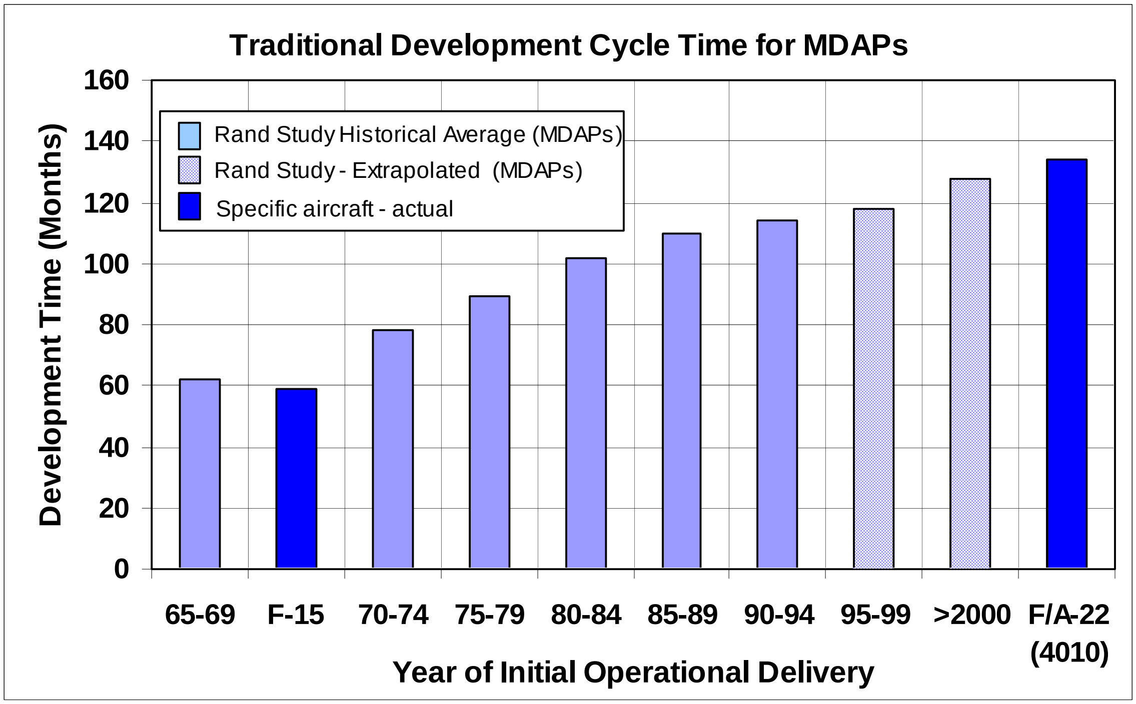

Figure 4. Trends in Major Defense Acquisition Program (MDAP) development time. (Based on Jarvaise et al., 1996).

In October 2002, the F/A-22 program delivered its first production-representative aircraft, S/N 4010,[5] 134 months after program go-ahead, more than double the 59 months it took to deliver (in November 1974) the first production version of the F-15, the aircraft the F/A-22 is replacing (Harmon et al., 1989).

In his book *Defense Conversion* (1995), former Undersecretary of Defense for Acquisition and Technology, Jacques Gansler, concisely identified legitimate concerns about development spans. He declared the 16.5-year average cycle time from concept to first production unit for U.S. weapons in the early 1990s totally incompatible with the pace of change in modern information technology where a new electronics line is obsolete in 6 to 18 months (Gansler, 1995). Dr. Gansler also made clear the dangers of post-Cold War, lone-superpower arrogance that might suggest we need not be concerned about these increasing acquisition times:

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[5] Aircraft 4010 was the first of eight production representative vehicles that followed the initial nine test aircraft. 4010 is considered equivalent to the "first production delivery" as represented in the Rand Study.

> There are those in the DOD who feel that, since the United States currently has a technological lead in weapons systems, time no longer matters. The reality is exactly the opposite. Time is now far more critical for a number of reasons. First, time is money. The longer it takes to develop and produce a weapon system, the more expensive it will be . . . In addition, as programs become stretched out and technology continues to evolve, the tendency is to keep trying to improve on the system under development, which increases costs even more. Weapon systems cannot be rushed into development or production before the basic technology has been proven. However, once it has been, and if it turns out to have a significant military advantage, then the only way the United States can maintain its technological superiority is to rapidly build and deploy the new systems. This is equivalent to the commercial need to speed up the time-to-market for new products to stay ahead of the competition (p. 105, 1995).

As recently as 2003, the need to focus on cycle times was emphasized in the updated DOD Directive 5000.1, *The Defense Acquisition System,* which drives to reduce cycle time as one of six guiding policies governing the Defense Acquisition:

> Throughout the Department of Defense, acquisition professionals shall continuously develop and implement initiatives to streamline and improve the Defense Acquisition System. MDAs and PMs[6] shall examine and, as appropriate, adopt innovative practices (including best commercial practices and electronic business solutions) <u>*that reduce cycle time*</u> *and cost, and encourage teamwork* [Emphasis added] (p. 2).

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[5] The MDA (Milestone Decision Authority) is the designated individual with overall responsibility for a program. The PM (Program Manager) is the designated individual with responsibility for and authority to accomplish program objectives for development, production, and sustainment to meet user's operational needs. (Department of Defense Directive (DODD) 5000.1, p. 2).

This guidance notwithstanding, the fact is that a decade of acquisition reform efforts since the *National Performance Review* in 1993 have consistently noted that military development cycle times are as much as 2.5 times longer than commercial cycles (Rogers & Birmingham, 2004).

Sources of the Increased Acquisition Spans Problem

Given the visibility and cost of MDAPs, the numerous studies and commissions became convinced that dramatic reductions in cycle times were possible based on analyses of past problems that caused development cycle times continue to increase. The F/A-22 program has felt the impact of the most common reasons why weapon system development cycle time has continued to expand instead of contract: funding and regulation, threat changes and technology development, acquisition culture, and unrealistic schedule estimates.

Clearly, varying budgets and funding profiles can substantially slow down weapon system development. In the first five years of the development contract in the early 1990s, the F/A-22 program underwent four major restructuring exercises as the result of funding reductions (F/A-22 SAMP, 2003). Besides generating significant turbulence in the management and direction of the program, these so-called “rephases” resulted in a substantial expansion of the F/A-22 cycle time, as well as a substantial reduction in the number of F/A-22 aircraft to be produced, as noted below. Beyond funding restrictions, the procurement regulations that number upwards of 30,000 pages and capture many reform initiatives over the previous 50 years, have themselves been sited as a source of increasing program length (Green et al, 2002).

Given a funded program to satisfy mission needs, changes in the threat or the strategic and tactical environments can drive decisions to modify requirements and slow the development to adapt force size and/or capability to the necessary changes. In the case of the F/A-22 program, internal DOD reassessments of national security needs in the post-Cold War world reduced the originally expected total and annual production of 650 airplanes at 48 per year, respectively, to less than 300 airplanes at 32 per year. In the process, the program survived Congressional attacks that nearly led to program cancellation in 1998 (Squeo, 2003).

To satisfy requirements, it can also happen that “state-of-the-art” technology assumed or expected to be ready for incorporation in the weapon system may fall short of the maturity needed or not deliver capability to the potential so confidently projected when the development decision was made. One example in the F/A-22 program concerns the difficulties of developing the leading edge intakes of the fuselage that funnel air to the engine. Another example is the side-of-body component that connects the aircraft wings to the fuselage. Each (and many others) involved design and development of not only the component itself, but of new processes required to meet the functional and structural requirements of the revolutionary F/A-22 design.

From the perspective of the Congressional watch-dog, the General Accounting Office (GAO), 30 years of evaluating weapon systems and the acquisition process led to the conclusion that the problems of meeting schedule commitments (as well as cost and performance goals) is rooted in the culture—the collective patterns of behavior exhibited by the numerous participants (including critics) in the acquisition process and the incentives for that behavior (GAO, 1992). While recognizing that individually, participants from various components of DOD, the Congress, and industry act rationally to pursue needs they see as aligned with the national interests, fear of disruption, deferral or even cancellation leads to a collective “environment that encourages selling programs, [and] often involves undue optimism, parochialism and other compromises of good judgment” (p 2). The result is predictable weapon system development problems, including schedule delays and consequent cycle time expansions that are essentially embedded in acquisition programs from the beginning.

William Perry, then newly appointed Secretary of Defense, cited the need for substantial changes in the culture and practices of those involved in the acquisition system in his statement before Congress in early 1994, *Acquisition Reform – Mandate for Change*. In a 1995 *Defense Weapon System Acquisition* report, the GAO noted that DOD's commitment to acquisition reform offered increased promise for real progress in changing the structure and culture of the acquisition process. However, the report nevertheless cited unrealistically optimistic schedules among other persistent, pervasive problems in the DOD acquisition process. Others have made similar observations about the difficulties of changes intended to reduce cycle time or implement other reforms (Holland, 1998; Gansler, 1989, 1995; Rumsfeld, 2001).

And one final cause of schedule slippage documented in an important research project by McNutt that is a direct antecedent of this study is simply that the emphasis on schedule or the tools to effectively, realistically plan and manage schedules have been inadequate to consistently meet schedule commitments. A primary recommendation was demonstration of the application and results of schedule-based information through near-term projects (McNutt, 1998).

In essence, then, several factors promote and direct attention to the weapon system development cycle time. From the primary motivation to get capability to the war fighters as soon as possible to the alarming evidence from DOD, GAO and research that cycle time is getting worse, there is substantial motivation to focus on the problem. In this dissertation it is that motivation that drives the investigation of an approach that has promise for improving schedules and schedule execution.

Though seeming to focus on one of the several factors discussed, dealing with the schedule problem could, in fact, have potentially beneficial effects on the others—

funding, threat, technology and culture. McNutt (1998) provided a compelling case that the well worn adage “time is money” is painfully true in acquisition management. The possibility that poor schedule performance in the past caused Congress to delay initiation or stretch-out programs with varying budgets and funding profiles would itself highlight the importance of attacking the development cycle time and schedule management problem. Though schedule management cannot directly affect technology development, proper schedule management can help anticipate impacts of delays and adjust schedules to avoid crises. Similarly, regarding embedded cultural problems, the development and demonstration and adoption of rigorous schedule management processes could produce better, more feasible schedules and eliminate the unrealistic optimism that is so frequently assailed in acquisition programs.

Adoption of CCPM to Address F/A-22 Schedule Management

The imperative to directly address specific schedule management problems during the development and early production phases of the F/A-22 weapon system acquisition program occurred in early 2000. Then, two pathways leading to initial and expanded use of Critical Chain Project Management (CCPM) within the F/A-22 program merged. One pathway involved Boeing’s plant outside of Seattle, WA, where results of initial CCPM use in the assembly area had shown promise in one part of the F/A-22 program. The second pathway, ultimately responsible for most of the CCPM application case studies documented in this dissertation, involved F/A-22 program leadership concerns about emerging schedule management problems in the transition from the Engineering and Manufacturing Development (EMD) to the Production phases of the F/A-22 acquisition cycle. Essentially, schedules were being missed (i.e., work was taking longer than projected in planning schedules); management was unhappy with a variety of well-accepted schedule management tools in use for schedule planning and management ranging from simple spreadsheets, to stacks of 100 or more complex, manually interrelated and updated Microsoft PowerPoint charts to increasing use of more sophisticated computer programs such as Microsoft Project™.

Acting for the team leadership to address the problems, LM Aero's F/A-22 Program Integrator and his counterpart, the government's F/A-22 System Program Office Technical Director, tasked the author, Casey, and a government civilian from the F/A-22 SPO, hereafter referred to as Pennington, to look into the potential of CCPM to help deal with the problems of concern. The ensuing search uncovered numerous examples of Critical Chain success in generating on-time or reduced cycle-time deliveries for many commercial and government-sponsored programs in the mid- and late-1990s, even though the CCPM process had only begun to take shape in the early-1990s. Besides its newness, the fact that CCPM had not been extensively applied to the development and early production phases of DOD acquisition programs by the late 1990s was not surprising, since schedule reduction was not a major or even significant focus of defense acquisition reforms during the 1990's. Cost and performance tradeoffs were the major focus. The combination of all these factors led F/A-22 leadership to decide that the potential value of CCPM should be evaluated in one or more areas of F/A-22 program beyond the use at Boeing.

To implement the decision, Casey and Pennington were directed to coordinate and lead efforts toward demonstration and evaluation of the CCPM approach on the F/A-22 program. Early on in their efforts, a third individual from the LM Aero Master Scheduling organization in Marietta, GA, hereafter referred to as Colby,[7] joined the effort. Essentially, these three comprised what Zaltman referred to as "change team" (1973)

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[7] The names Pennington and Colby are fictitious names, but used to simplify reference throughout the dissertation to real people central to the CCPM application described.

with responsibility for (1) identifying areas in the organization in need of change, (2) tailoring of the CCPM solution to selected areas of application, and (3) the implementation and follow-through of the solutions.[8]

Originally, the effort was expected to involve a single pilot effort beyond the use at Boeing. Essentially, the expectation was that positive results in one area, combined with the already positive evidence from the use of CCPM in the assembly area at Boeing, would lead to program wide implementation of the CCPM approach. However, for a number of reasons, the F/A-22 leadership encouraged Casey and Pennington to find other opportunities to use the CCPM approach within the F/A-22 program, thereby prompting the multiple-case study that is documented in this dissertation. The evolutionary nature of the research is reflected in the selection and execution of multiple cases as well as by the chronological order in which the cases occurred. Together, the case studies reflect a fundamental proposition of this dissertation that the environment of the F/A-22 program is non-uniform. That is, the planning, scheduling and execution challenges faced across the program occur in operational contexts that differ.

Besides the case studies, the dissertation recognizes the vitally important role played by the F/A-22 organizational leadership, here referred to by the reference “Program” or “Program-level”. As is made clear in a separate chapter (Chapter 5), the leadership activities acted as the bridge between the initial use of CCPM at Boeing, and the other applications of CCPM covered as case studies in this dissertation.

The specific case studies address the use of CCPM in the following program areas and locations:

- Major aircraft component assembly at the Boeing plant in Seattle, WA.

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[8] Zaltman defined the second responsibility as “selection of innovative solutions” but in the present context, “tailoring” is more appropriate, since the CCPM innovation was selected as the innovation of interest.

- Post-assembly manufacturing process—aircraft finishes—at the LM Aero plant in Marietta, GA.
- Flight Test Operations at the Combined Test Force at Edwards AFB, CA.
- Supplier team development of a computer module at multiple supplier locations.

Even though the Boeing implementation occurred prior to the author's direct involvement as participant observer, it is of interest for two reasons. First, it is the purest manufacturing application. Since significant assembly operations are required in virtually any weapon system program, review of the decisions and implementation in the manufacturing operations context can inform the overall observations about CCPM employment. Second, the Boeing application is also important because success there was a major factor in the sequence of actions leading to the F/A-22 leadership-level decision to evaluate CCPM in other areas of the F/A-22 program.

The LM Aero implementation of CCPM in an F/A-22 manufacturing process area occurs at the Marietta final assembly facilities and is called *finishes* or *coatings*, the complexity of which is greater than the "paint aircraft" task of more traditional programs. Multiple, highly complex processes, materials, and tools and rigidly controlled environments are required to meet the very stringent stealth design[9] and operational needs established by the government.

The implementation of CCPM by the Combined Test Force (CTF) at Edwards AFB, CA, is unique within the F/A-22 program since Edwards is essentially the only place where intensive total weapon system testing—predominantly flight testing—is

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[9] The coatings and finishes applied to the surfaces of the F/A-22 aircraft are just two elements of the overall design that make the F/A-22 aircraft nearly impossible to detect by enemy weapon systems in operationally significant parts of the electromagnetic spectrum.

conducted.[10] The three different CCPM applications that occurred in the dynamic CTF environment are documented as separate implementation case studies in this study.

Finally, the supplier team development of a key product—a new module for the F/A-22 computer—is a complex, multi-player process overseen by LM Aero. Evaluating CCPM in this environment is useful because, as mentioned earlier, well over 50 percent of the parts, components and subsystems on the aircraft are developed by vendors and integrated into the major components or final F/A-22 assembly by LM Aero or its major partner, the Boeing Company. In addition, multiple suppliers are frequently involved in weapon system acquisition (Rogers and Birmingham, 2004), so results of the F/A-22 supplier implementations of CCPM may provide insight regarding the potential for broader application in other weapons system development programs.

Individually and as a group, these areas are representative of the project management challenges faced across the F/A-22, as well as other aircraft development programs and other weapon system development programs in general (Fox, 1974; Gansler, 1995; Eskew, 2000; Olsen, 2000). Together they provided the basis for identification of decisions and implementation problems related to CCPM in the IPT environment of the F/A-22.

Analysis of the problems revealed in the multiple case studies led to formulation of solutions to overcome the problems encountered. The application of these solutions is verified in the following mini-case studies addressed in the cross-case analysis of the research (Chapter 9):

- Multi-project supplier application (Germantown, MD).
- Post-assembly modification operations (Marietta, GA).

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[10] The only exception is the initial air-worthiness flights conducted after final assembly at Marietta prior to transfer of the aircraft to Edwards AFB.

The Research Questions

To evaluate CCPM as an organizational innovation that may have promise in dealing with the problem of planning and managing weapon system development schedules, the dissertation addresses the following primary research question:

How and why does the Critical Chain Project Management process improve schedule planning and execution over traditional approaches in various areas of the F/A-22 program?

It should be noted that within the context of the constantly increasing span times, while it is to be hoped that improvement methodologies lead to reduced cycle time, the first step is to arrest the increase. Therefore, an important measure of success is that schedules be achievable, so the ”improved schedule planning and execution” element of this research question can be satisfied with a schedule that remains fairly stable and can be executed to completion on time. Said another way, if CCPM provides a process to reliably plan, schedule and execute in a way that the product or process delivery goals are met, then the CCPM innovation will have proved its value.

Within the top-level research question, specific questions are:

1. How and where has CCPM permitted development and execution of more feasible or shorter schedules than traditional approaches for product/system development in general?

The answer to this question provides a global perspective on the range of industries and environments that have seen benefits from the implementation of CCPM, as well as the mechanisms that are claimed to have generated these improvements.

2. How is the CCPM approach to schedule planning and execution different than traditional approaches?

The answer to this question provides insight into contrasts between the traditional “standard” approach to project/program schedule planning and management and CCPM.

3. Why was the CCPM innovation successful (or unsuccessful) in improving schedule planning or execution in the organizations of application on the F/A-22 program?

The answer to this question permits an evaluation of the substantive aspects of this study: Can we understand why CCPM did or did not work in the areas of application?

4. How can we learn from this study?

The answer to this question raises the perspective from the individual cases to the more global view of the aggregate meaning of results and observations.

Because of the breadth and depth of the multiple cases addressed here it is not unreasonable to speculate about possible applications of CCPM in other weapon system development programs. In doing so, from a methodological perspective, the study challenges the belief that case studies are only generalizable to theory or to theoretical propositions, not to populations or universes (Yin, 1994).

Organization of the Dissertation

The remainder of the dissertation fleshes out the several subjects briefly introduced in this overview chapter. Chapter 2 describes the background leading to the study and describes relevant literature to place this study in relation to the stream of literature to which it is intended to contribute. Chapter 3 describes the overall research methodology, the F/A-22 organization, and the generic form of the CCPM approach at the heart of the study. The bulk of the description and analysis of the research is contained in Chapters 4 through 8, in the order and over the period depicted in Figure 5. In this sequence, Chapter 4 (the application at Boeing) is separated from Chapter 6 through 8 (other applications) by Chapter 5, which, as noted earlier, concerns the Program-level actions which acted as a bridge between the first and follow-on applications. Chapter 9 then documents the analysis of the several implementations, stepping back from the “trees” to look at the “forest” by comparing, contrasting and integrating results of the separate applications and elevating the perspective and insight to the higher, Program level. Chapter 10 presents conclusions, recommendations and other findings that highlight the contributions to the organizational innovation literature. Recommendations for follow-on research are also presented.

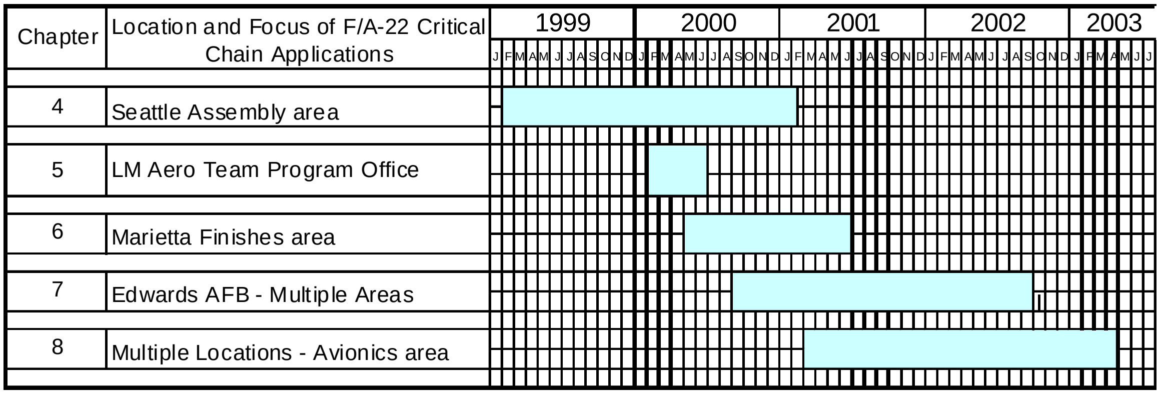

Figure 5. Focus and chronological relationship of the CCPM applications.

Summary

Chapter 1 introduced the problem of DOD weapon system acquisition programs with constantly increasing development spans, despite calls for reductions in those spans. In the face of that continuing dichotomy between program performance and management direction, the purpose of the dissertation is to report on and assess the capability of Critical Chain Project Management (CCPM) as an organizational innovation to deal with schedule management in several areas of the F/A-22 program, the largest acquisition program of the late 20th and early 21st century. Using multiple case studies of CCPM applications, the objective is to explore future strategies and mechanisms for dealing with schedule management issues, possibly leading to further research and DOD policy encouraging its use on future programs. At the same time, the adaptation of existing organizational innovation knowledge facilitates insight regarding the CCPM innovation itself in the context of the DOD acquisition environment, contributes to the stream of organizational innovation literature that relates to large, complex organizations, and provides the basis for future research.

Chapter 2: LITERATURE REVIEW

Overview

This chapter documents continuing evidence that an organizational innovation in schedule management is needed to help develop weapon systems so that the US military forces will have them as soon after the identification of need as possible. This chapter begins with detail from pertinent literature on the paucity of attention to reduce weapon system development cycle time through better schedule management. Then, given the motivation to try to improve schedule management, the chapter reviews the traditional solution for schedule management, Critical Path Method (CPM), which remains the dominant approach in public and private industry for planning and managing schedules. The substantial data suggesting that the approach has been less than fully successful in managing development schedules essentially leaves a gap that the Critical Chain Project Management (CCPM) approach has the potential to fill. This CCPM approach is discussed in terms of its success, how it is viewed by skeptics and proponents and evidence that it does, indeed, qualify as an organizational innovation.

The foregoing leads to a discussion of the organizational innovation literature in terms of innovation *types, impact* on the organization, *structural level and actors* involved in adopting the innovation, and the *innovation process* for application of innovations. So that CCPM can be properly examined across the multiple cases studied in this research, a tailored model called the Casey Hybrid Innovation Process (CHIP) model is developed based on Rogers (2003) framework employing the stages heuristic.

Issues and Problem Identification

Problems, Limited Attention and the Need for Research

Despite the numerous sources noted in Chapter 1 that directly focus on DOD acquisition and call for substantially reduced cycle times, the fact that only half of DOD development programs meet their schedules was documented in a recent, comprehensive examination of the problem by McNutt (1998).[11] Equally disappointing, the academic journals which often examine vexing problems and rigorously screen potential solutions provide little indication of attention to the problem. As an example, the author's review of nearly 10 years of articles through 2003 in the flagship publication of the defense acquisition community, the *Acquisition Review Quarterly* (recently renamed the *Defense Acquisition Review Journal*) is reflected in Figure 6. Numerous articles touched on policy concerns about cycle time. However, there was only limited coverage, four percent, on the methods or approaches for better planning, controlling and reducing cycle time or for improving the schedules that are planned and executed within any system's cycle time.

This problem of limited attention is not limited to DOD acquisition. Gaynor (1992) asserted that in general, "US industry has ignored the concepts and importance of managing the time to accomplishment, now referred to as cycle time, time-to-market, simultaneous or concurrent engineering, enterprise-wide development, concurrent process development, and by other designations"(p. 3). He emphasized that solutions had to address the holistic, systematic nature of cycle time, a perspective that was echoed in the mid-90s by others (LaBerge, 1996; Chubb, 1996).

Bearing further testimony to the lack of focus on schedule performance, McNutt (1998) conducted an extensive survey of acquisition personnel. Figure 7 reflects his finding that schedule was fourth in priority among other acquisition process goals for those personnel most closely involved in the acquisition process for the Air Force. McNutt also made an important contribution towards understanding the reason for the

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[11] Not only does the title, "Reducing DOD product development time: The role of the Schedule Development Process", suggest that McNutt's unpublished dissertation is relevant; in fact, the information and recommendations of his research acted as a catalyst and direct predecessor for the current study.

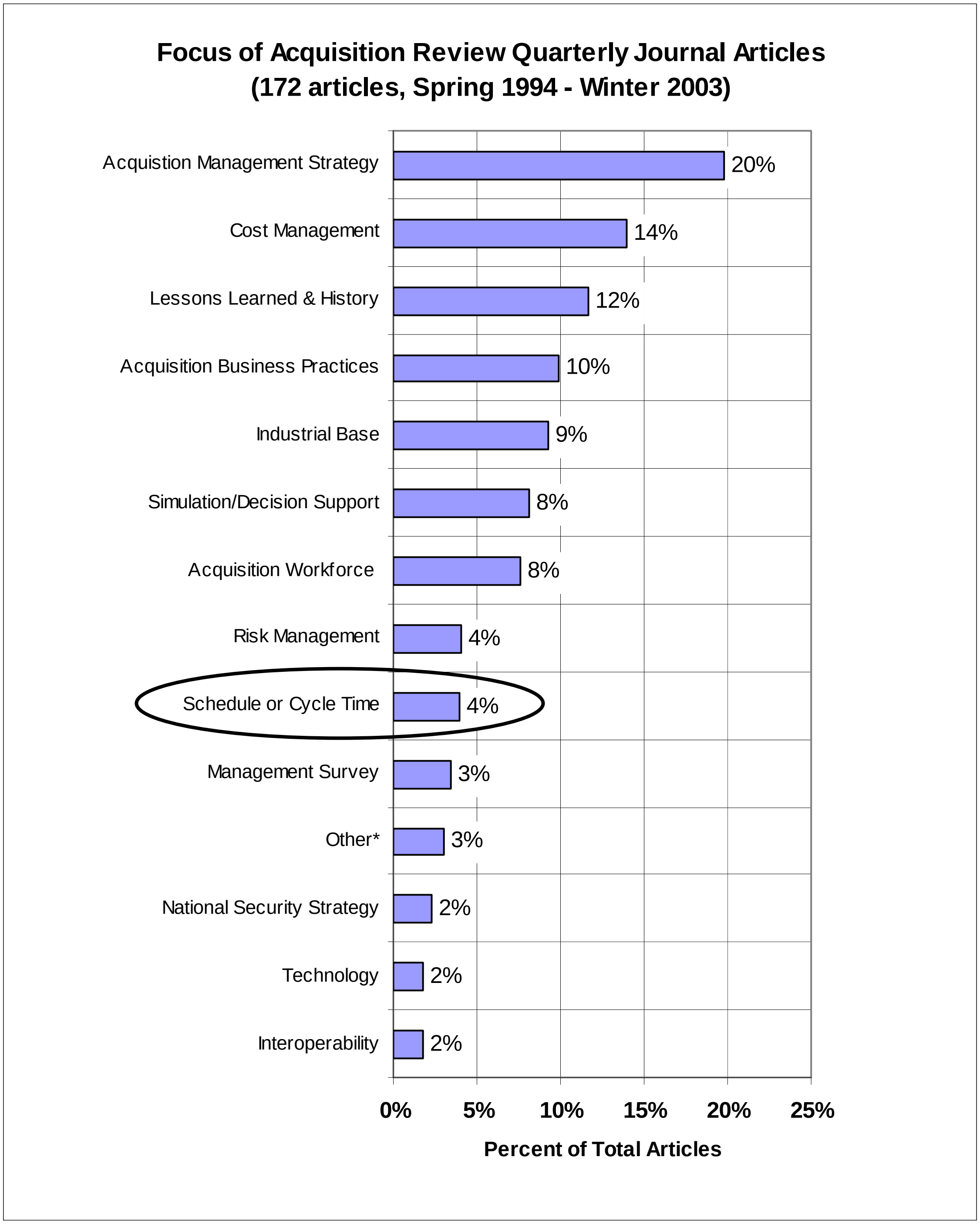

Figure 6. Distribution of articles in the Acquisition Review Quarterly Journal.

apparent dichotomy between reduced cycle time goals and increasing cycle time reality. He established that the key barriers to reducing development time for military systems were: the lack of effective schedule-based information and tools, the lack of schedule-based incentives, and the overriding impact of the funding-based limitations on

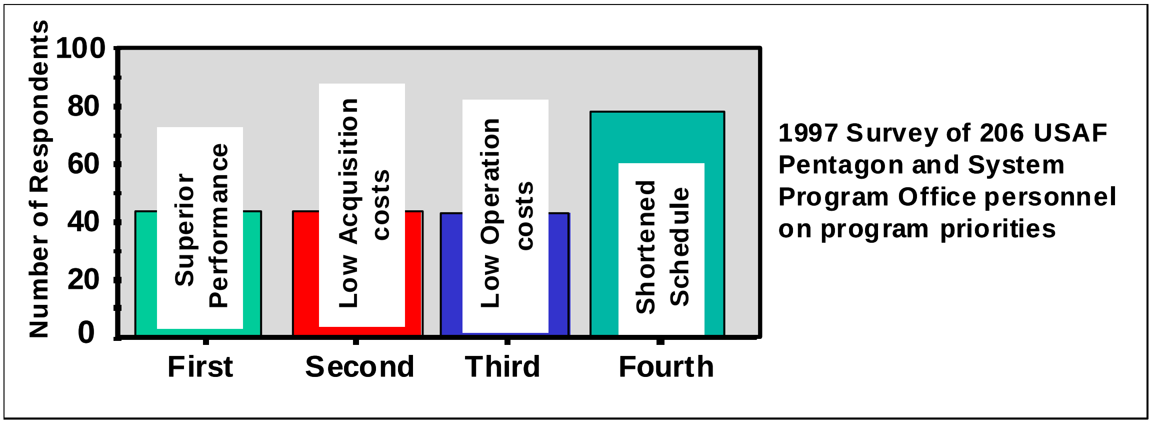

Figure 7. Ranking of program objectives by key program personnel (McNutt, p. 183).

defense schedules. To overcome these barriers, McNutt made several overarching recommendations. Two of his recommendations are not directly pertinent to this study, namely: to provide incentives for reducing cycle time, and to mitigate funding-based constraints on development projects. However, the other three recommendations are relevant to this study. In fact, the case studies that are part of this study attempt to directly respond to these other recommendations, specifically:

- Provide clear leadership on reducing cycle time
- Develop and use rigorous, schedule-based information
- Demonstrate the application and results [of schedule-based information] through near-term demonstration projects (McNutt, p. 319-322, 1998).

These recommendations become even more important in view of the relatively new “Reality Based Acquisition Policy for All Programs”. This policy was promulgated by the Assistant Secretary of the Air Force for Acquisition (SAF/AQ) and established “shortening the acquisition cycle” as the primary objective (Department of the Air Force, 4 June 2002). This policy contrasts with the dominant concern for weapon system development *cost* in the post-Cold War defense system acquisition world. This emphasis on cost had earlier (1994) spawned DOD Directive 5004.2 that established a highly placed organization, the Cost Analysis Improvement Group (CAIG), for which there is no equivalent directive that demands focus on scheduling. To leave no doubt that the new policy mandated a sharp change in thinking oriented to schedule achievement, the SAF/AQ policy letter included the following among the “commander’s initial guidance” regarding policy implementation:

> Speed is important. In devising and implementing acquisition approaches, the concept of time or schedule as an independent variable is one that must override prior concepts of delivering the ultimate capability at whatever cost and schedule is necessary to do so (Department of the Air Force, SAF/AQ, p. 2, 4 June 2002).

Even with this enlightened recognition of the importance of shortened acquisition development, however, the initiative will have little impact unless the tools and techniques are developed and demonstrated as suggested by McNutt. As a result, a major objective of this dissertation is to respond to the obvious gap in the literature related to acquisition development program management by evaluating the potential of the CCPM innovation to provide a tool for schedule planning and execution. Essentially, the dissertation will add to empirical research that captures what is actually going on during organizational innovation, research that is relatively recent but increasing (Boer and During, 2001).

Current and Potential Approaches to Managing Development Schedules

As logical and common-sensible as McNutt’s recommendations are—perhaps even mandatory in view of guidance from SAF/AQ—it would seem almost certain that they would long ago have been the catalyst for action to focus on major weapon system acquisition schedules, despite prior emphasis on cost. Indeed there have been efforts to improve schedule management in the broader project management community. With some exceptions (e.g., Kemps 1992),[12] literature on project management (Levine, 2002; Kerzner, 2000; Walker,1998; Pittman, 1994) frequently recommends the Critical Path Method (CPM) that originated in the 1950s and which remains the dominant approach for planning and executing schedules. Some consider its use essential for project planning, scheduling and control (Candela, 2003; Floyd et al, 2003; Githens, 1999). The Program Management Institute characterizes CPM as one of three "widely known mathematical analysis techniques for schedule development" in its Guide to the Project Management Book of Knowledge (PMBOK Guide, p. 75, 2000).[13]

When used in the acquisition process, CPM typically assists the development of acquisition system parts, subsystems, major components and, finally, the overall weapon system by facilitating development of a network structure that depicts relationship and span times of required tasks. Then, management of program schedules that evolve from CPM in DOD is centered on what is called the Earned Value Management System (EVMS). In brief, EVMS is based on a hierarchical organization of functional activities called the Work Breakdown Structure. The functional activities are organized to deliver products within the framework of an Integrated Master Plan (IMP)—the contractual commitment—on a timetable captured in an Integrated Master Schedule (IMS). The combined use of CPM and EVMS permit the linking of time and dollars required for completion of the tasks. Value is "earned" as tasks are completed. EVMS is advertised as a "powerful tool" that supports the management of time, cost and scope through calculation of cost and schedule variances, forecasts of cost and schedule at completion and highlighting the possible need for corrective action (Anbari, 2003).

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[12] Excluded from the list of those who do not strongly advocate the Critical Path Method are virtually all those adherents to the Critical Chain approach. Kerzner, long recognized as a, if not "the", premier expert in the area of project management has included an excellent chapter on CCPM in his most recent book (2003).

[13] While not identified as the "preferred" or "first choice", CPM garners the most attention in PMI articles on the three schedule analysis/management techniques. The other two techniques are Graphical Evaluation and Review Technique (GERT) and Program Evaluation and Review Technique (PERT). Critical Chain is mentioned in the PMBOK only as a technique to account for limited resources.

Yet, despite its widespread use for planning and managing DOD weapon system acquisition programs and even granting that acquisition schedules are affected by the many factors noted earlier, the continually expanding cycle times suggest that the combination of CPM and EVMS has been less than universally successful. There are understandable reasons for this.

CPM success has been most limited when assumptions of unlimited resources and deterministic activity/task durations are invalid (Moisuddin and Selim, 1997), as is most frequently the case. In addition, the primary focus on task (vs. project) completion and the failure to recognize resource availability and dependencies, significantly reduces the statistical probability of completing a chain of dependent tasks on schedule (Gemmill and Edwards, 1999; Bowers, 1995). This is especially true when iteration is involved, because it is “a fundamental characteristic of product design” (Denker et al, 2001).

For EVMS, the inability to assist the project manager by clearly, consistently and accurately predicting project success or to reliably highlight the need for corrective action is a direct result of treating all tasks as having equal value, when in fact some tasks are far more crucial to a schedule than others. In the failure to recognize this distinction, it is common for EVMS metrics to present misleading information regarding the percent of project complete. In fact, in assessing the value of EVMS, the Government Accounting Office (GAO) found program managers who characterized attempts to use EVMS data for program decision-making as tantamount to “managing by looking through the rear view mirror” (GAO, 1997). Beyond government projects, assessments of EVMS also question its value in project management. For example, in his survey of 400 project management professionals working 180 Fortune-100 company projects, Thamhain found that EVMS was used by 41 percent of the people, but assessed it as having little value (Thamhain, 1998). Similarly, while West and McElroy (1998) acknowledged that earned value *analysis* facilitates reports of work done, they concluded that EVMS is not a management tool because it does not show the future forecast of project success.

The literature related to project planning and scheduling details numerous efforts to overcome the limitations of CPM, and by association, EVMS, for which CPM is typically a vital component. Rahbar and Rowings (1998) acknowledged CPM's utility in schedule analysis, but developed what they called "top-down back-to-front project planning" to overcome what they saw as CPM's flaws regarding planning. Moizuddin and Selim (1997) cited extensive research on efforts to develop heuristics for dealing with CPM's deficiencies with resource-constrained project scheduling and argued that a simple, elegant, iterative technique called "tabu search" could be successful in many situations. Bowers (1995) described in detail a set of algorithms for a concept called "resource constrained critical path" to mitigate the impact of resource limitations in the traditional application of the CPM. As a way to improve performance of CPM-based schedules, Vanhoucke and Demeulemeester (2003) incorporated the financial concept and calculations of Net Present Value to help project managers using CPM to decide how best to employ "early start" and "latest start" options for tasks not on the critical path.

Going even further, there are those who regard the results of employing CPM and other network-based approaches (e.g., Program Evaluation Review Technique or PERT) as fundamentally flawed even when enhanced with probabilistic estimating refinements, resource loading techniques, heuristics or when combined with waterfall and spiral approaches or concurrent engineering and teaming approaches (Lyneis et al, 2001; Denker et al; 2001). The view of such critics is that traditional concepts and tools tend to oversimplify or encompass relatively static perspectives that cannot successfully deal with the size and dynamic, complex character of huge projects (Denker et al, 2001).

The conclusion of the foregoing review is that the traditional solution to the problem of schedule planning and execution, CPM by itself or in association with EVMS, will not satisfy the need for improvements in F/A-22 schedule planning or performance. Essentially, the evidence justifies the dissatisfaction of F/A-22 team leadership with the performance of existing tools such as Gantt charts and spreadsheets as well as CPM (embedded in Microsoft Project™ software). In fact, the evidence reinforces the existence of a significant gap in the availability of tools to solve a vexing schedule management challenge that underscores the acquisition development span problem.

Potential Solution: Introduction to CCPM and Current Views of CCPM

CCPM: Background and Indicators of Success

Fortunately, as noted earlier, during the time the flaws and shortfalls of the CPM approach have become increasingly apparent despite pursuit of methodological “fixes” and efforts to improve it, a growing amount of literature has emerged related to, or based on, what is called the Theory of Constraints (TOC) (Goldratt, 1990a, 1990b, 1992, 1994; Detmer, 1997). Dr. Eliyahu Goldratt, the acknowledged originator of TOC and its application to the production environment, introduced CCPM to the stream of management literature as the first significant new approach to project management in over 30 years with the 1997 publication of a best selling business novel, *Critical Chain*. Founded on the scientific approach, Dr. Goldratt’s unique construct adapts the hard science of his physics doctorate and experience to the softer science of organization management. TOC/CCPM addresses organizational projects at the systems level, and translates to the management arena the scientific conviction that there are no real conflicts in nature, but rather only perceived conflicts. To resolve these apparent conflicts, TOC/CCPM forces explicit attention to underlying problems using cause and effect logic to that reveal the core problems at the systems level. Even before the book describing this approach, evidence of the application of TOC concepts to project management was beginning to emerge in dissertations, textbooks, and some articles.

In the area of dissertation research, Pittman (1994)[14] used a combination of thought experiments, simulation, and cause and effect logic to conclude that a TOC project planning and control heuristic effectively applied central elements of TOC to the management of a single project. He recommended that research "should extend the present work to projects which require multiple resources for each activity and multi-project environments" (p. 222). In a follow-on effort, Walker's 1998[15] dissertation extended and expanded Pittman's research methodology and applied it to a multiple-project environment. He found that the TOC-based heuristic performed better than other heuristics on all summary measures in the multiple-project environment. Among several recommendations, Walker suggested research into the organizational aspects of multiple project management (p. 239). While these sources provide a necessary step in the stream of investigation into this field of knowledge, they also call for empirical research on the application of TOC-based project management to real world situations. This dissertation responds directly to those calls by looking at CCPM in the real-world and very complex environment of the F/A-22 acquisition development program.

Beyond research evidence such as that of Pittman and Walker, several authors have documented the CCPM process and the potential for dramatic savings in cost or schedule or both (Newbold, 1998; Cox and Spencer, 1998; Kendall, 1998, 2003; Leach, 1999, 2000). Of course, despite claims of potential success for the Theory of Constraints (TOC) and CCPM by Dr. Goldratt and other proponents, the concern for actual documentation of success is important and captured in the first research question

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[14] Entitled, "*Project management: A more effective methodology for the planning and control of projects",* Pittman pursued his research at the University of Georgia under Prof. James F. Cox, an author, widely acknowledged expert on the Theory of Constraints and CCPM, and advisor on the APICS series on Constraints Mnagement.

[15] Entitled "P*lanning and controlling multiple, simultaneous, independent projects in a resource-constrained environment,"* Walker also pursued his research at the University of Georgia under Prof. Cox.

identified earlier: **How and where has CCPM permitted development and execution of more feasible or shorter schedules than traditional approaches for product/system development in general?**

The most comprehensive documentation of success has been Mabin and Balderstone's work, *The World of the Theory of Constraints* (2000), the objective of which was to "compile an annotated bibliography of published materials relating to TOC" (p. v) beginning in 1990. The authors surveyed some 400 items from around the world, including (at the time) nearly 40 books and over 100 journals. From the published quantitative results related to the use of TOC by over 80 companies, the authors were able to substantiate many claims for improved operations, though the number of "observations" supporting each claim varied, depending on the data provided by the source. Though data presented was based primarily on manufacturing, and did not specifically segregate the results from projects, overall summary metrics provide a sense for the potential benefits:

- Lead Times: Mean reduction 70 percent, based on 32 observations; over three-quarters of the sample experienced reductions in lead-time greater than 50 percent.
- Cycle-Times: Mean reduction of 65 percent, based on 14 observations.
- Due-Date Performance: Mean improvement of 44 percent, based on 13 observations.

Beyond this overall review of the successful application of TOC to both production and project environments, there are many CCPM successes documented in the literature. Even as a publicity stunt, one must be struck by the impressive application of CCPM by the non-profit group, Habitat for Humanity, to complete a house in 3 hours and 45 minutes. This was almost one hour faster and used half the number of people required to produce the previous record (Simpson & Lynch, 1999).

Larry Leach, an experienced project manager and author, notes in his book "Critical Chain Project Management" that organizations "complete projects in one-half or less time of previous or concurrent similar projects, or as compared to industry benchmarks" (Leach, 1999, p. 40) and backs up the claim with the following specifics:

- The Harris Corporation used CCPM to build a new semiconductor wafer plant and bring it up to 90 percent of capacity in 14 months, compared to the industry standard of 90 percent capacity in 46 months.
- The Israeli Aircraft Industry reported that use of CCPM on major maintenance of passenger jumbo-jets permitted the company to reduce average turnaround time from three months to two weeks and, because of the success, increase backlog from two months to one year.
- Lucent Technologies applied CCPM to research and development projects and succeeded in reducing project span times in excess of 25 percent.

Of most interest to the present study are those applications of CCPM that occur in the military setting. As noted earlier, not many are documented. However, two applications initiated after the effort described in the present study have already documented impressive results.

At the Marine Corps Maintenance Center, Albany, Georgia, ground combat vehicles and other major pieces of equipment are regenerated and reconstituted (i.e., overhauled) to meet the combat readiness needs of the Marine Corps. In 2001, in the face of worsening difficulties meeting equipment repair commitments and increasingly common requests for more time and money to do assigned work, the Theory of Constraints approach was proposed as a solution. As reported by Srinivansan et al, (2004), in its first application to the MK-48 heavy-duty hauler, the use of the CCPM plan reduced the repair time from 167 days to 58 days (i.e., 65 percent) (p. 141). Where the Center had only been producing five units per month vs. the demand for 10, implementation of the CCPM improvements consistently generated *more* than 10 units per month with the flexibility to produce anywhere from 10 to 23 units per month. In a second implementation involving the LAV-25,[16] results using the CCPM approach reduced repair cycle time from 212 to 119 days (i.e., 44 percent) (p. 141). At the same time, repair costs were reduced by 25 to 30 percent, and all product lines were brought up to 99 percent on schedule performance (p. 142).

The other military example addressed the Engineering and Manufacturing Development (EMD) phase of a weapon system program, Global Hawk, which is smaller in scope and funding level than the F/A-22. Global Hawk is the designation of an Air Force high altitude, unmanned, aerial vehicle system designed to provide real-time intelligence in various theaters of military operations. The total team was challenged to accelerate the transformation of what was a technology demonstrator into a deployable system to support the urgent post-9-11 needs of theater commanders charged to free Afghanistan during Operation Enduring Freedom. As a subcontractor to the Air Force's prime contractor, Northrop Grumman, Raytheon was tasked to produce the Golden Hawk's integrated sensors and ground station. Within a comprehensive productivity improvement program called Raytheon Six Sigma (R6σ™), Critical Chain was used to successfully deliver the system six months ahead of what was a 13-month schedule (Blair & McKenzie, 2004). The authors noted that "Implementation of *Critical Chain Project and Buffer Management* typically results in project schedules that can be 15 to 25 percent shorter than traditional schedules but with considerably more reliability of the promised final project due date with less chaos and rescheduling" (p. 209).

Overall, the cross-section of industrial and military applications of CCPM or a combination of Theory of Constraints and CCPM provides solid evidence of impressive successes. Typically, reports attribute these successes to the way the CCPM approach

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[16] Landing Assault Vehicle (LAV).

treats uncertainty, the employment and close attention to what is called buffer management (described in Chapter 3), and the reduction in negative behaviors that can often seriously undermine project goals. In addition, the Marine Corps Maintenance Center report provided insight on one other aspect of CCPM implementations that is commonly reported. The authors noted that the limitation on the Center's capacity to meet production demands was not a physical resource constraint, but rather a policy constraint induced, in that case, by a scheduling process that was "pushing products out to the shop floor without regard for the status of its resources" (Srinivansan et al et al, 2004, p. 139).

Views of Critical Chain

Despite the reported successes of CCPM applications that are representative of many others, the Critical Chain approach has been the subject of much controversy. Early authors advancing the Critical Chain Project Management approach were unreserved in their belief that the days of the Critical Path Method (CPM) were numbered. After Goldratt's *Critical Chain* in 1997, one of the first to write about Critical Chain Project Management within the larger framework of the Theory of Constraints was Newbold in 1998. Based on the success he observed in his own and others work, he noted that "the traditional ways of managing projects don't guarantee success; they will eventually guarantee failure" (p. xxi). He claimed that the critical chain scheduling method "is probably the most important new development in project scheduling in the last 30 years" (p. xxxiii). In his well respected text cited earlier, the originator of the term CCPM, Larry Leach, said "the project success rate using the existing critical path paradigm is poor for all types of projects in all types of cultures" (2000).

At the same time, adherents to the "traditional" approaches to project management and project scheduling were initially skeptical and generally less enthusiastic about CCPM. Many reviews and critiques in this stream of thought appeared in the *Project Management Journal*, the academic and intellectual voice of the Project Management Institute (PMI), or *PM Network,* a magazine forum for project management practitioners. The initially critical tone of the articles is not surprising since, as mentioned earlier, PMI is responsible for the Project Management Book of Knowledge (*PMBOK Guide*®), in which CPM and EVMS have long been pillars of the project management process. For example, some suggested that “Goldratt’s solution is far from original” (Levine, p. 9, 1999) or “nothing new” (Raz et al, 2002) and strongly disagreed with some of the concepts. Simpson and Lynch noted that some “insist CCPM is simply a repackaging of established concepts and can therefore be safely ignored” (1999). Others conclude that “[only a] few of the critical chain concepts are valid and therefore should be integrated into the *PMBOK® Guide*” (Globerson, p. 63, 2000). These authors seem to suggest that marginal adjustments would permit sufficient strengthening of the traditional (Critical Path or PERT) methods so that CCPM could be eliminated as a separate (and competitive) approach to project management.

Schuyler (2000) was somewhat more balanced, but expressed the view that “the stochastic model is the core of effective project risk management” (p. 60) and the use of deterministic calculations in the Critical Chain approach as a significant deficiency. Herroelen and Leus (2001) cited a litany of approaches to resource constrained project scheduling problems not specifically addressed by the critical chain approach, including net present value, minimizing average flow, project lateness, number of tardy activities, resource availability costs. In this and another article (Herroelen et al, 2002), the authors suggested that CCPM could be useful, but mathematically supported their serious concern that the fundamental approach on the calculation of buffers to protect against uncertainty could be easily oversimplified. They and others (Cohen et al, 2004; Piney, 2000; Schulyer, 2000) suggest various ways that different techniques can and should be used to produce success that, in their view, use of the CCPM approach is unlikely to achieve if applied in the original version.

The foregoing cross-section of views conveys the on-going controversy about whether or not critical chain is new and revolutionary as claimed by some of its advocates, or just a distillation of well-known principles and minor revisions of time-worn techniques as suggested by the skeptics. The way to resolve this apparent dichotomy for purposes of this study is to view critical chain as an innovation, because the concepts and applications of the critical chain project management approach are consistent with so many perspectives on what constitutes an innovation.

For example, recalling Peter Drucker's observation that a great deal of new technology is not new knowledge, Steyn (2000) expresses his view that "innovation is new perception…putting together things that no one has thought of putting together before, things that have been around a long time" (p. 363). Earlier, Wheatley (1992), on the cutting edge of the new science of chaos and complexity, expressed a similar view of innovation and placed it in the context of organizations. She said:

> Innovation is fostered by information gathered from new connections; from insights gained by journeys into other disciplines and places; from active, collegial networks and fluid, open boundaries. Innovation arises from ongoing circles of exchange, where information is not just accumulated or stored, but created. Knowledge is generated anew from connections that weren't there before. When this information self-organizes, innovations occur, the progeny of information-rich, ambiguous environments (p. 112).

Indeed, Wheatley's general description of innovation seems to accurately describe the specific character of applying critical chain concepts to the frequently ambiguous, highly dynamic project management situation. Not exactly "self-organizing" to be sure, but as noted earlier, CCPM emerges in a several step process from the

Theory of Constraints based on Goldratt's transformation of hard sciences systems thinking to the soft science of management, through the application of TOC to the production environment and finally to the uncertain, often ambiguous program/project environment. Importantly, while some of the strongest proponents of CCPM recognize that 'new ideas' can be traced back to preceding ideas and many of the factors CCPM forces attention to were long recognized, they emphasize that the power of CCPM lies in the relationships of the ideas, the system of planning and control. From the perspective provided by Wheatley, even those who critique critical chain as "nothing new" would likely, perhaps begrudgingly, agree that CCPM does represent an innovative "putting together" of things known, but in a way not done before.

Besides possessing characteristics which logically identify CCPM as innovative, especially from the broader, organizational perspective highlighted by Wheatley, CCPM satisfies other, traditionally accepted definitions of innovation from the user's perspective, since it is an idea, practice or object that is perceived as new by the relevant unit of adoption (Zaltman et al., 1973; Rogers, 2003). The CCPM process also conforms to the definition of *organizational innovation* articulated by Gross, Giacquinta, and Bernstein, "any proposed idea, or set of ideas, about how the organizational behavior of individuals should be changed in order to resolve problems of the organization or to improve its performance" (p. 16, 1971). This perspective is useful because the CCPM innovation does require different behaviors on the part of individuals in an organization. Specifically, CCPM emphasizes on-time *project* goal accomplishment and mitigation of typical, negative human behaviors vs. the traditional focus on timely accomplishment of individual *tasks* within the project (which does not consistently lead to project goal accomplishment). Rogers (2003) notes:

> It matters little, so far as human behavior is concerned, whether or not an idea is objectively new as measured by the lapse of time since its first use or discovery.

> The perceived newness of the idea for the individual determines his or her reaction to it. If the idea seems new to the individual it is an innovation (p. 12).

To be sure, there are more complex definitions of innovation, e.g., “a transformative idea that works” (Dantzer, 2002) or for organizational innovation, e.g., “combines the development and implementation of new ideas, systems, products or technologies” (Damanpour, 1991). However, at their core, these and others emphasize the perspective adopted by this dissertation, that what matters is the newness of the idea to the organization adopting the innovation(s), a view that is consistent with a fairly recent and sweeping review of literature. Entitled “Organizational innovation and organizational change”, Hage (1999) cites sources from 25 years to support the observation that “organizational innovation has been consistently defined as the adoption of an idea or behavior that is new to the organization” (p. 599).

Organizational Innovation – Theoretical Constructs of Interest

As relatively simple as the view that an “innovation is something new to the organization” appears on the surface, Damanpour and Gopalakrishnan (1998) reviewed scholarly approaches to the subject and concluded that “after more than 30 years of research on organizational innovation, we are still far from suggesting answers to simple questions of interest to both researchers and practitioners” (p. 2). That situation seems understandable in light of Downs and Mohr’s observation in 1976 (recalled by Gopalakrishnan and Bierly) that “the innovation process is one of the most complex organizational phenomena for which a unitary theory of innovation is unacceptable because it led to empirical instability and theoretical confusion” (p. 108, 2001).

The difficulties notwithstanding, the theoretical constructs of interest have to do with *type* of innovation, the *impact* of the innovation on the organization taken as a whole, the *structural level and actors* of the organization involved in initiating and/or implementing an innovation, and, most importantly, the *innovation process* by which an innovation is actually applied within the organization. The discussion below addresses these constructs in increasing order and depth related to their importance here.

The *type* of innovation is straight-forward and characterized for present purposes as a simple distinction between two types of innovation, product and process.[17] In contrast with “product innovations” which “are outputs or services that are introduced for the benefit of customers or clients,” CCPM is clearly a “process innovation” encompassing “tools, devices, and knowledge in throughput technology that mediate between inputs and outputs” (Gopalakrishnan and Bierly, 2001). In general, certainly in the cases described, the CCPM innovation is definitely a process intended to mediate between inputs and outputs by scheduling input resources and activities to facilitate the work and decisions affecting or producing the output of the organization.

In this dissertation, the *impact* of the CCPM innovation can be characterized as “incremental,” because each application was initiated and supported as an opportunity to assess the potential utility of CCPM to the unique schedule management challenges in a particular F/A-22 environment.[18] Given this targeting, it would not be appropriate to characterize the innovation as a sweeping implementation which would have a “radical” impact across the program. The use and meaning of the terms “radical” and “incremental” herein are similar to the bifurcation of innovations as seen by other researchers,[19] but specifically aligned with a construct called the “theory of innovation radicalness.” Consistent with this theory, CCPM is an “incremental innovation” that

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[17] Other scholars use these terms in more detailed breakdowns. For example, Francis and Bessant (2004) examined areas targeted by innovation in terms of products, processes, positioning (of the firm or products) or paradigm (of the firm). Baker (2002) drew a distinction among innovations as products, processes, services or business concepts.

[18] Depending on the results over time (beyond the span of this study), the CCPM innovation could be implemented as a radical innovation at a later time if directed by the F/A-22 senior leadership.

[19] As reported by Damanpour and Gopalakrishnan (1998), Normann (1971) used “variation” and “reorientation” to distinguish between refinements and fundamental changes in products. Knight (1967) and Nord and Tucker (1987) used “routine” and “non-routine” to distinguish between minor and major changes in products or processes and Grossman (1970) used “ultimate” and “instrumental” to distinguish between an innovation that was whole and complete versus one that could eventually lead to the ultimate innovation.

involves changes which are a moderate degree of departure from existing practices (Damanpour and Gopalakrishnan, 1998; Dewar and Dutton, 1986, O'Connor and McDermott, 2004). In contrast, "radical innovations" are substantial or fundamental changes in the activities or products of an organization which are clear departures from existing practices, often accompanied by like changes in organizational structure.[20] To qualify as a radical organizational innovation in a complex acquisition program like the F/A-22, the application would have to have been far more global and time-compressed than reflected in the pace and coverage of the CCPM innovation illustrated here.[21] Depending on the results over time, the CCPM innovation could be expanded and accelerated as a radical innovation at a later time (beyond the span of this study), if directed by the F/A-22 senior leadership.

With the CCPM innovation straight-forwardly established as a "process" *type* with "incremental" *impact* on the organization, the discussion now turns to the constructs that will be used most heavily to assist in the analysis of the CCPM applications, namely those that relate to *structural levels and actors* and the *innovation process* of applying an innovation in an organization. The order for discussing these subjects is *structural levels,* then the *innovation process* for application, then the *actors* involved—essentially the *where, what* and *who* of an innovation. The organizational *structure* and *levels* provide the context and backdrop *where* an innovation is applied. The *innovation process* identifies *what* has to be done, i.e., activities involved in executing the initiation and implementation stages. And the *actors*—whether individuals or groups—are *who* operate across the structural levels to influence or carry out the activities within the

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[20] The criteria for a radical innovation was quantified in one study to be "a 5-10X (or greater) improvement in performance or a 30-50% (or greater) reduction in cost" (O'Connor and McDermott, p.13, 2004).

[21] In fact, an example of a radical innovation for the F/A-22 program had occurred earlier with the program-wide adoption of the concepts of Lean Engineering, an approach to improvement patterned after that of the Toyota Company (Womack et al, 1991; Womack and Jones, 1996). As will become clear in Chapter 4, the use of CCPM was integrated with the application of the lean engineering efforts at the Boeing plant.

organizational framework. *Actors* are also covered last in sequence because unique individual roles are better understood after the innovation process model is described.

Organizational Innovation Structural Levels

To differentiate between the primary *structural levels* of the organization involved in initiating and/or implementing an innovation, the terms “Program” and “Operational” will be used. “Program” relates to the F/A-22 team’s senior leadership’s involvement in, and influence on, the initiation of CCPM innovation use in various F/A-22 areas and locations. The “Program” structural level initiates, encourages or directs critical activities without which applications of CCPM would likely not happen. In the hierarchical F/A-22 team organization, the lower boundary of the “Program” level is just above the level where the CCPM innovation is put into operation to support accomplishment of physical work by the Integrated Product Teams, hence the use of the term “Operational” to capture this latter structural perspective.

The terms “Program” and “Operational” are chosen for their suitability in the complex structure of a major defense acquisition program like that of the F/A-22. At the same time, however, their use is generally consistent with similar distinctions in current structural theories, such as the “dual-core” theory of innovation by Daft (1978) and also noted by others (Damanpour and Evan, 1984; Ahire and Ravichandran, 2001). Like the use of the word “administrative” in that theory, “Program” innovations typically originate from the upper level of a weapon system acquisition organization since that is where responsibility for structure, control systems and the coordination mechanisms lies. Also like the dual-core theory, there is the expectation that innovations originating within the Program level follow a kind of “top-down” process of implementation (Daft, 1978; Damanpour and Gopalakrishnan, 1998). However, the Program/Operational construct here does not anticipate that the program innovation will be associated with a mechanistic structure as stipulated with administrative innovations[22] (Daft, 1982). Acquisition organizations are characterized as *highly* professional, with significant decentralization in decision-making both by the delegation of that authority to the working level IPTs and by sheer necessity.[23] The use of the term "Operational" emphasizes the working level where the innovation must be accepted and implemented in order to generate the desired effects of the innovation in support of the primary work accomplished by the responsible Integrated Product Team that generates the product.[24]

The use of the terms "Program" and "Operational" will be further clarified in Chapter 3. The importance of the Program level is recognized by a separate discussion (Chapter 5) as well as by appropriate treatment in both description and analysis of the other case study chapters which concentrate primarily on the Operational-level activities involved in applying the CCPM innovation.

Development of the Casey Hybrid Innovation Process (CHIP) Model

The fourth theoretical construct for purposes of the dissertation relates to the *innovation process.* Because of its primary importance for establishing expectations and understanding of the nature, flow and utility of the CCPM innovation, the discussion highlights the broader organizational innovation process literature, details the Rogers version of the innovation process closest to present needs, and describes the modifications of the Rogers framework to create the Casey Hybrid Innovation Process (CHIP) model formulated to support process analysis of the case studies in this paper.

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[22] "A mechanistic structure is needed when an organization must adapt to changes in goals, policies, strategies, structure, control systems and personnel. (Daft, 1982). Thus, low employee professionalism, high centralization in decision making and high formalization of behavior facilitate the top-down process of administrative innovations" (Damanpour and Gopalakrishnan, p. 8,1998).

[23] The need for decentralized execution is underscored in the case of the F/A-22 program by the over 1100 first tier suppliers (King and Driessnack, forthcoming, 2005) mentioned earlier.

[24] This description of "Operational" contrasts with the the alternative to administrative innovations in the dual-core theory, technological innovations, which pertain to products, services and production process technologies *directly* associated with the primary work activity of the organization. (Daft, 1978; Gopalakrishnan and Bierly, 2001)

Organizational Innovation Process Literature

Within the range of analytic frameworks used by scholars in the organizational innovation arena, the most encompassing starts from an idea and proceeds to some end state where the innovation is fully institutionalized. In general, these have been captured under rubric of "the ambidextrous theory of innovation" Duncan (1976). This theory employs a stages heuristic that divides the process into *initiation* and *implementation,* exactly the same top-level stages as identified in the approach taken by widely cited sources, Zaltman et al (1973), and Rogers (1962, 2003). The *initiation stage* includes all the activities from discovery of a problem to the search for an innovation (or use of a known innovation) and information that will permit the organization to decide to adopt the innovation to deal with the problem. The *implementation stage* consists of all activities associated with changes in the innovation and/or organization, initial use and continued use until it becomes routine (Zaltman et al, 1973; Duncan, 1976; Rogers, 2003).

Other frameworks diverge from the ambidextrous theory by essentially focusing on one stage and either excluding or only briefly mentioning the other stage. For example, Kwan and Zmud (1987) developed a five-stage model of innovation, including initiation, adoption, adaptation, acceptance and use, for their research in the information technology area. Essentially, all but the last stage dealt with the initiation phase, placing great emphasis on the need during initiation to establish conditions within the organizational structure and personnel to facilitate success, after which "use" was fairly straight forward. Despite this seeming imbalance of emphasis on initiation versus implementation, the model has gained widespread acceptance and has been used in several telecommunications and information technology studies (Ahire and Ravichandran, 2004). Similarly, Geffen and Judd (2004) developed a model that addressed establishment of innovative initiatives in the public sector science and technology arena; it also focused in detail on the initiation stage, demonstrated through several representative case studies, but was light on the implementation stage.

The problem with these more focused frameworks is that while emphasizing initiation or outcomes, they divert attention to the process as a whole and essentially revert to the time prior to Zaltman's emphasis on the need to study single innovations over time, an approach which has largely been followed since the early 1970s (Rogers, 2003). Borrowing from another theoretical perspective, Zaltman's caution to avoid focus on just one stage of the innovation process is echoed in criticism of the stages heuristic in the public policy arena,[25] precipitated by scholars who only focused on one stage or another or by others who failed to acknowledge the iterative nature of the policy development and implementation process (Sabatier, 1999).

Actually, the encouragement in the literature to look at the innovation process as a whole (versus one stage) is consistent with the desire to examine all aspects of CCPM innovation use in the several case studies documented in this research. Because none of the theories or models seemed exactly suited to the present research, the need for a hybrid model was apparent. Before describing the CHIP, however, we must first discuss its foundation in the work of Rogers.

Rogers' Innovation Process Theory

Everett M. Rogers' expanded version of the encompassing approach captured in the popular "ambidextrous theory" term was most recently documented in the 2003 edition of his' work and depicted Figure 8. Though Rogers is not without critics (Bordenave, 1984; Deshpande, 1984), even the critics regard his work as the benchmark in innovation diffusion and their reviews of his work find fault at the margins rather than with the core substance. For the most part, Rogers work continues to be

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[25] The generally accepted "stages" policy process encompassed initiation, estimation, selection, implementation, evaluation and termination (Deleon, p. 21, in Sabatier, 1999).

highly regarded. One reviewer (Ellsworth, 2001) characterized the 1995 fourth edition update of his original 1962 work as “arguably the leading treatment of theory and history” on change (p. 91).

Rogers’ refinement of the ambidextrous theory has appeal here because it suggests detailed expectations for what might be observed in the innovation process by breaking the two stages down further into the phases shown in Figure 8. Regarding the *agenda-setting* phase, where problems and needs are prioritized and the search begins for an innovation to satisfy the needs, Rogers notes that the catalyst to a search for an innovation can be either a “performance gap”—the difference between an organization’s expectations and actual performance—or a shock to the organization (p. 422). Indeed, the Minnesota studies (Van de Ven, Angle and Poole, 1989), regarded as the single most important collective effort focusing on innovation in the late 20th century, have documented a mass of data demonstrating the role crises play in moving organizations to adopt innovations (Hage, 1999).

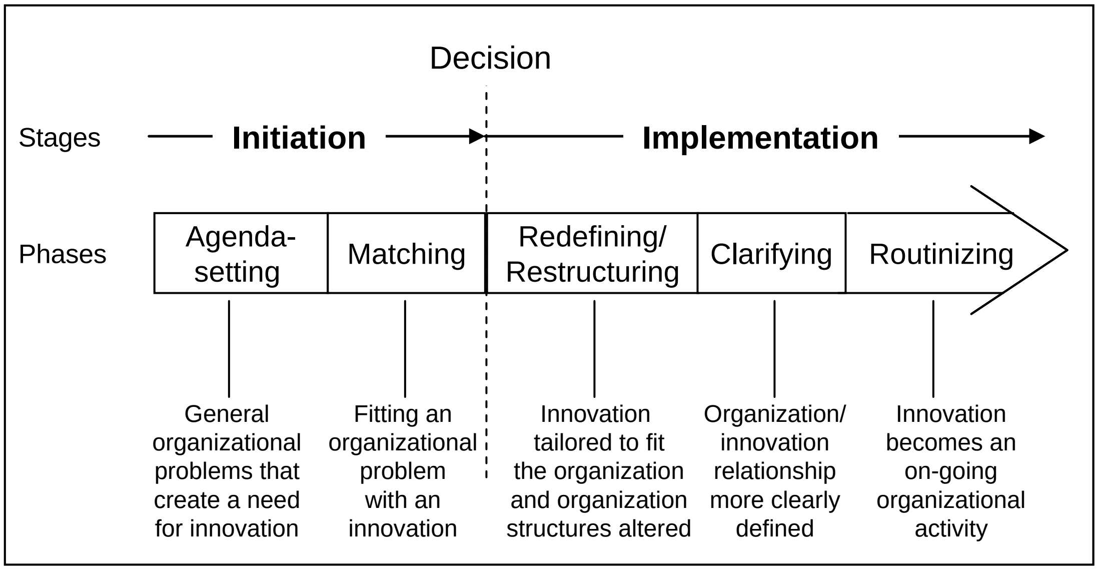

Figure 8. Representation of Rogers’ innovation process model (based on Rogers, 2003).[26]

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[26] To remain consistent with the taxonomy of the “ambidextrous theory of innovation”, Rogers’ use of the terms subprocesses and stages, has been replaced in the diagram (and as used in this study) by the terms stages and phases, respectively.

In the initiation stage of Rogers' innovation process model, besides recognizing a problem as part of *agenda-setting*, organizations search the environment for innovations to meet the problems. At the same time, Rogers agrees with the observation made over 20 years ago by March that innovations in organizations "often seem to be less driven by problems than by solutions" (March, p. 568, 1981). Rogers also paraphrases March's further comment that organizations face many problems, but possess knowledge of only a few innovations that offer solutions. As a result, the chance of identifying an innovation to cope with a particular problem is relatively small, but if one begins with a solution, there is a good chance that the innovation will match some problem faced by the organization (Rogers, p. 423, 2003).

The next two components of Rogers' model in Figure 8, *matching* and the *innovation decision,* are also useful in recognizing the need for some type of activity that permits the organization to conclude that a particular innovation has the potential to "match" the problem faced. The idea of a conscious decision to proceed to the implementation stage is important, as is understanding the forms this decision can take. As described by Rogers (2003), the types of innovation-decision that have emerged in innovation research are:

1. Optional innovation-decisions – choices to adopt or reject by an individual independent of other members of a system.
2. Collective innovation-decisions – choices to adopt or reject made by consensus among the members of a system.
3. Authority innovation-decisions – choices to adopt or reject that are made by a relatively few individuals in a system who possess power, status or technical expertise… [An] authority-innovation decision is one with which the organization's employees must comply.

Rogers indicates that at least one of these three types of decision will act as the separator between the initiation and implementation phases of the overall process, though a decision to proceed with an implementation should not be regarded as final. Regardless of the kind of decision to proceed, a *contingent innovation decision* can still be made at any one of the remaining phases to suspend or terminate the innovation.

Given a decision to go on to the implementation stage, the first phase—*redefining/restructuring*—is important because the innovation almost never fits the situation "exactly." According to Rogers, "redefining/restructuring occurs when the innovation is re-invented so as to accommodate the organization's needs and structure more closely" (p. 424, 2003). The *restructuring* part of the conjoined term relates to the organization itself, and recognizes that just as the innovation may require change to fit the problem, so also might the organization require modification to facilitate use of the innovation.

The *clarifying* and *routinizing* phases of the implementation stages of Rogers' model are quite straight forward in that *clarifying* amounts to further refinement and improved understanding of the innovation and *routinizing* occurs when the innovation becomes part of the "way of doing business" (Rogers, 2003).

Development of the Casey Hybrid Innovation Process (CHIP) Model

In the main, the description of the stages and phases of the Rogers' model seem valid and can be accepted as a point of departure. However, there are shortfalls in Rogers' model that require development of hybrid model for use in this research. One shortfall has to do with the very limited emphasis on the evaluation of the implementation, an unacceptable flaw in the environment of DOD acquisition programs. The other shortfalls are the implied orderliness of, and number of decisions in, the Rogers innovation process model.

The concern about evaluation arises because in an engineering-dominated, integration-focused organization such as LM Aero or in as technical a program as the F/A-22 and its far-flung web of defense industry suppliers, the major measure of value that could justify the new process is quantitative evidence, and the more the better.

As a result, rather than redefine one of the existing phases, *evaluation* is established as an additional phase of the implementation stage to recognize that evidence must be presented to gain support for continued and/or expanded use of the approach as well as to deal with the resistance to change. Figure 9, then, reflects the author's modification of the Rogers model that produces the Casey Hybrid Innovation Process (CHIP) model. The depiction includes the evaluation phase and emphasizes other aspects of the process for purposes of the dissertation.

As part of the evaluation stage of the CHIP model, two equally important and relative questions must be addressed. One of these questions is: "was the result better?" Response to this question requires establishment of a baseline that identifies what outcome the current, pre-innovation process did or would produce if applied to the same project. While generally quantifiable, this relative assessment of an innovation's

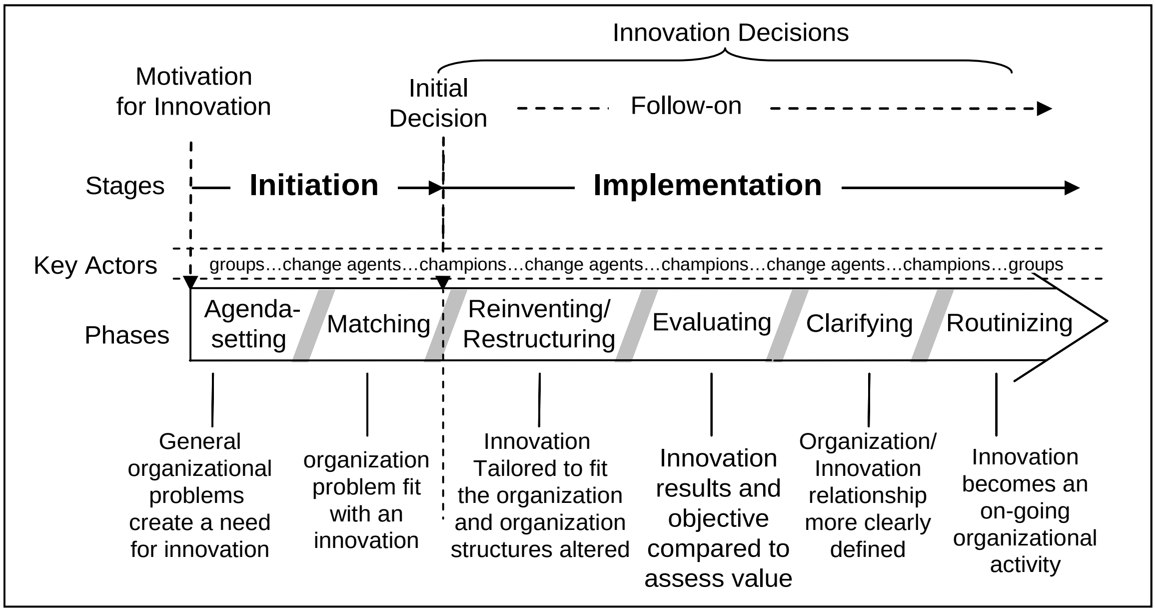

Figure 9. Casey Hybrid Innovation Process (CHIP) model (based on Rogers, 2003.)

“goodness” is made difficult because in both generic project and product development, there is a “moving baseline” associated with the inherent dynamics of the environment, as discussed further in Chapter 3, Study Limitations.

The other important relative question is “was the result driven solely or mostly by the innovation?” Response to this question may require qualitative judgments, because it is often difficult to assign exact quantitative values to the innovation and other factors that are changing in the dynamic process of weapon system development and test. Both questions must be answered by the evaluation phase as well as possible, despite the difficulties.

Results of the evaluation phase can prompt confirmation of the innovation decision for the organization where the innovation was first employed. In this case, the follow-on use of the innovation will likely prompt at least some measure of *clarifying* of the innovation before institutionalization in the *routinizing* phase within that organization or sub-organization; substantial reinvention *may* be required. On a broader scale, results of initial implementation *evaluation* can be the basis for authority or collective innovation-decisions to expand use of the innovation throughout the larger organization beyond the area of the first implementation. On the downside, if results of the evaluation phase are not compelling, they can be the basis for a contingent innovation decision to suspend or reject further use of the innovation for organizational unit in which the innovation was attempted or even reject use of the innovation the entire organization as a whole.

To avoid misconceptions about the orderliness of the innovation process, the depiction of CHIP model in Figure 9 shows other points of emphasis that differ from, or add emphasis to, elements of the Rogers model. The slanted separators between the stages are intended to show that the process is neither as neat nor are the phases as mutually exclusive and equal in length as shown in the Rogers model (Figure 8). In general, all or some part of each phase must be completed before the next phase commences, but rather than sharp lines of demarcation there can be blended or overlapped phases, periods of transition and even very abbreviated phases as well as iterations between and among the phases. In another somewhat subtle modification of the Rogers model, the first phase of the implementation stage is renamed *reinvention/ restructuring,* where *reinvention* is defined as “the degree to which an innovation is changed or modified in the process of its adoption or implementation” (Rogers, p. 180, 2003). The preference for *reinvention* is based on the clarity of the term[27] and to assert that for present purposes its meaning is restricted to changes in the innovation, which are considered more likely than *restructuring.*[28]

In addition, where the Rogers model implies a single decision with perhaps a follow-on contingency decision, the CHIP model depiction reflects the expectation of an initial innovation decision, followed by other follow-on decisions due to the organizational complexity of the multi-tier, multi-team structure of a major defense acquisition program.

The adoption of this process approach follows the advice of Hage (1999) who has published extensively on organizational innovation and change and noted that “in the context of innovation research, probably the most critical omission is the process approach” (p. 608). Beyond the F/A-22 program, adoption of the CHIP model as a framework for description and analysis is also intended to facilitate recommendations regarding expansion of CCPM applications within DOD to credibly plan and meet schedules for the acquisition of major weapon systems. The possibility of more general application of CCPM beyond the F/A-22 program, of course, depends heavily on the

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[27] In Rogers, “redefining” is not really given explicit meaning, though it is a subset, along with “restructuring,” of the reinvention of an innovation in an organizational setting.

[28] In the CHIP model, *restructuring,* at least as applied to the incremental innovation that is the focus of the present research, is expected to be relatively minor within the context of the complex, multi-company organizational structure of a DOD acquisition program. At the Operational level, IPTs implementing the innovation are required to comply with the well-established and difficult-to-change structure and reporting processes dominated by the rest of the organizations that are not involved with application of the innovation under study.

strength of the evidence produced by the data and analysis of the applications within the F/A-22 described in the remainder of the dissertation.

Key Actors in Innovation: Change Agents, Champions and Groups

As noted earlier, operating within and across the Program and Operational levels of the organization to influence and facilitate the activities associated with the innovation process are a set of *actors* that critically affect promulgation and application of an innovation. In this context, Ostrom's description of an *actor* as a single individual in an organization or a group within an organizational entity functioning as an organizational actor (in Sabatier, ed., p. 42, 1995) is useful. This global element of the organization innovation process is emphasized in the CHIP model and its Figure 9 depiction ("…groups…change agents…champions…"). Groups are very important in facilitating innovations by their support or in frustrating or delaying application of organizational innovations by withholding support. This is especially true in the presence of the complex F/A-22 organizational structure described in Chapter 3. However, the more frequent repetition in Figure 9 of the special terms for the roles of individual actors in the innovation process, "change agents" and "champions," serves to add more emphasis than is captured in Rogers' model (2003), and reflects the dominance of individual actors over groups in the research.

Rogers viewed the emergence of individual "champions" of organizational innovation at some point in the overall process as both predictable and important:

> The champion is a charismatic individual who throws his/her weight behind the innovation, thus overcoming the indifference or resistance that the new idea may provoke…*The presence of an innovation champion contributes to the success of an innovation in an organization.* Schon (p. 84, 1963) stated "The new idea either finds a champion or dies" (Rogers, p. 414, 2003).

There is also evidence of Schon's observation cited by Rogers (2003), that where CCPM falters, the absence of a champion or the presence of the opposite of the champion is likely to be part of the explanation. Rogers points out that "anti-champions" (that is, opponents) can prevent a new technology from reaching the routinization phase of the innovation process" (p. 414). A corollary to Schon's observation might be: The new idea can die at the hands of a determined anti-champion.

As to characteristics, Howell and Higgins (1990) conducted an extensive literature review on innovations and champions and reported that champions frequently inspire others with their vision and, despite strong opposition, persist in promoting the vision "to a degree that goes far beyond the requirements of their job" (Schon, 1963, p 84). The literature review also found champions described as risk takers, socially independent, politically astute, and inclined to display persistence and dedication despite frequent obstacles and imminent failures (Schon, 1963).[29]

Rogers (2003) also highlighted the important role of the "change agent," defined as "an individual who influences client's innovation-decisions in a direction deemed desirable" (p. 366). Rogers emphasized that the change agent provides a communication link, facilitating the flow of information about the innovation from a change agency to an audience of clients (p. 368), and the change agent role varies from helping to develop a need for change in the beginning of the process to, finally, achieving a "termination relationship"— developing a self-reliant capability in the client organization and essentially putting him/herself out of business.

Within the CHIP model for very complex acquisition program organizations, both individual actor roles are important throughout the innovation process and it is important to understand the distinction between "champions" and "change agents." The

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[29] Both references to Schon are quoted by Howell and Higgins (1990).

"champion" is a strong supporter, encourager, programmatic facilitator,[30] occasional director and strong believer in the concepts, products and pay-off of the innovation. In general, the "champion" is concerned with the strategic direction of the organization, focuses mainly with "big picture" organizational goals and outcomes, and does not get involved in the details and mechanics of the innovation.

The "change agent," on the other hand, is very definitely and fairly deeply involved in the innovation from advocacy to initiation to implementation. In the CHIP model, the "change agent" does what Rogers describes and more. As the advocate and facilitator, the change agent is regarded as the innovation expert by the "Program" and "Operational" level team members. As such, it is important that the change agent be conversant with details and mechanics of the innovation methodology and even able to demonstrate and use the facilitating software. The change agent is expected to assist understanding and support trouble-shooting when initiation or implementation seems to be going awry to the point that the innovation is at risk of rejection.

As noted earlier, the foregoing discussion of key *actor's* roles was delayed until after description of the CHIP model to permit better understanding of the unique nature of "champions" and "change agents" in the organizational innovation setting. With that purpose having been served, it should be understood that because of their integral connection, *structural levels and actors* will be "re-connected" in the same subsection of case studies analysis. In that context, it is important to understand that groups, change agents and champions are not necessarily isolated to either Program or Operational levels of the acquisition program organization; in the case of individual actors, they may operate in more than one role as well as at more than one level depending on the situation, as was true for the author.

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[30] "Programmatic facilitator" is intended to convey the fact that the CHIP model innovation champion will assist in assisting with acquisition Program-level issues, e.g., funding, contractural interpretations that removes potential roadblocks or employs contract mechanisms to permit use of the innovation.

Summary

This chapter reinforces in detail the problem of increasing weapon system development spans introduced in Chapter One. First, the chapter detailed the limited attention to ways of dealing with the problem of acquisition program schedule planning and management that is reflected in the paucity of journal articles and documented in a comprehensive dissertation devoted to the subject. The chapter then described the traditional and dominant approach to schedule management, the combination of the Critical Path Method and Earned Value Management, the limited success of which prompts the need for an innovative approach to the problem. As the candidate approach addressed by the dissertation, the origins of, and both adversary and advocate perspectives on, the Critical Chain Project Management process was described, as well as evidence that CCPM legitimately qualifies as an innovation.

The organizational innovation literature was then reviewed, with particular attention to constructs related to *type* and *impact* of an innovation, the *structural level and actors* involved in an organization’s adoption of an innovation and, finally, the *innovation process* of applying an innovation in an organization. The CCPM innovation was clearly identified as a process *type* innovation, and expected to be applied with “incremental” *impact* on the organization, consistent with the “theory of innovation radicalness.” As to *structural level*¸ the terms “Program” and “Operational” were terms adopted to suitably distinguish between the structural levels involved in, as well as to facilitate analysis of, the innovation process for the huge, complex acquisition program that the F/A-22 organization represents.

As to the primary research focus on the *innovation process* of applying the CCPM innovation, Rogers' elaboration of the “ambidextrous theory of innovation” became the most appealing source of a framework for describing and analyzing the multiple case studies of this dissertation. For purposes of the dissertation, the Casey

Hybrid Innovation Process (CHIP) model that incorporates and expands Rogers work was created to establish expectations for the innovation process as well as to facilitate analysis and description of the process of organizational innovation in each case study.

At the bottom line is that the DOD weapons system development time spans have continued to expand in the face of numerous claims that they can be reduced and numerous reform efforts to achieve the reductions. The limited emphasis on the importance of schedules that underlie these increasing development spans creates an obvious gap as well as an opportunity for development of empirical research on methods to better manage schedules.

The research described and analyzed in this dissertation specifically addresses the gap in the literature on the documentation and understanding of better methods to manage major weapon system development schedules. Results of this research on the ability of CCPM to support on-time achievement of F/A-22 program goals or delivery of F/A-22 products on time within budget respond directly to recommendations from several sources (Pittman, 1994; Walker, 1998; McNutt, 1998). Furthermore, results of the research will contribute to the stream of organizational innovation literature and address implications for the focus and methodological approaches of future research. Substantively, success in these applications could lead to DOD policies encouraging or mandating wider application in other acquisition programs to turn the corner on the path towards the long-called-for reduction in acquisition cycle times.

Now, having described the organizational innovation constructs that will be the basis for analysis, Chapter 3 lays the methodological ground work and describes the CCPM innovation in detail to permit detailed description and analysis at individual and multiple case levels.

Chapter 3: RESEARCH DESIGN and METHODOLOGY

Overview

This chapter frames, integrates and provides the foundation for the remainder of the dissertation. Initially, the overall methodology, adapted from Yin (1994, 2003), is described. In addition, the exploratory nature of the research is described as well as the constraints on the ability to provide explicit comparative analysis between the CCPM approach and more traditional approaches to schedule planning and management. Then the chapter addresses two elements that establish the foundation for the case studies, namely the F/A-22 organization and the details of the CCPM innovation.

The F/A-22 organization is a central part of the environment within which the F/A-22 program is executed and the F-22 program context within which efforts to apply and evaluate the CCPM innovation are carried out. Various organizations and individuals within the organization operate to sometimes support and sometimes limit the initial and follow-on CCPM innovations.

In a detailed introduction, the CCPM innovation is described in terms of its theoretical and philosophical foundation and key elements of the methodology. This discussion is somewhat dense, but important to understand so the actions taken as part of CCPM initiation and implementation make sense in the context of the case studies described in follow-on chapters.

The last part of the chapter describes the organization of information that is common to the case study chapters, Chapters 4 through 8, which leads to chapters that analyze the multi-case study information (Chapter 9) and present recommendations and other findings (Chapter 10).

Case Study Research Model, Protocols and Study Limitations

Case Study Research Model

As outlined in the preceding chapter, this research effort extends the Theory of Constraints' and its Critical Chain Project Management (TOC/CCPM) concepts of planning, scheduling, buffering and project control to the environment of DOD major weapon system development. The study goes beyond the single- and multiple-project applications of TOC/CCPM by Pittman (1994) and Walker (1998), respectively, that used simulation of illustrative networks as the evaluation tool.

At a top level, the research design as a multiple-case study was adapted from Yin and illustrated in Figure 10. The initial choice of the case study approach was based on the conviction that the context for the application of CCPM on the F/A-22 program is different than that encountered in other contexts—even other military programs that are non-acquisition in nature (e.g., the Marine Corp Maintenance Center example described in Chapter 2). Within the overall case study realm, the choice to document the multiple applications of the CCPM innovation in this study vice just a single case study was made

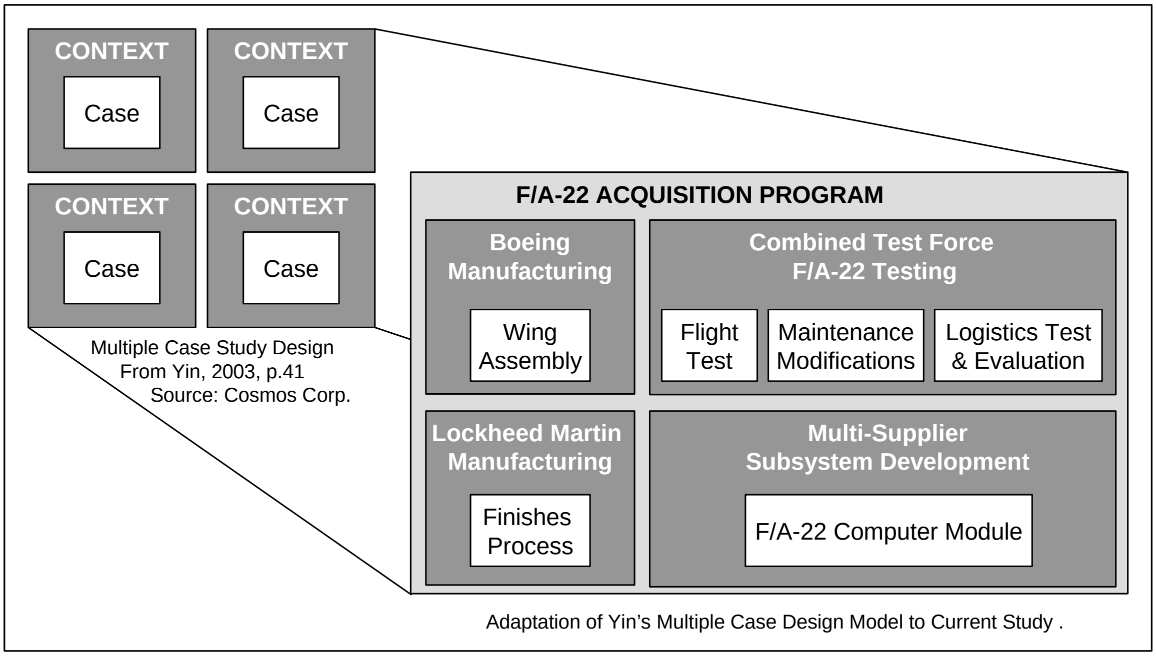

Figure 10. Basic research model (based on Yin 1994, 2nd ed. and 2003, 3rd ed.).

principally because the work activity and contexts within the F/A-22 program where CCPM was applied differ in the fundamental ways described in Chapter 1.

Besides the work activity and contextual differences, another reason for a multiple-case study is that noted in Yin (2003), quoting Herriott and Firestone (1983): "The evidence from multiple cases is often considered more compelling, and the overall study is therefore regarded as more robust." In the current study, the expectation of success across the various case studies has the potential to provide a preponderance of evidence that CCPM could provide value-added schedule management assistance in many other areas of the complex and expansive F/A-22 acquisition program.

Given the choice of a multiple-case study strategy, the methodology for carrying out the research effort is also adapted directly from Yin, as shown in Figure 11. Of major significance is the fundamental expression of theory that is evaluated in the research project, that application of the CCPM innovation improves schedule planning and execution in the F/A-22 program over past practices. In this model, of almost equal importance to the theory being evaluated is the feedback loop, indicated by the dotted line in Figure 11. Yin (2003) notes:

> The loop represents the situation in which important discovery occurs during the conduct of one of the individual cases…[and] redesign should take place before proceeding further. Such redesign might involve the selection of alternate cases or changes in the case study (i.e., data collection) protocol. Without such redesign, you risk being accused of distorting or ignoring the discovery (p. 51).

As will become clear in the reports of the case studies themselves, use of this inherent methodological flexibility was very important. To emphasize that point, the box in the Yin's generic methodology called "design data collection protocol" has been expanded to "design implementation & data collection protocol", since there were evolutionary developments in the implementation process over the span of the case studies. In fact,

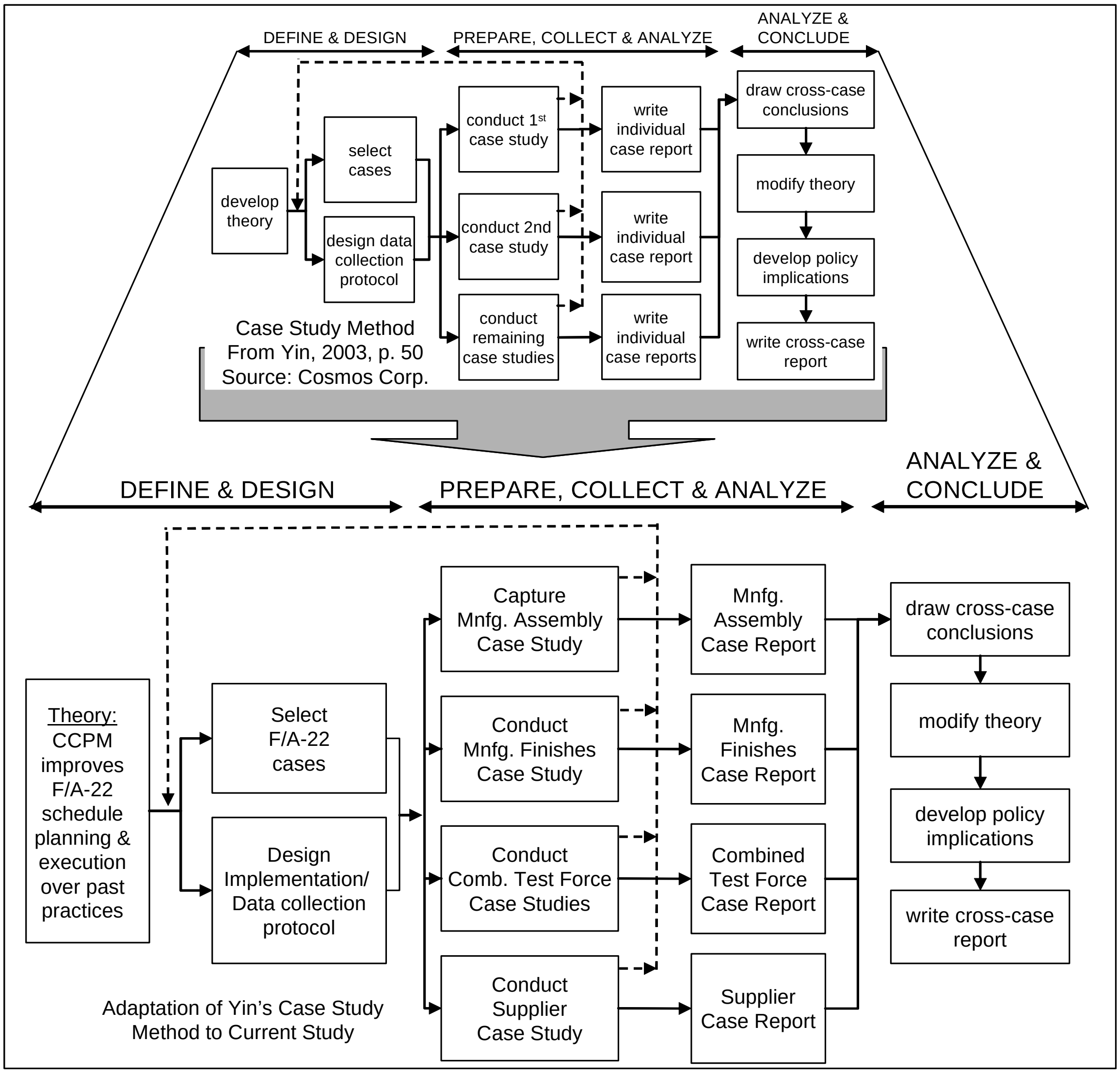

Figure 11. Multiple-case study methodology (based on Yin, 1994, 2nd ed. & 2003, 3rd ed.).

another demonstration of the inherent flexibility of the methodology is the inclusion of the supplier case study itself, prompted by the unexpected opportunity, encouraged by F/A-22 Program-level management, to evaluate CCPM in the centrally important area of supplier component development.

Within this model, the dissertation will employ an exploratory research methodology to evaluate the relatively new CCPM innovation in the complex, real-world environment within which the F/A-22 is being developed. The choice of the exploratory research is deemed suitable, given that the data set that is available or developed in the case studies—individually and as a group—is relatively small (Flynn et al, 1990; McCutcheon and Meredith, 1993; Meredith et al., 1989), and that is particularly true for DOD acquisition programs. Regarding CCPM specifically, though the Critical Chain is in the relatively early stages of implementation across projects compared to methods in use for decades, there is a growing body of case studies outside of DOD. Even so, while effective in other commercial and public settings, since CCPM has not been applied directly in the EMD and transition to production phases of a major defense acquisition program as large and complex as the F/A-22 program, applying and documenting application of CCPM there adds an important dimension to the body of CCPM case study evidence.

Within the framework of this program, the unit of analysis for this research project is the Integrated Product Team (IPT), essentially the implementation group at the Operational level in each case study, e.g., Manufacturing Assembly, CTF/Maintenance Modifications, etc. There are two primary reasons for this decision. First, the one point that has become apparent to the author in over 12 years as a member of the F/A-22 team is that every Integrated Product Team is absolutely convinced that the challenge to build the product for which they are responsible is in many ways unique compared to virtually every other IPT. Second, related to the first, is that even solid success produced by CCPM in one area cannot automatically assumed to be a predictor of success in another area, even though both are part of the same F/A-22 program. As a result, the IPT, essentially, the implementation group is the level to which observations, conclusions, and recommendations will be related in the individual chapters of this study. Only in the cross-case analysis is it expected that broader observations may be made, based on the preponderance of supporting evidence from the different cases.

Case Study Protocols: Implementation, Data Collection, Quality

Implementation

The implementation protocol for the case studies was designed to be essentially the same for each case study in terms of procedural steps and sequence (described in the section “General Description of the CCPM innovation methodology” later in this chapter). However, it was known at the outset that one of the objectives of the overall evaluation of CCPM was for the F/A-22 to become self-sufficient with respect to implementations. That is, based on the (optimistic) assumption that CCPM would prove its worth, F/A-22 management wanted the capability to initiate expanded application of the CCPM innovation in other areas of the program without having to depend on the technical support of consultants contracted to assist in the initial applications. Essentially, the initial CCPM implementations led by a technical services contractor in the manufacturing finishes, CTF/Flight Test and CTF/Maintenance Modification case studies were designed as “train-the-trainer” efforts. During the CCPM implementations in those areas, the two Lockheed Martin change team members, Casey and Colby, followed the implementations closely and, with additional training, were permitted to conduct the implementation in the Supplier area largely on their own.

As noted above, the other important aspect of the implementation protocol was the flexibility to modify in the depth and timing of the implementation procedures (while still retaining the sequence of procedural steps). This flexibility was specifically employed during the application of the CCPM innovation in the Supplier case study because of findings in the Manufacturing Finishes and CTF case studies.

Data Collection

Table 1 below reflects the plan for data collection using a format adapted from Yin. Because of the author’s role as participant observer in all the case studies, the

Source of Evidence	Strengths	Weaknesses	Case Study Use*						Efforts to Mitigate Weaknesses
			1	2	3	4	5	6	
Documentation	- stable, repeatedly reviewable - unobtrusive - exact details of event - broad coverage	- retrieveability can be problematic - selectivity biased if collection is incomplete - reporting bias of author - access problematic	☑	☑	☑	☑	☑	☑	Plan for document use involved unbiased output of the computer software used to create plans or to record progress of project to management, thereby offsetting "selectivity" and "reporting" biases
Archival records	- (same as above) - precise & quantitative	- (same as above) - access problematic	☑	☑	☑	☑	☑	☑	Primary source is official record of processes before CCPM (where available)
Discussions (Includes structured surveys w/ open-ended questions)	- targeted to case study topic - insightful--provides perceived causes	- bias due to poor questions - response bias - errors w/ poor recall - reflexivity--participants tells what discussion leader wants to hear	☑	☑		☑		☑	Discussions carefully constructed to be neutral; response is focused on key personnel; Mnfg Assembly surveys subject to recall bias--all others planned in close proximity to case study conducted; reflexivity mitigated by candor of engineers
Direct Observations	- reality--covers events in real time - contextual--covers context of event	- time-consuming - selectivity unless broad coverage - reflexivity--event flow affected by observation - costly (due to human observation hours)		☑	☑	☑	☑	☑	Time and cost absorbed in that tracking & observing cases was primary job of PO (author); broad coverage due to PO involvement in all cases; reflexivity mitigated by intensity of venue participant dedication to mission (vs. CCPM) & data reflecting results;
Participant Observation (PO)	- insightful into interpersonal behavior & motives	- bias due to event manipulation by investigator							PO bias due to role as advocate for CCPM mitigated because players in each venue only interested in "real results" not what PO thought or said
Physical Artifacts	- insightful into cultural features - insightful into technical operations	- selectivity - availability	☑	☑	☑	☑	☑	☑	See "Documentation" above
* Note: Numbers represent the chronological order of case studies:1 = Mnfg Assembly; 2 = Mnfg Finishes; 3 = CTF-Flight Test; 4 = CTF Maintenance Mod; 5 = CTF Logistics Test & Eval; 6 = Supplier Development									

Table 1. Plan for data collection from multiple sources (based on Yin, 1994).

normally separate categories of “Direct Observation” and “Participant Observation” have been included as one partially separated row. The numbered columns relate directly to the plan for data collection in each of the case study and the last column identifies efforts to mitigate the weaknesses in the data collection method noted by Yin.

The opportunity to use discussions and surveys as part of the data collection was limited and opportunistic because they were conducted within the normal work hours of the participants.   Both the use and form of discussions and surveys varied with the application and had dual purposes that ran parallel in the case studies: first and foremost to satisfy the F/A-22 team interest in the effectiveness of CCPM, and second to support the purposes of dissertation research. For clarity, this dual purpose was made known to the individuals who participated in discussions or surveys and participants were also told that they would only be identified with a position (e.g., IPT leader, engineer, scheduler). The primary purpose and the fact that participation in discussions or surveys was part of the normal work necessarily led to an emphasis on “how does it work/not work” rather than “why does it work/not work” questions.

Regarding the small group of discussion and survey respondents, 20 in all, their selection was based on a single criterion. In every case, the respondents were selected (or offered the opportunity to respond to the survey) because they were intimately involved in the use of the CCPM methodology, either as managers, planners, technical leaders, schedulers/trackers or users.[31] This was done because the interest was specifically focused on the CCPM process, so some knowledge and experience with the use of the CCPM process was essential. At the same time, since there were both team and research interests, a number of the “how” questions were asked to gain insight into the user’s view of the CCPM process versus other schedule planning and execution processes employed in the past.

As to the potential for non-response bias, it is considered relatively small. The only key person not involved in discussions of the case study in Finishes at Marietta was

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[31] This use of a small group targeted because of their knowledge and experience in a particular process is not unusual. See for example Pell and Adler (1994), who interviewed 15 members of 5 teams in 4 companies to draw numerous conclusion about intergroup conflict in multifunctional product teams.

one of the supervisors in. However, two other supervisors were in discussions and are considered representative. Regarding the survey of key personnel in the case study of supplier CIP-2K computer module development, half of the 20 personnel to which the survey was sent did not respond. The 10 that did respond had a mix of responsibilities (manager, technical lead, or scheduler) and sources (prime contractor or supplier) nearly identical to the total group polled. Though small in number, the respondent group was large enough to satisfy the purposes of the survey, i.e., to get a sense for different perspectives on the CCPM innovation from the geographically dispersed group working on the CIP-2K module.

Structured discussions lasting 30-45 minutes, led and documented in notes by Casey and Colby, were only used in the CCPM applications in the Finishes IPT area at Marietta.[32] The notes were combined in an electronic copy of the discussion form and provided to the participants for comment and corrections. Changes were made based on these corrections and the discussion results finalized and archived. For purposes of analysis, all discussion comments and observations were combined on a spreadsheet and qualitatively assessed for similarities and differences. Results were then summarized, combined with quantitative results and presented in briefing format to the participants and, subsequently, to management, as a way to provide insight on the performance and perceptions of the CCPM innovation in the Finishes IPT.

Surveys were conducted with a small group of key personnel involved in the CCPM application at Boeing and a larger group in the supplier development of the F/A-22 CIP-2K computer module. These were structured in spreadsheet form, addressing, for the most part the same “how” questions that had been emphasized in the Finishes

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[32] The Boeing application in assembly operations was essentially complete and by the time surveys were provided, only three replies were received. As a result, information derived was used very carefully. Because of the intensity of operations at the Combined Test Force, Edwards AFB, CA, neither interviews nor surveys were used. Because of the geographic dispersion of the application associated supplier development of the F/A-22 CIP-2K computer module, surveys were used.

application discussions. The mode of correspondence was between the author and respondents via electronic mail. When results were received, all answers were combined in a master spreadsheet and analyzed for similarities and differences. Results of this process were summarized and presented to working group and management meetings and to provide insight on performance and perceptions of the CCPM innovation. Samples of both discussion and survey forms are included at Appendix B

Quality

The three indicators of the quality of empirical social research are construct validity; external validity; and reliability. All are addressed in the study using the techniques suggested by Yin (1994, 2003).

Yin identifies two steps required to meet the test of *construct validity*: (1) select the specific types of changes that are to be studied related to the objectives of the study and (2) demonstrate that the selected measures do indeed reflect the types of change that have been selected (Yin, 2003, p.35).

In response to the first step, recall that the objective of the study is to evaluate the impact on schedule planning and execution produced by the use Critical Chain Project Management within the context of the F/A-22 weapon system acquisition program. Given that objective, the following are the specific types of changes and that are to be studied and the selected measures:

- *Change 1:* Demonstrated on-time achievement of CCPM schedules. *Measure:* Difference between planned and actual schedule commitment to specific objectives.
- *Change 2:* Improved ability over past practices to anticipate and mitigate difficulties in schedule execution. *Measure:* Variable (direct contextual comparison; when possible, discussion/survey responses to specific questions on the issue).

- *Change 3:* Improvement in schedule performance over past practices. *Measure:* Direct comparison (where comparable data for similar project in the past exists).

In each case, multiple sources of data will be used and, where possible, key informants will be used to review drafts of analysis, conclusions, and recommendations.

Regarding *external validity*, the generalizability of study findings beyond the immediate case study, Yin points out that reliance in case study research is analytic generalization, that is, the effort is “to generalize a particular set of results to some broader theory” (Yin, 2003, p. 37). Essentially, while this can be a very serious problem with single case studies, it is already mitigated by the multiple-case design of this study. The extent to which it is mitigated, however, depends on the extent to which replication of the study methodology and results are consistent across the studies. As noted earlier, the adjustments in implementation protocol suggest what is true across the studies. That is, the context of each study is different enough that some tailoring of the implementations process was necessary. Even so, as planned, replication is preserved in the execution of the case studies to maximize external validity.

Finally, *reliability*—elimination of errors and biases in a study—is a key concern of empirical research in general and in this research project in particular. Susceptibility to investigator bias is the most intense concern and discussed in a separate section below. Importantly, the defendable objectivity of hard evidence helps to limit the impact of any bias on whether or not CCPM did, in fact, improve schedule planning and, particularly, schedule execution in the areas of application. More problematic is the “how” or “why” research questions regarding the potential explanation of success or failure with CCPM. To get at those questions, discussions or structured surveys involving key personnel are the basis for conclusions where use of those tools was feasible. In the end, of course, it is the responsibility of the researcher to analyze the data and draw as well as defend conclusions and recommendations.

Study Limitations

Of fundamental importance in the expression of the constructs driving this study are the words “improved…over past practices.” These words naturally prompt interest in "past practices" to collect data that provides a qualitative and, where possible, quantitative basis for comparative analysis. As noted in Chapter 2, the more sophisticated of these traditional approaches is the Critical Path Method. CPM is the algorithmic engine that drives many commercial project management software products, perhaps the most popular and ubiquitous of which is Microsoft Project™ (or MS-Project™). However, experience in the F/A-22 program areas where CCPM case studies were conducted has shown that a combination of Gantt/Milestone charts and Critical Path Method (CPM) had been used, but had not consistently produced plans, schedules and execution success that supported the needs of the overall program.

While the absence of success or, in some cases, outright failure, in the use of traditional methods prompted interest in, and use of, the CCPM innovation, identifying and documenting the kinds and extent of good or bad changes associated with a new process applied in the development environment is problematic. That is because such efforts must deal the limitations imposed by the very nature of the development process. As a weapon system acquisition program like the F/A-22 evolves during the EMD phase, things change with each successive aircraft, consistent with the mandate that both design and processes mature with each successive test article. In the Engineering and Manufacturing Development phase of the F/A-22 acquisition program, nine flying and two ground test vehicles were produced, but the products—the parts subsystems, systems and major components—are not all identical in sequential aircraft. In various ways, processes, parts, materials, protective coatings and specialized finishes, even some shapes change as knowledge and experience continually improves and matures the products and processes to most effectively produce the F/A-22 Raptor.

Because of those changes and the high perishability[33] of information that permits before and after analysis, it is difficult to generate a true “apples-to-apples” comparison of the impact of schedule management systems. Said another way, it would be ideal to have a project completely planned and executed using Gantt charts, CPM, or other methods and a nearly identical project completely planned and executed using Critical Chain, but those situations were rare. Where these more explicit comparisons cannot be made, less precise relative comparisons of the “before and after CCPM” are made using the best data available.

One further constraint on analysis is the inability to assure unequivocal isolation of the impact of CCPM on schedule performance in the areas addressed. This is because there are many factors at work that could conceivably explain any change in performance or, at least, confound or reduce the clarity of any evidence presented. As will be shown in the assembly area at Boeing, CCPM was one of several improvements consciously activated simultaneously. In the finishes area at Marietta, the work force was becoming more proficient with the materials and processes associated with stealth coatings than with the first airplanes. Thus, in virtually all of the applications of CCPM, there was the effect of what Rogers (2003) called a *technology cluster—“*one or more distinguishable elements of technology that are perceived as closely interrelated” (p. 14). To meet the interpretive challenges associated with this effect, the approach to somehow deduce the separate influence of CCPM on schedule performance is to use multiple indicators to the maximum extent possible.

Participant-Observer-Change Agent-Champion (POCAC)

Finally, though noted above regarding *reliability*, the author was not only participant-observer, but change agent and champion (POCAC) for use of the CCPM

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[33] Because of schedule volatility forced by the dynamic development environment, the author found that schedules detailed enough to permit comparison with CCPM were either non-existent or could only be obtained from the electronic archives of an individual who had saved them for personal reasons.

innovations. This makes author bias potentially the most significant study limitation on the credibility of the results and therefore deserving of treatment in this separate section. As a result it is important to defend that posture and note efforts to mitigate the effects.

Before discussing the negative aspects of the role, it is important to emphasize the most frequently sighted value of being an “insider” in the conduct of research. As reported by Labaree (2002), “Merton (1972) defined the insider-outsider position as an epistemological principle centered on the issue of access” (p. 100),[34] where it is assumed that intimate knowledge from the “inside” generates insights that an “outsider” would find difficult or impossible to access. Because of direct involvement in activities that crossed the spectrum of challenges and locations in the F/A-22 program for eight years before becoming involved with CCPM, that assumption of access is valid in the case of the author. However, there is a caveat to “insiderness” noted by Labaree (2002), namely that the researcher’s place on the continuum where insiderness and outsiderness reside is circumscribed by the relationship between the observer and the phenomena being observed. In the case of the authors various roles, this observation is quite important. The extent to which I was an “insider” to the team and environment where CCPM was applied, at least at during the initiation stage, is debatable. As noted earlier and in the organizational description that follows, virtually every IPT on the F/A-22 program considered itself the bastion of expertise in its area of responsibility at the Operational level as described in Chapter 2. As a result anyone, including the author, not officially assigned to that IPT was something of an “outsider”. Though it is fair to say that my status came closer to “insiderness” as the innovation process proceeded toward the common goal of improved schedule performance, it never transitioned to absolute “insider.” Even with that caveat, however, I was, without question “inside” the F/A-22

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[34] Though evolving from and focusing on the discipline of ethnography, the broad and comprehensive coverage in Labaree’s article “*The risk of ‘going observationalist’: negotiating the hidden dilemmas of being an insider participant observer”* was a very valuable source of insight on participant observer issues.

team with insight on the culture of the F/A-22 program and an understanding of contractor and government operations that an outsider could not easily or, perhaps, ever access. As or more importantly, that "pure insider" role at the Program level with the opportunity to influence the Operational-level IPT areas of CCPM application was essential to the representativeness and breadth of the aggregate multiple case-study.

Even with those benefits, however, the potential down-side in terms of study reliability must be addressed. One aspect having to do with the "front-end" gathering of data for the descriptive portion of the case studies was addressed in Table 2. There it was pointed out from a "source of evidence" perspective that the strength of the participant observer stance is that it provides "insight into interpersonal behavior and motives" and the weakness is that there can be "bias due to investigator's manipulation of events."[35] These "normal problems" become more intense because of the addition of the almost overshadowing change-agent/champion roles that the author was also playing. It was apparent to all key personnel in all applications of the CCPM innovation that the author was a representative of management and expected—as managements' "man on the scene" and, as such, an "outsider"—to assist evaluation of a solution to a problem that was perceived in the implementing IPT's performance. In that light, depending on the individual in the IPT, though behaviors could be "observed", motives might be kept hidden from the author-as-observer out of concern that negative motives (or perceptions) on the part of the IPT member might be inimical to the implementing IPT's interests (Larabee, 2002). Similarly, the weakness might be even more exacerbated. As Babbie (1992), the author *The Practice of Social Research* (6th ed.), noted regarding the participant-observer:

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[35] For innovations, the potential for participant observer bias is compounded by what has been called pro-innovation bias. Rogers notes that "one of the most serious shortcomings of [innovation] research is it's pro-innovation bias…that an innovation should be…adopted by all…more rapidly…[without] reinvention or rejection" (p. 106, 2003).

> Ultimately, *anything* the participant does or does not do will have some effect on what is observed; it is simply inevitable. More seriously, what you do may have an important effect on what happens (p. 289).

Quite clearly, as change-agent and, in some cases, supervisor driving the adoption of the CCPM innovation, the author's actions fall into the "important effect" category.

On the "back-end" of the case study where the descriptive data is analyzed, the strengths and weaknesses can be characterized in similar language to the data gathering phase. The participant observer strength would be that "analysis can focus on the issues most important to the organization" as it tries to understand results, decide whether to reject or expand use of the innovation and, in the latter case, to improve the innovation process. The weakness would be "interpretive bias due to the investigator's manipulation of data." As in the case of the descriptive phase, these factors are affected by the several POCAC roles. Reducing the strength *could* be the attention to issues that enhance the perception of positive performance in the use of the innovation for which the participant observer is the leading advocate. Similarly, intensifying the weakness is that the tendency toward a positive interpretive bias is, perhaps, more likely so that the benefits of the innovation are highlighted and the weaknesses are given less visibility, "soft-pedaled" in the vernacular of the salesman.

One other problem frequently noted in the literature on the participant observer role is that of ethics, which can take various forms, but in the current study is primarily related to positioning and disclosure. The positioning and disclosure relates to the need to establish one's position as "insider" researcher. While there are some situations when deceit regarding one's true objectives of association can be justified (e.g., more reliable and valid data if the subjects are not aware of the research objectives) (Babbie, 1992), the predominant advice is to declare the role of "insider" researcher upon entry into the environment where the research will be conducted (Labaree, 2002).

Addressing the ethical issue first, I made no secret of the dual objectives of the study with the members of the organizations where the CCPM innovation was applied. At the same time I made it clear that the official team purpose of evaluating CCPM in various applications and my purposes in using the opportunity to conduct research were essentially the same, though perhaps on different levels. The team purpose was to find a better way to plan and manage schedules on the F/A-22 programs; the purpose in my research was to use the same information as the basis for suggestions on DOD policy on better ways to plan and manage schedules on weapon system development programs in general, as well as to contribute to the organizational innovation literature.

The remedies useful in protecting the reliability and validity of the data from any source, including participant observer, were applied to the maximum extent feasible. Multiple sources of evidence were used in every application of CCPM and, where possible, the principle of data triangulation was used (Yin, 2002). Where multiple sources of data are limited regarding performance, the validity of the raw data output of the software supporting the critical chain process is quite unequivocal and therefore quite reliable and valid in and of itself. A second principle is creation of a case study database (Yin, 2002). This was done during the case studies and included notes and memoranda for record, the archiving of the daily or weekly reports on the progress of the implementation, the retention of the completed discussion and survey forms, and the construction of detailed narrative chronologies of each of the case studies. The final principle is to maintain a chain of evidence. For this study, following this principle was primarily embedded in the electronic retention of the data base and the translation of that data into the graphical displays provided in each case study.

Regarding the avoidance of investigator bias in the conduct of the analysis, the primary approach was to use multiple sources to measure success (e.g., comparison with results of the same process before and after CCPM was available, comparison of results with objectives established at the outset of the implementation phase, etc.). In addition, the analysis used “explanation” building (Yin, 2002), that is, the study attempts to identify other explanations for the results that might not be due to the impact of the innovation. As pointed out earlier (in Study Limitations), this is difficult to do in a development program where several changes may impact the result, but the attempt is made in any case.

As a final point, there are two factors that regulate the author’s authority and, therefore, the vulnerability to bias. The first is self-regulation. The drive toward objectivity is enhanced by the author’s grounding in studies and analysis roles. Some 9 years (out of 24 years) of active duty as an Air Force officer involved assigned roles as a lead analyst in Air Force Studies and Analysis and as Director of the Air Force Center for Personnel Analysis. The specific tasking was to “shed light” on controversial issues with rigorous objectivity, under pain of severe chastisement for “cooking the books.” The same kind of discipline established in the Service was further hardened in the over 14 years of experience as principle investigator on government funded studies and in a variety of roles in the system engineering discipline of the F/A-22 program. The other regulating factor is the fierce independence and objectivity of the IPTs responsible for the areas where CCPM was applied. Dominated by pride in their professional integrity as engineers or highly specialized technicians and harboring a healthy skepticism about any processes suggested from outside the IPT, the possibility of reaching an invalid conclusion by manipulating events or data is made highly improbable. In this particular instance, where there is a chance that anyone—participant observer, change agent or champion—might claim things about the IPT’s own situation that are not reliable or valid, the IPT members, from technician to leader and everyone in between, will very vocally reject the claims in an IPT structure where access to IPT or Program leadership is only a phone call away. That kind of access is immediately available and would be used to correct any misrepresentations the author might make in any of the POCAC roles in spite of the complexities of the organization described in the following section.

Organizational Environment

Geographical Arrangement of Key Organizational Actors

As host to the applications of the CCPM innovation, the F/A-22 program is a complex structure—organizationally diverse and geographically extended. Figure12 reflects the two lines of authority or direction that affect team management. One comes from the government, led by the F/A-22 System Program Office (SPO) at Wright Patterson AFB, Dayton, OH. Other direction originates from the contractor F/A-22 Team Program Office (TPO) located in Fort Worth, TX, headquarters for LM Aero.

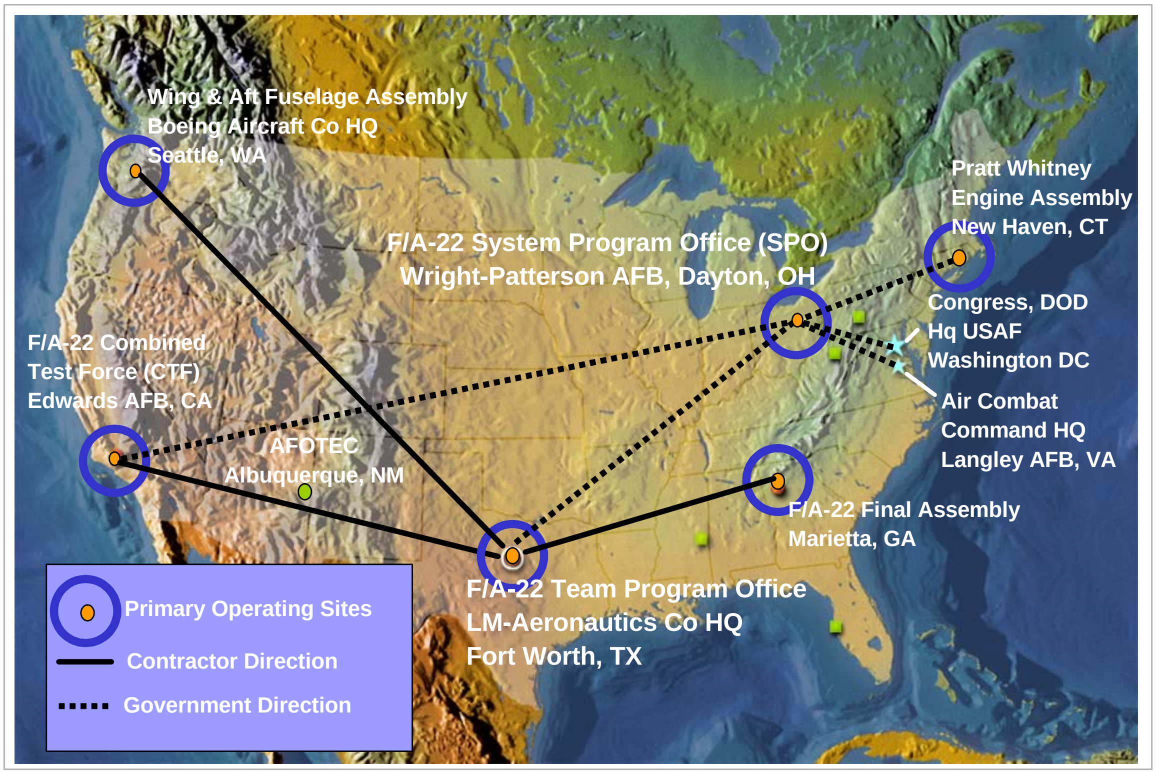

Figure 12. F/A-22 Program hierarchy and primary operating locations.

In the Air Force, the SPO for a major weapon system development program like the F/A-22 is responsible for overseeing development of the system that meets the operational requirement established by the Air Force command that will “own” and employ the system when development is complete, in this case, the Air Combat Command (ACC) at Langley AFB, VA. While organizationally part of the Air Force Materiel Command at Dayton, the SPO is operating under the close scrutiny of the Pentagon (Air Force and DOD), and the Congress in Washington, and, of course, members and leaders at several levels in Air Combat Command.

All together these organizations, with resultant interlacing, overlapping webs of direction, interest and authority, all linked with seemingly instantaneous, internet and telephone communication, form a major part of the landscape in which the F/A-22 system development is carried out. In fact, the several entities within this organizational superstructure included not only the corporate and government organizations, but another vitally interested and important organization. That is the Air Force Operational Test and Evaluation Center (AFOTEC), headquartered at Kirtland AFB, Albuquerque, New Mexico. AFOTEC is the independent testing organization responsible for evaluating the F/A-22’s ability to accomplish its operational mission. The AFOTEC assessment of the F/A-22’s operational capability is a crucial input to Pentagon decisions about how many and how fast additional F/A-22 aircraft will be built.

Hierarchical Arrangement of Key Organizational Actors

Within this backdrop, the F/A-22 organization itself was the first acquisition program for which use of Integrated Product Teams (IPTs) was a contractual requirement. This was a daunting challenge considering that the process had never been implemented before on a program as large as the F/A-22, the Lockheed Martin contractor team had not used the IPT process as such,[36] and the government customer wanted to be involved on a daily basis (Cox, 1993).

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[36] Lockheed Martin, Boeing, and, prior to acquisition by Lockheed, General Dynamics

To satisfy the requirement, the people and organizations doing the system development job are organized into a hierarchy of multi-disciplined teams that include both contractor and SPO designers, engineers, manufacturing and test personnel—a structure that avoids past program problems of functional "stovepipes." Despite the difficulty of capturing all the interlocking relationships, Figure 13 is the author's representation of the larger F/A-22 organization as it existed during the conduct of the case studies. The nature of the F/A-22 team suggests the term VIM^{5}DO—virtual integrated multi-layer/lateral/organizational/team/product Development Organization[37]—could be used as a broad descriptor to cover organizations using such a range of technologies and produce such sophisticated products as the F/A-22 Raptor.

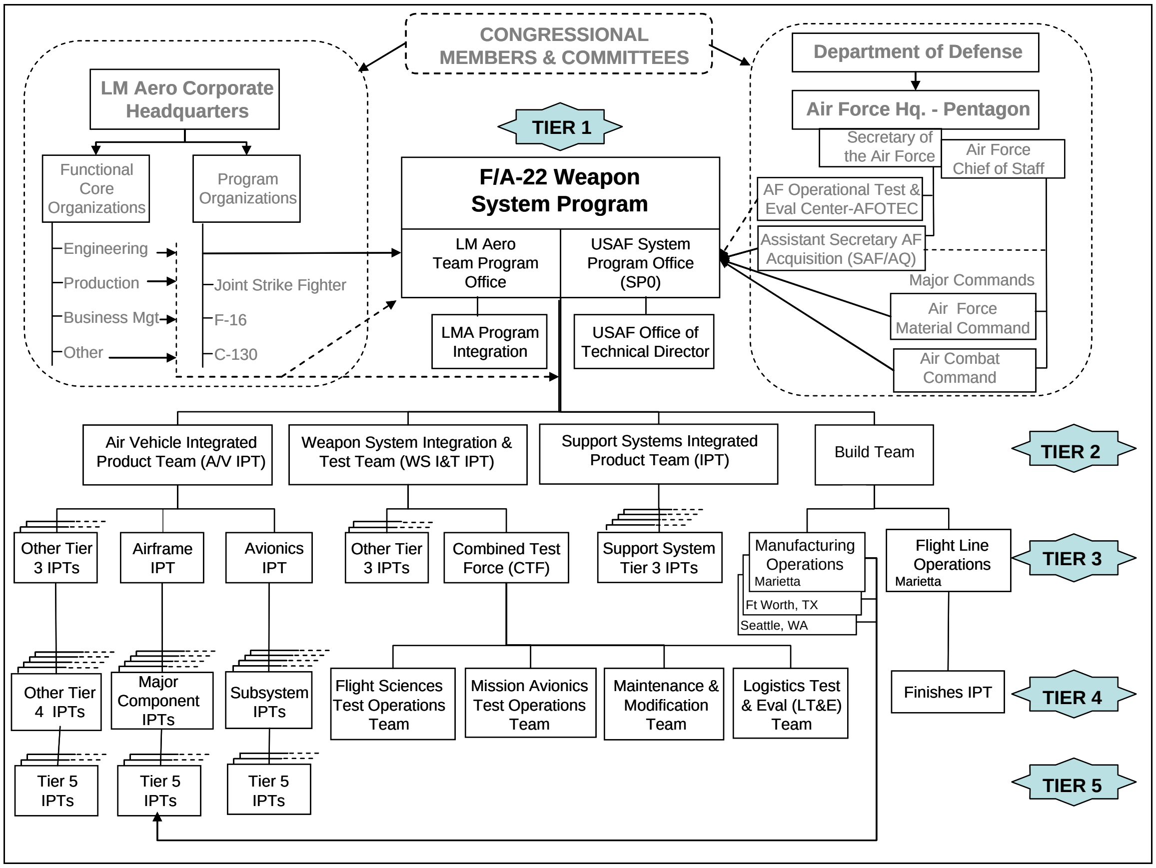

Figure 13. Representation of the internal F/A-22 organization and external actors.

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[37] This is a further refinement of a term, VMDO, standing for virtual multi-lateral (multi-organization, multi-team) development organization. The term was coined by O'Sullivan (2003) from study of a lead firm and its suppliers developing one product. The F/A-22 programs' number of suppliers, layers, products, etc., almost compels expansion of the term.

The “weapon system” Tier 1 encompasses all aspects of the aircraft and program and is led by the government SPD and the LM Aero VP/GM. At Tier 2 is the next breakdown of the weapon system into the most important Integrated Product Teams and leaders, such as the F/A-22 Air Vehicle IPT, the Weapon System Integration and Test IPT, Support Systems IPT, etc. Typically, the IPT structure is aligned with the Work Breakdown Structure. For example within the Air Vehicle IPT, there is a subordinate Airframe IPT. Within the Airframe IPT, there are IPTs responsible for the major components that were depicted in Figure 2, e.g., a Forward Fuselage IPT, a Wing IPT.

The dotted frames above the formal IPT structure in Figure 13 all represent organizational entities that have important roles and significant influence on the conduct of the F/A-22 program, especially from a policy perspective: the LM Aero corporate headquarters with its program guidance and functional organizations; DOD and the Air Force structure with its headquarters and major commands; and the Congressional members and committees with their own overlapping areas of interest and oversight.

Even as many elements that are represented, there are some that are not. For example, there was a need to avoid trading the unwanted effects of parochialism within the functional stovepipes of an organization for perhaps equally unacceptable effects of what could become “product stovepipes” with associated and potentially equally negative parochialism. To make sure that the IPTs were integrated across IPTs as well as within IPTs, a function called “analysis and integration” (A&I) was invented. At the Tier 2 and in some larger Tier 3 IPTs, the A&I role required a separate team of people called an A&I IPT or, simply, the A&I Team. This A&I role had dual purposes, in that it first made sure that the system engineering processes, e.g., requirements management, configuration control, risk management, were being consistently employed and tracked by subordinate IPTs. Secondly, the A&I teams were key players in cross-IPT communication and information sharing.

Key to making the Integrated Product Team organization work was a fundamental policy that LM Aero instituted when it first initiated the IPT structure and process on the F/A-22 program. That policy was to give IPT leaders the responsibility and commensurate authority for managing their team to assure the product met F/A-22 requirements within a system engineering framework of metrics and processes across all teams.[38] Essentially, this meant that each product team leader at a given tier level would assign tasks to his subordinate, and *empower* that subordinate IPT leader with the responsibility and authority to use his resources and to select the processes most appropriate to accomplish the goals from those developed or available within the F/A-22 team or offered by the core organization. In very rare circumstances was the upper tier IPT leader to second guess the lower tier leader. Policy regarding authority/responsibility link was maintained throughout the development process for the F/A-22.

The insistence on IPT level authority/responsibility was vitally important for the effort to initiate CCPM projects. The policy enabled—in fact, required—Operational-level decisions to implement CCPM demonstration projects instead of requiring what might otherwise have been a daunting organizational challenge if ratifying Program management approval were required. To focus on the key roles played by IPT leaders, Figure 13 has been modified in Figure 14. In this new form, the key players from several tiers within the overall organizational are linked to the CCPM innovations. The locations noted at the bottom of the diagram directly related to the case studies reinforce the geographical range of the overall study.

In effect, the applications of the CCPM innovations depicted in Figure 14 involved a set of actors that affected the process and outcome of applying the CCPM innovation.

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[38] The prescience of this policy instituted at the outset of EMD in 1991 has been validated by IPT performance in the F/A-22 program and by recent research on control of new product development and project performance. Bonner et al, showed “a negative association between the use of upper manager-imposed process controls and project performance” and “the degree to which upper-managers intervened in project-level decisions during the project was negatively related to project performance” (p. 233, 2002).

The division of the diagram into the two background "fill" patterns reflects the discussion in Chapter 2 on the structural levels involved in organizational innovation. Although several IPT organizational tiers are involved, key personnel basically operated in one or the other or both of the Program and Operational organizational structural levels.

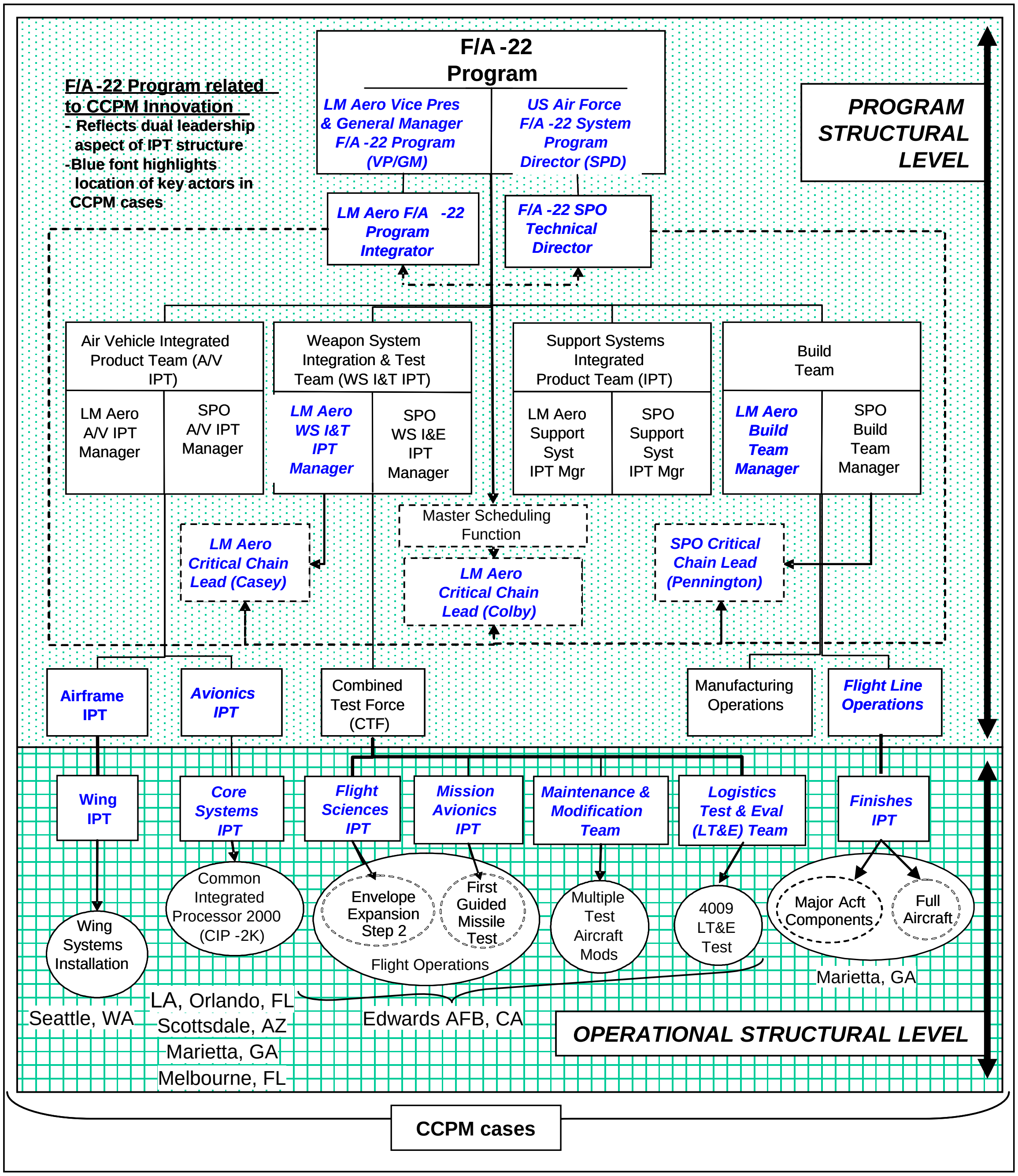

Figure 14. F/A-22 IPTs, structural levels and actors and links to case studies.

Also highlighted in Figure 14 is the dashed line that connects members of key change agents and champions, Casey, Pennington and Colby, with each other and with the Tier 1 leaders/champions who encouraged employment of the CCPM innovation for the benefit of the host IPT and for the overall F/A-22 Team.

Before proceeding to the case studies of CCPM employment, however, it is important to describe one other component of the study common to all of the case studies, namely, more details on the concepts, vernacular and process involved with the CCPM innovation itself.

General Description of the CCPM Innovation Methodology

As noted earlier, Critical Chain is a systems approach to management that differs in important respects from the critical path method (CPM) that is the traditional basis for project management.[39] In this section, however, the focus is on several elements on which the Critical Chain approach to project planning and execution is based, including CCPM's explicit consideration of resource constraints, variability, and mitigation of human nature which can adversely affect results. Overall these elements in the Critical Chain system allows project managers to deliver required content on time, within budget with focus on far fewer tasks. The "far fewer tasks" are those on the Critical Chain.

The Critical Chain Network Building Process

Critical Chain begins with a planning process that first identifies objectives (what is the purpose of the project?), deliverables [what product(s) will the project deliver?], and success criteria (how will we know when we are done?). Then the planning process requires development of a detailed, credible network of tasks representing the work and

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[39] Though not critical to understanding the case study research on the implementation and results of CCPM in the case studies, at Appendix B the description which follows here is largely repeated, but expanded to explicitly include distinctions between the Critical Path Method and the Critical Chain approaches to project management.

precedent relationships[40] between/among tasks necessary to accomplish the objectives and deliver the required products within clearly defined success criteria. Instead of the common practice of deciding "what we do first" toward project goals, Critical Chain often begins with the product and works backwards, considering "what is absolutely necessary" before the product can be generated. The network is built "in reverse" considering what is necessary before each task can be accomplished.[41]

Central to the Critical Chain approach is emphasis on the equal importance of the interdependencies associated with tasks and resources, whether the resources are people, parts, facilities or other types of resources. Critical Chain draws on the knowledge of those who will do the work to establish or verify the interdependencies and key integrations points in the task network as well as establish the number and types of resources required to accomplish the tasks.

This central emphasis on resources and resource dependencies is repeatedly emphasized in the Critical Chain Project Management approach and is reinforced by the definition of the Critical Chain within a project: *The Critical Chain is the longest sequence of task- and resource-dependent activities in a project.*

Estimating Durations for the Critical Chain Project Network

Critical Chain clearly recognizes the nature of variability associated with task accomplishment in operations and project environments. As recommended by most project planning approaches, Critical Chain solicits information about task durations from those responsible for doing the work. However, instead of using a single number to estimate task duration (including enough safety to be confident the task time will not be overrun in practice), Critical Chain assumes that the range of estimates will occur within

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[40] Specifically, which tasks must be done first, which sequences of tasks or operations must be done in series, which can be done in parallel, etc.

[41] This approach toward network development in reverse is often referred to as the "necessity-based approach" vs. the "flow-based approach" starting from the beginning as is common with CPM.

a skewed (vs. normal) distribution as reflected in Figure 15. Instead of assuming that variability will occur evenly about the middle, Critical Chain recognizes that a given task might take less time than the mean or median estimate, but if variability occurs, it might drive the task time well beyond the median. The range of estimates is from "aggressive-but-possible" (ABP) on the low end to "highly probable" (HP) on the high end.

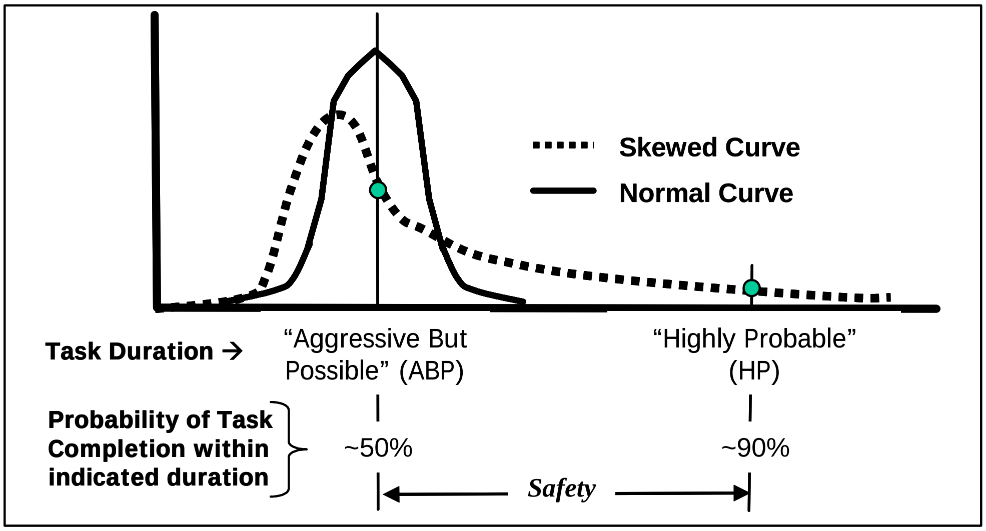

Figure 15. Assumed distribution of task durations and completion probability.

The *aggressive-but-possible* estimate, referred to simply as the "aggressive" or "ABP" estimate, is the duration that would occur if all the required resources—parts, personnel, engineering drawings, etc.—are available when needed and the worker (or work group, if applicable) is allowed to focus entirely on this task. This ABP duration is thought of as having an approximately "50/50" or 50 percent probability of success.

At the other end of the estimating range, the *highly probable* estimate is the duration that includes sufficient safety to deal with the variability that could occur during the execution of the instant task based on past experience with the same or similar tasks. Variability might be caused by delayed or quality-deficient parts, parts that have to be repaired, situations requiring engineering direction that must be clarified before the task can be completed, or lack of proficiency or unavailability of a particular labor specialty. Any of these sources of variability will use up some, all of, and occasionally more than, the safety that is embedded in the HP estimate.[42]

The difference between the two estimates is a measure of the uncertainty (or variability) in task accomplishment, and regarded by Critical Chain as safety. Instead of embedding the safety in each task-duration, Critical Chain aggregates this safety into a system of "buffers," mainly Feeding Buffers (FBs) and a Project Buffer (PB). Because less safety is needed at the project level than the total safety embedded in each task (since early finishes in one task can offset late finishes in another), Critical Chain uses a portion of total safety in these buffers and strategically places the buffers to assure that the project or operation is completed on time. Essentially, the buffers represent protection against problems in the accomplishment of tasks due to "common causes" (variations in duration that predictably occur because they are part of the system within which projects are performed).[43] The Project Buffer provides protection from normal variability for the sequence of the Critical Chain tasks The Feeding Buffers protect the Critical Chain from variability on the "feeding chains"—the sequences of tasks providing an input to, or leading to a point of integration with, tasks on the Critical Chain. By definition, since the Project Buffer represents variability that will occur with a high degree of certainty, the time in the Project Buffer will progressively be consumed as the project moves to completion at a time represented by the end of the Project Buffer.

Given an accurate network incorporating durations and resources at the task level verified by appropriate subject matter experts (SMEs) and enabled by software that executes the critical chain algorithms, the Critical Chain approach generates a schedule

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[42] The "highly probable" (HP) estimate is sometimes termed the "safe" estimate in other references. HP is preferred herein to avoid the connotation that the estimate is somehow so "safe" as to be certain. In fact, as "HP" more correctly implies, this estimate will occasionally be exceeded.

[43] Buffers capture the philosophy of Edwards W. Deming, the great quality advocate of the 20th century, regarding the handling of "common cause" and "special cause" variation and predictability. An individual task taking longer than estimated is likely within the realm of common cause variation. A series of tasks that have all taken much longer than expected are in the realm of special cause variation (Kerzner, 2003)

set back from the projects completion/delivery date. Once pertinent resource contention is resolved[44] to remain within any resource limits, the Critical Chain is identified and Project and Feeding Buffers are inserted.

Graphic Views of the CCPM Project Network

In Figure 16 a simple project is depicted with the Critical Chain tasks shown in bold outline. For purposes of illustration, only one of each type resource is available.

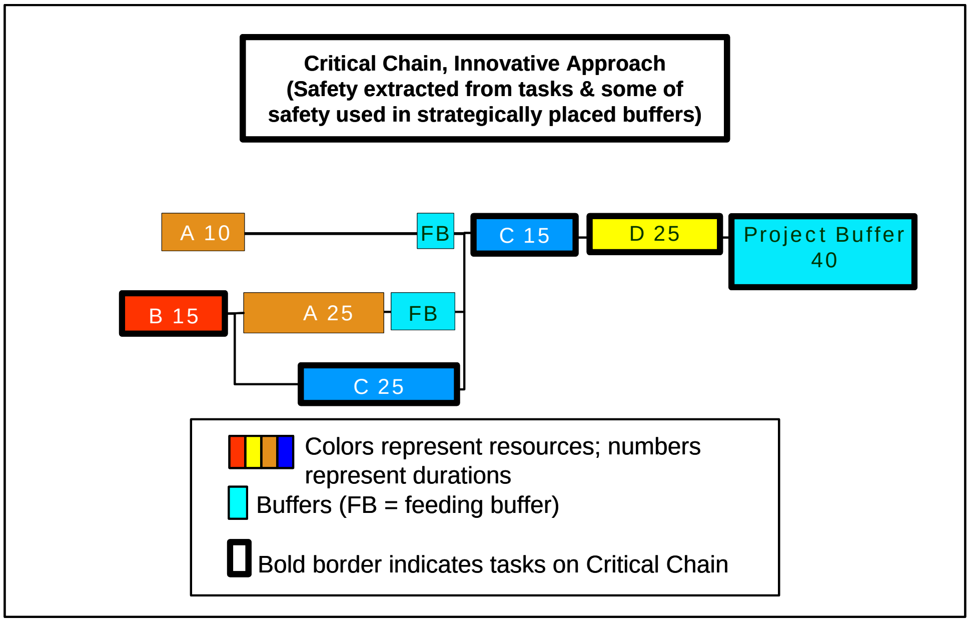

Figure 16. Depiction of Critical Chain project networks (adapted from Kendall, 2005).

The CCPM network shows the resolution of the conflict between the demand for Resource A on the top and middle paths of the network. The Feeding Buffers (FBs) are inserted to assure that the non-Critical Chain tasks are begun sufficiently early to assure that those tasks will be completed so there is no delay in the integration of the products from A10 and A25 with the result of C25. Importantly, the use of FBs is intended to assure stability in the Critical Chain tasks. The result can be presented in many ways,

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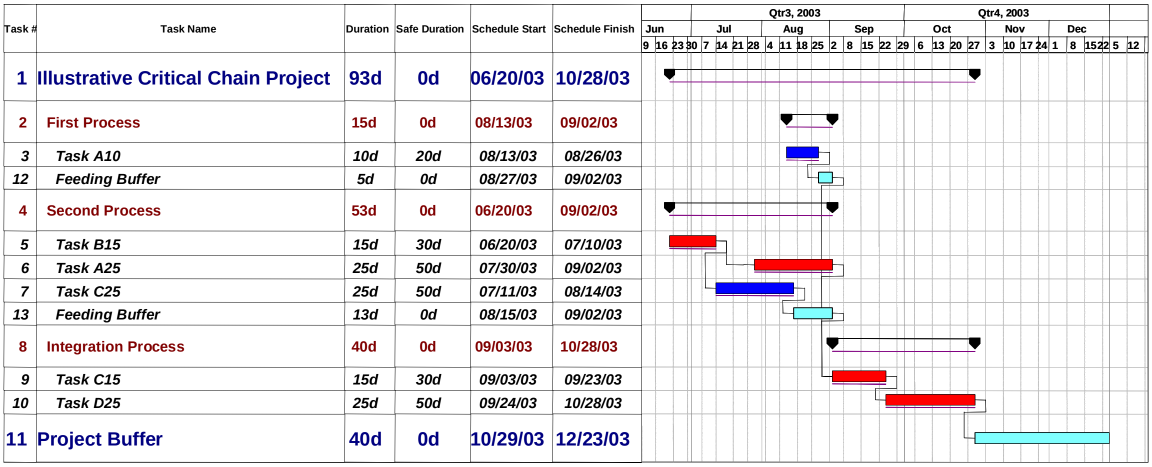
[44] The meaning of *resolved* here is that limited resources are not allowed to be simultaneously assigned to more tasks than there are resources to support. For example if two tasks require resource X at the same time and there is only one qualified resource X, the tasks will moved or “pushed” so that they can only occur in series, not parallel. In this context, the resource contention is said to be *resolved, deconflicted,* or *broken.*

most commonly in Gantt-chart format. The Critical Chain network depicted in Figure 16 is shown in Figure 17 as a Gantt chart.

The color coding on Figure 17 is important. The tasks on the critical chain are depicted in red and completion of them is most crucial to keeping the project moving to on-time completion. Any changes in the non-critical tasks (shown in navy blue) will not reduce the total span of the project. The bars shown in teal blue color are the buffers which, during the planning phase, provide an indication of how much variability is expected. Once the project is initiated and work is begun, it is imperative both that the precedence established in the network be faithfully followed and that frequent updates on task progress be accomplished and entered into the Critical Chain software to facilitate Buffer Management (as described below).



Task #	Task Name	Duration	Safe Duration	Schedule Start	Schedule Finish
1	**Illustrative Critical Chain Project**	**93d**	**0d**	**06/20/03**	**10/28/03**
2	**First Process**	**15d**	**0d**	**08/13/03**	**09/02/03**
3	***Task A10***	***10d***	***20d***	***08/13/03***	***08/26/03***
12	***Feeding Buffer***	***5d***	***0d***	***08/27/03***	***09/02/03***
4	**Second Process**	**53d**	**0d**	**06/20/03**	**09/02/03**
5	***Task B15***	***15d***	***30d***	***06/20/03***	***07/10/03***
6	***Task A25***	***25d***	***50d***	***07/30/03***	***09/02/03***
7	***Task C25***	***25d***	***50d***	***07/11/03***	***08/14/03***
13	***Feeding Buffer***	***13d***	***0d***	***08/15/03***	***09/02/03***
8	**Integration Process**	**40d**	**0d**	**09/03/03**	**10/28/03**
9	***Task C15***	***15d***	***30d***	***09/03/03***	***09/23/03***
10	***Task D25***	***25d***	***50d***	***09/24/03***	***10/28/03***
11	**Project Buffer**	**40d**	**0d**	**10/29/03**	**12/23/03**

Figure 17. Gantt chart depiction of schedule for CCPM network project.

Recognizing and Dealing with Potentially Negative Behaviors

Critical chain recognizes that at a systems level one of the major constraints to on-time accomplishment of tasks and total project is the tendency for workers to try to do more than one task at a time, i.e., to “multi-task” when assigned more work than can be completed in the time available, what might be referred to as “bad multi-tasking.” This is not so much a failure of the workers, who will do the best they can with the work assigned, as it is a failure of the supervisors/managers responsible for task assignments. The significant penalty of multi-tasking (as reflected in Figure 18) is that completion of work—whether paperwork in an office setting or tasks on the manufacturing floor—is extended by the extra time for physical and mental set-down/set-up when leaving/ returning to a task.[45] A fundamental mandate for managers using Critical Chain concepts is to avoid multi-tasking by insisting on a "relay-runner" mentality, i.e., workers concentrate on completing the task in the order dictated by the Critical Chain schedule in the minimum time for the conditions at hand and passing on completed work.

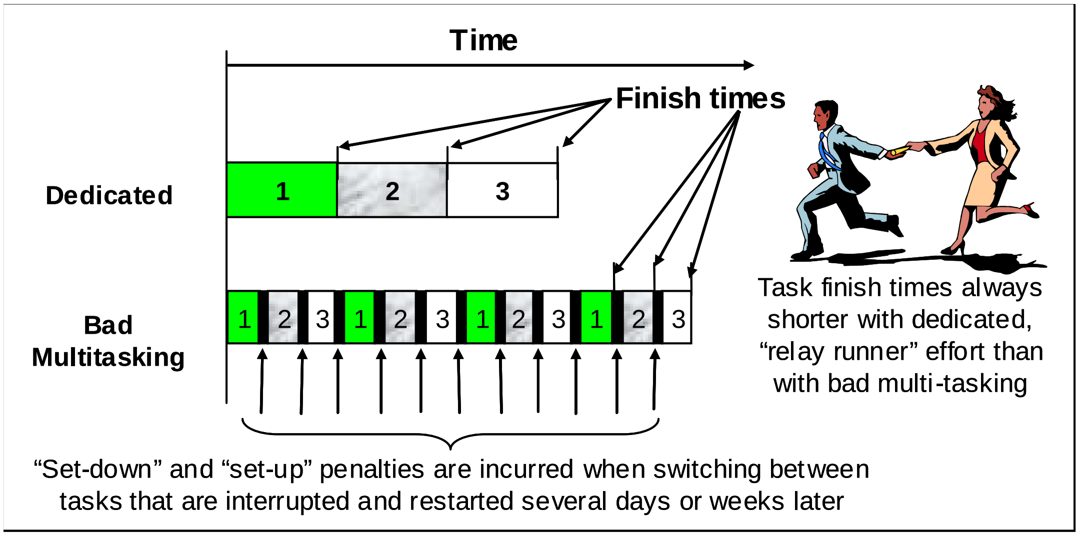


Figure 18. The penalty of multi-tasking: extended task durations (adapted from Kendall, 2005).

Critical Chain also recognizes the potential harm associated with several kinds of human behaviors and provides a strategy for dealing with the behaviors that can negatively affect achievement of project goals in a timely manner. Typically these behaviors evolve from the fact that the individual is aware (and may have even insisted) that there is safety time embedded in the estimated time within which s/he is now expected to complete the task. Examples are:

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[45] Studies have shown that the impact of multi-tasking by workers is to increase total project time by 20-40% over what can be accomplished by workers who focus on a task until it is completed (Rubenstein and Meyer, 2001).

- Parkinson's Law, applied to projects/operations, suggests that workers will typically use all available time (including safety) to finish a task, even if conditions would have permitted accomplishment early. Essentially, the worker uses up safety not needed on his/her task that might be needed elsewhere for completion of the total project on time.
- "Student Syndrome" suggests that like a student who waits until the last minute to complete an assignment for which more than adequate time was originally provided, a worker, knowing there is embedded safety in a project task may delay starting it, but then find it impossible to complete the task in the remaining time if any problems arise[46] (since there is no safety left to permit the worker to deal with the problems).
- The "3-minute egg" rule suggests that when task completion criteria are not clear, the measure of task completion becomes the span of time the same or similar task has taken in the past. Essentially, the worker will continue to "shine" the result/product until the estimated time is used up. Embedded safety time not really needed is wasted.
- Protect your Credibility, known colloquially as "CYA," this negative behavior suggests that workers are reluctant to pass on work that is completed in less time than they themselves had estimated. Because of fear that their future estimates will be arbitrarily reduced by management, the worker will waste embedded safety time by continuing to tinker with the effort until the estimated time is used up.

The strategy for avoiding these negative behaviors is embodied in a combination of the "relay runner" mentality (noted above) and frequent updates of progress on the tasks under way. Actually, as explained below, though these frequent updates on individual tasks do help identify negative behaviors when present, they are actually

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[46] An example the student who, even after gaining an extension (i.e., safety) on an assignment due date still ends up "burning the midnight oil" in an effort to meet the deadline only to find out that crucial information available at the now-closed campus library is essential for assignment completion. Had the student started earlier, the need would have been recognized, but now it is too late, any safety has been wasted and the work will be incomplete or suffer poor quality. The development/production analogy is clear.

required so that a crucially important component of the CCPM process—Buffer Management—can be employed.

Critical Chain Buffer Management

In a major difference between CCPM and other project management approaches, Critical Chain employs a practice called “Buffer Management” for driving execution to on-time achievement of project goals. Buffer Management focuses attention on completion of the total project(s) instead of individual tasks. Management action is initiated based on the amount of the project buffer that has been used (automatically depicted as “buffer penetration” by supporting software using information from frequent updates) compared to the portion of total work accomplished as the project progresses. Because it is a *projection* of buffer penetration based on progress to date, this metric is an early warning of problems and permits action to avoid crisis and still complete the project on time. In the simplest approach, the buffer is divided into thirds, as shown in Figure 19. The first third designated as the “green” zone (Zone 1), the middle third is designated as the “yellow” zone (Zone 2), and the last third designated the “red” zone (Zone 3). If the buffer remains in the “green” zone, no action is necessary. If buffer penetration is projected to be in the “yellow” zone, especially early in the project, management should be pro-actively planning (and presenting to upper management)

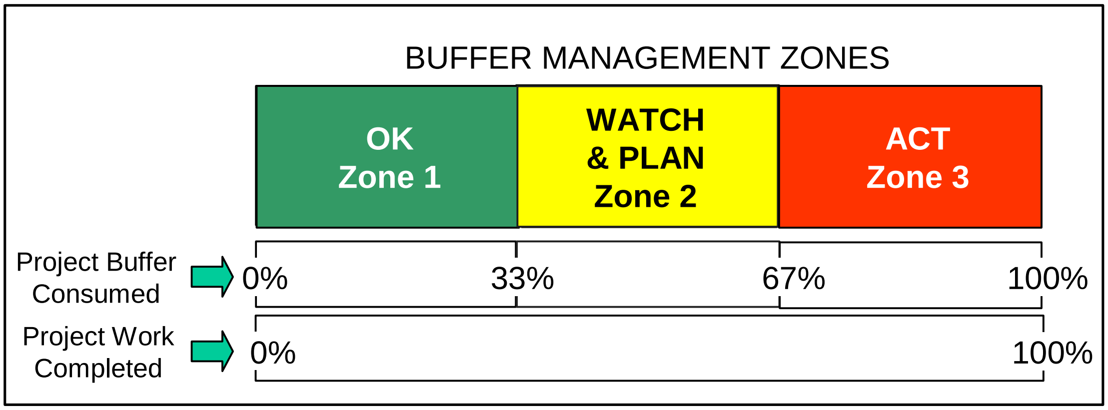
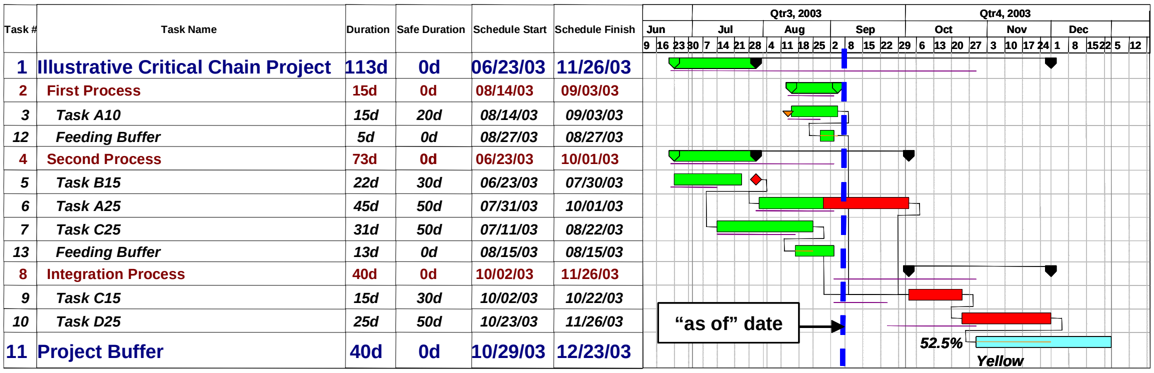


Figure 19. Division of Project Buffer into management zones.

what actions might be taken if greater than expected variability forces projected buffer penetration into the “red” zone. Such actions might include replanning to permit parallel instead of sequential accomplishment of some tasks (even accepting some risk to do so), addition of resources, change of priorities, or other options unique to the project.

Figure 20 illustrates the point using the project depicted earlier in Figures 16 and 17.   In this representation, the project has been implemented and the plan has transitioned to the “tracking” mode, where progress is shown by the green color and by the extent of “buffer penetration” (the thin line in the middle of the project buffer bar in Figure 20). If, as in Figure 20, the updates show that the Buffer penetration moves into the “yellow” zone quickly based on trends generated by frequent updates, the project manager might initiate the action planned earlier without waiting for entry into the “red” zone. Of course, since it is realistic to plan on use of the entire the project buffer as noted earlier, no action may be necessary if the project is close to the end when buffer penetration is projected into the “red” zone.



Task #	Task Name	Duration	Safe Duration	Schedule Start	Schedule Finish
1	Illustrative Critical Chain Project	113d	0d	06/23/03	11/26/03
2	First Process	15d	0d	08/14/03	09/03/03
3	*Task A10*	*15d*	*20d*	*08/14/03*	*09/03/03*
12	*Feeding Buffer*	*5d*	*0d*	*08/27/03*	*08/27/03*
4	Second Process	73d	0d	06/23/03	10/01/03
5	*Task B15*	*22d*	*30d*	*06/23/03*	*07/30/03*
6	*Task A25*	*45d*	*50d*	*07/31/03*	*10/01/03*
7	*Task C25*	*31d*	*50d*	*07/11/03*	*08/22/03*
13	*Feeding Buffer*	*13d*	*0d*	*08/15/03*	*08/15/03*
8	Integration Process	40d	0d	10/02/03	11/26/03
9	*Task C15*	*15d*	*30d*	*10/02/03*	*10/22/03*
10	*Task D25*	*25d*	*50d*	*10/23/03*	*11/26/03*
11	Project Buffer	40d	0d	10/29/03	12/23/03

Figure 20. Illustrative Critical Chain project during project execution.

Critical Chain Approach to the Multi Project Environment.

Initially, CCPM was used for the planning and execution of a single project. However, there are usually many other projects in various stages of planning, scheduling and execution at the same time. Quite frequently, many of the same resources have responsibilities to execute tasks in more than one project, in some cases, several projects. Clearly, without precautions to avoid it, such a situation might almost guarantee some of the "bad multi-tasking" described earlier.

To handle the multi-project situation, the Critical Chain Project Management methodology has been further developed. As part of the development, the "precaution" to avoid bad multi-tasking is embodied in an approach which "synchronizes" the projects by staggering them so that more heavily tasked resources [(called the "drum" or "strategic" resource(s)][47] are not simultaneously assigned tasks in two or more projects.

The result is sometimes referred to as "good multi-tasking" because the strategic resource(s) can operate within each project under the relay runner strategy—complete the task as soon as possible and pass on completed work—and only then move to tasks in another project which has been appropriately staggered. In addition to "stagger" to assure efficient leveraging of the most hard-working and precious resources across projects, there is another mechanism called the "capacity," "synchronization" or, as preferred herein, the "strategic resource" buffer between projects to assure variability in one project does not jeopardize the delivery commitment of another subsequent project.

Figure 21 presents a simplified view of the "synchronization" process. Prior to attempting to synchronize the projects, each is individually planned with the same rigor as described earlier, including durations, assignment and deconfliction of resources, identification of the single project Critical Chain and insertion of buffers. Here we are pretending that the projects are identical, with the priority order the same as the project number. The three projects all use the same kinds of resources, but there is only one of each kind. As indicated by the lightning bolt symbols, the top-left "initial situation" depicts the clear, unequivocal conflict in the demand for "blue," which is the most heavily

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[47] "Drum" is the traditional reference for the more or most heavily tasked resource in a project , and is derived from the fact that it sets the pace for accomplishment of the goal, much like the military drum beat in rigid military maneuvering of the 17th and 18th century. Drum is also used to designate a similarly tasked resource across projects. Herein, the term "strategic" is preferred in the multi-project application because its allocation and use is a strategic concern at the Program level above the tactical concerns of a single project.

tasked—strategic—resource across the three projects. To eliminate the obvious conflict, the projects are "staggered" (top-right window in Figure 21) to assure that "dark blue" is not simultaneously tasked by more than one project. At first glance, this looks fine.

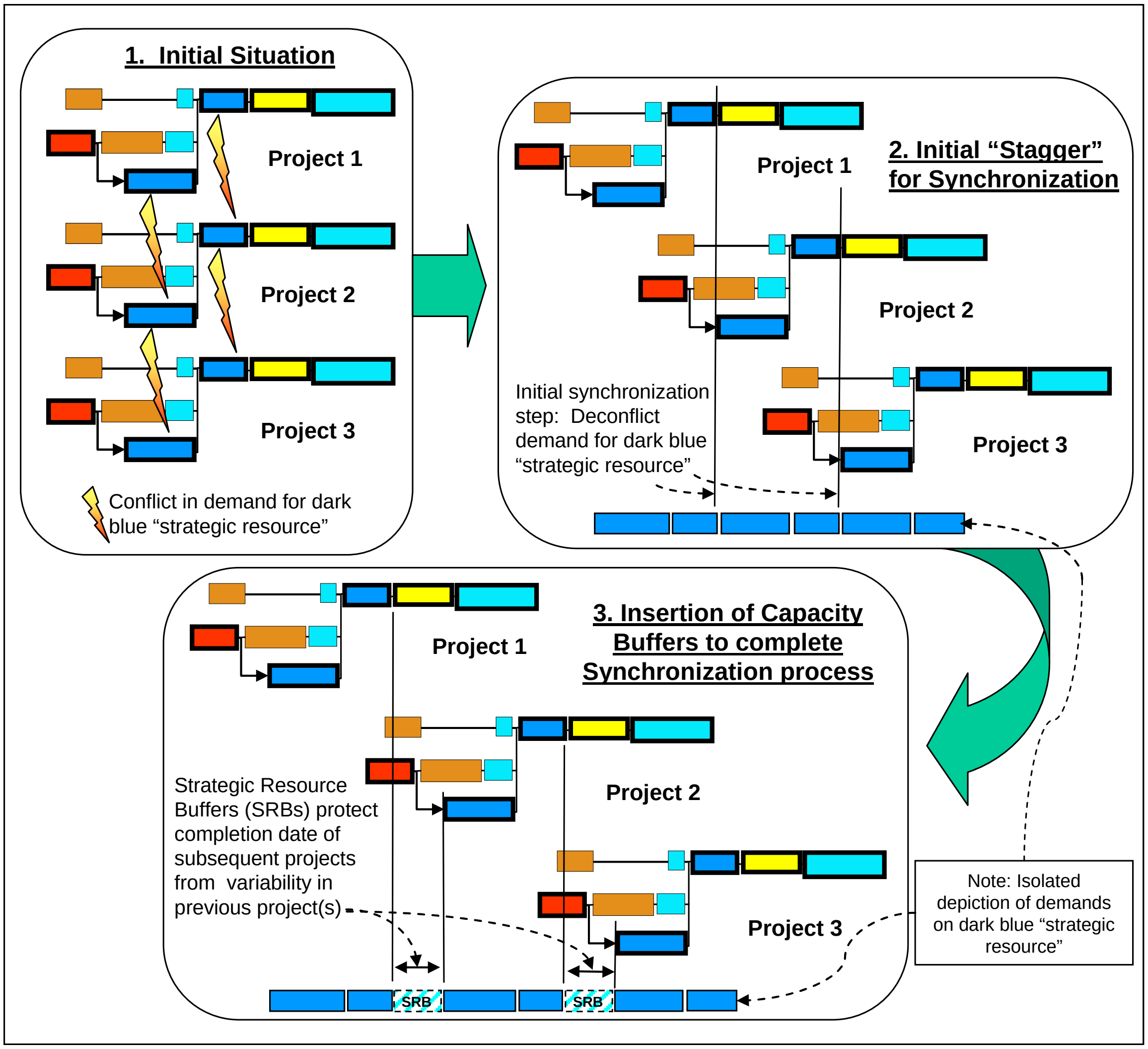

Figure 21. Staggering projects and using strategic resource buffers to assure executability (adapted from Kendall, 2005).

However, recalling that the display reflects the aggressive task durations and we realistically expect to encounter some variability, it is highly likely that the second dark blue task in Project 1 will actually be completed later than shown. As a result, we should expect a conflict between projects in reality during execution, and the first dark blue task in Project 2 will slip out, possibly putting delivery at risk. To avoid that risk, the final solution is shown in the third, lower window of Figure 21, where “strategic resource buffers” have been inserted and extend the stagger of the projects.

Essentially, the CCPM methodology (and supporting software) creates a delay in the beginning of the second and third projects so that each is protected from expected variability in the execution of strategic resource tasks in the previous project. In a way analogous to a single project, the portfolio of projects can be considered feasible and reasonably immune from variability because of insertion of feeding, project buffers and strategic resource buffers. In both cases the relay runner discipline and honoring the “stagger” across projects is very important to project and portfolio success.

Of course, it might be observed that in some cases the company or individual project managers do not have the flexibility to simply stagger the projects and insert capacity buffers, because the resulting projected delivery dates do not meet the mission need or customer demands. In these cases, something has to be changed—the priority order changed, the work flow planned differently (again, sometimes imposing more risk), more resources added, etc. In any case, the CCPM methodology and supporting software provides powerful tools to exercise “what-ifs” to adjust the outcome. In some cases, it simply is not possible and “desired” delivery dates cannot be met. Even in those cases, CCPM offers convincing evidence that everything the project manager can do is being done. Unless the customer changes requirements, plans or resources, the result “is what it is,” providing common ground for all concerned.

With the foregoing as a background, it is useful at this point consider the second research question: **How is the CCPM approach to schedule planning and execution different than traditional approaches?** The following lists the primary differences:

- CCPM places overwhelming emphasis on achieving the project goal on time, expecting and accepting variability in task completion durations. The traditional

CPM process emphasizes on-time task completion even though almost all tasks can be completed on time and project still fail because of the few tasks not on time.

- The emphasis on resources is reflected in the definition of the critical chain as the longest sequence of task and resource dependent events, whereas the traditional approach defines the critical path as the longest sequence of task dependent events.
- CCPM handles variability by (1) recognizing that the difference between aggressive and highly probable estimates for task duration is safety, (2) developing the schedule based on the aggressive time, and then (3) elevating use of “safety” by embedding it in Feeder Buffers to stabilize the critical chain and the Project Buffer absorb variability in task accomplishment while protecting the on-time completion of the project goal. In the traditional approaches, safety is embedded in each task and often wasted due to a variety of human behaviors inimical to project success.
- Critical chain avoids multi-tasking by following the “relay race” approach to task completion, inhibits other negative behaviors by insisting on the discipline of following task precedent order, frequent updates, and operational decisions based on buffer management. Without the stability of the schedule provided by buffers and buffer metric, traditional approaches accept negative behaviors and are forced to decisions based more on potentially misleading intuition than useful data.

Overview of the Case Study Chapters

The following chapters present the description and analysis of the CCPM as an organizational innovation in the F/A-22 weapon system acquisition program. Figure 22 below provides the roadmap for the case study chapters. Each Chapter is organized into Parts A and B. Part A presents the CCPM innovation in terms of a detailed description (what was done). Part B presents analysis of the CCPM innovation in three subparts. The first evaluates the construct validity of the case studies, examining each of the changes that were expected from the outset. The second part of the analysis examines innovation from the theoretical perspective incorporated in the CHIP model. The final part of the analysis section analyzes the implementation from the perspective of the Program and Operational *structural level* and the *actors* involved.

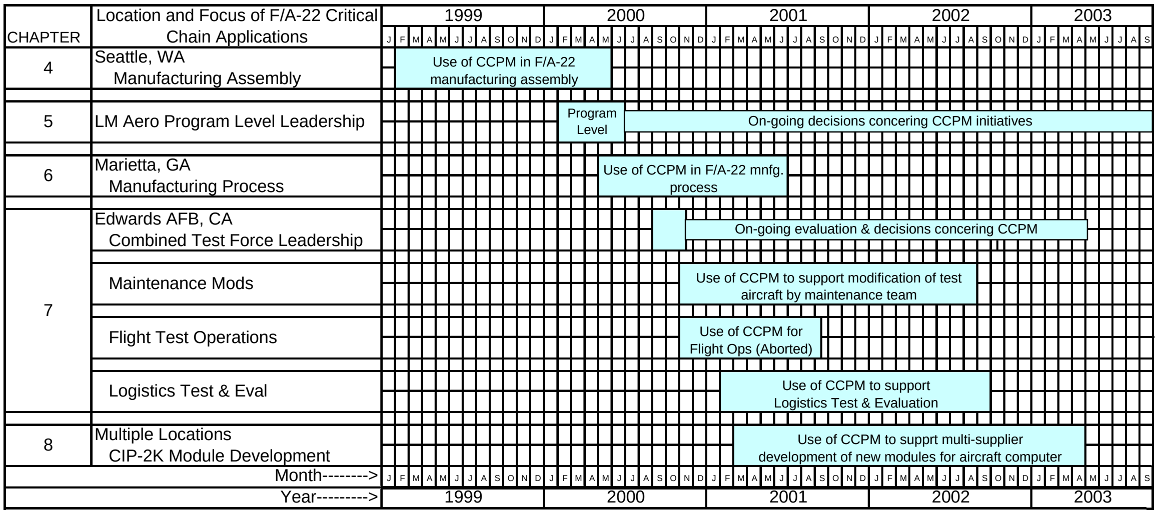

Figure 22. Order and content of case study chapters.

Chapter 4 addresses the Boeing implementation, based primarily on work documented before the author became directly involved in a participant observer role. Chapter 5 describes the initiation phase at the F/A-22 Program level because of its importance as the precursor of all CCPM applications except in the Boeing assembly area. Chapter 6 describes the initiation, success and eventual termination of the CCPM innovation in the finishes area at Marietta, GA. Chapter 7 describes the multiple applications of CCPM at Edwards AFB, CA, within the Combined Test Force, where there was an initiation phase somewhat akin to that described in Chapter 5. As indicated in Figure 22, the separate CTF CCPM applications are presented together because the context and leadership is common to all, though the attitude and success varied widely across the innovations. Finally, Chapter 8 documents the multi-supplier development of the F/A-22 computer module with the support of schedule planning and execution support from the employment of the CCPM innovation.

Summary

This chapter explained the design and methodology for this research study adapted from Yin's models of case study research. The organization was described in some detail to provide the context for the case studies. The geographical span and internal and external organizational structure demonstrates the complex environment in which F/A-22 development and transition to production is carried out. A variation on the organizational "wiring diagram" highlights the many parts of the hierarchy affecting the CCPM case study settings as well as highlighting how the components and key personnel of the F/A-22 team fit into the Program and Operational levels of the organizational structure construct described in Chapter 2. Details of the concepts and mechanics of the CCPM innovation provide an understanding of the unique aspects of the innovation which can be viewed as advantages and handicaps, depending on the application environment.

Together, the details of the organization and the CCPM innovation, combined with the discussion of the *structural levels and actors* as well as the CHIP model in Chapter 2 provide the foundation for the description and analysis of the case studies.

Chapter 4: CCPM INNOVATION IN MANUFACTURING ASSEMBLY

Overview

This chapter describes and analyzes the use of Critical Chain Project Management in a manufacturing assembly setting, specifically, several areas the Boeing Company's plant at Renton, WA, just south of Seattle. The Boeing use of CCPM is important both as an excellent example of the entire organizational innovation process and as the catalyst for broader program application of the CCPM innovation. In the process of initiating and implementing the CCPM innovation, the Boeing case study also addresses and provides the only direct and specific example of how CCPM can be made compatible with the system discussed in Chapter 2, Earned Value Management System, which provides information required by the government. As will be described in this chapter, the Boeing application of the CCPM innovation involved the assembly process, for three different components related to the wing of the F/A-22, as shown in Figure 23.

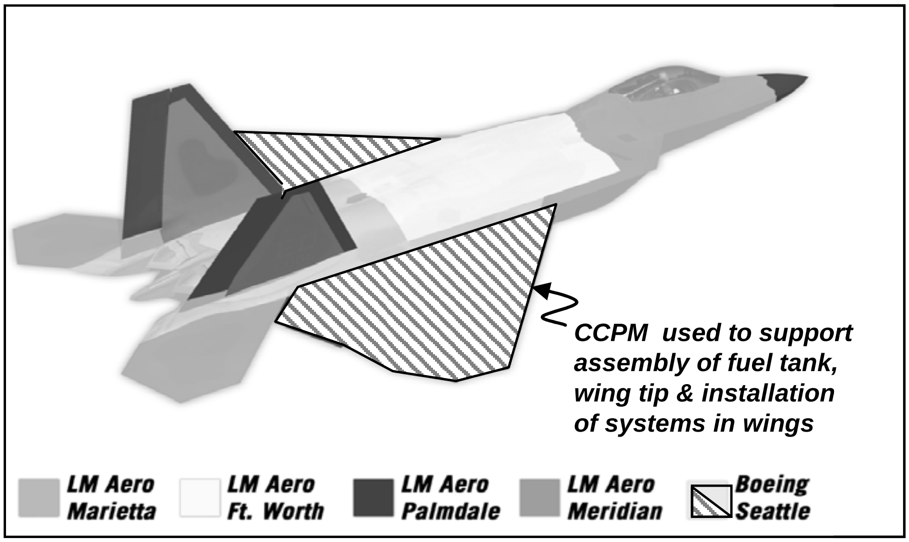

Figure 23. Boeing use of CCPM in assembly processes.

The Boeing implementation is set apart from the other case studies in an important way from the perspective of the research approach. Elsewhere, the author was directly involved and collected or developed virtually all of the material and information for the description and technical analysis. In this case, by the time the author became involved, Boeing had already completed the initiation phase, as well as all the reinvention/ restructuring and most of the evaluation phases of the implementation stages as described in the CHIP model. As a result, the description and technical analysis is heavily dependent on data contained or derived from internal and published reports (Christ, 2001, 2003) of the initiation/implementation process.

Part A: Description

Initiation

In the early 1999, some 18 months after the first flight by the first F/A-22 EMD test aircraft in September 1997, there was increasing pressure across the program to complete other F/A-22 test aircraft under the EMD contract. The program had survived a Congressional attempt to kill the F/A-22 program by suspending funding in the late summer of 1998. Still, the threat of program reduction or cancellation clouded the future as the F/A-22 team worked a variety of cost, schedule and technical challenges. Taken together, the difference between what the F/A-22 program needed and what the Boeing Team was producing was clear and unacceptable.

Intense efforts were initiated to prevent further slips in schedules affected by complex producibility problems[48] and timely parts supply. To meet the 1999 aircraft delivery commitments, the F/A-22 assembly floor workforce at the Boeing Company's Seattle plant was doubled to 200 mechanics in a nine-month effort. In addition to the steep increase in manpower, a central manufacturing process improvement office was opened to establish initiatives to deal with problems.

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[48] An example of a producibility problem is the "Side-of-Body" casting used to connect the wings to the fuselage. Titanium was selected as the material that best balanced cost, weight, strength and durability, but had never been used in this particular application. Early problems with process control and minute but unallowable defects had to be overcome and a second casting supplier qualified to reduce risk. This and other such technically complex problems were overcome, but the time required added pressure to an already tight schedule

Two of the personnel assigned to this process improvement effort were seasoned engineers who had personally initiated a very successful application of Theory of Constraints in a Boeing printed circuit board plant prior to assignment to the F/A-22 program (Wagoner, 1998). The more senior of the two was given the title Lean Manufacturing Manager and given the responsibility to lead the Lean Improvement Team. On the basis of initial investigations and analysis of the F/A-22 situation, the two engineers became convinced that a form of the CCPM should be part of the solution.

Another straight-forward choice among potential solutions was adoption of an approach to improvement that had been successful elsewhere in Boeing manufacturing operations. The approach was embodied in what was called Accelerated Improvement Workshops or AIWs. AIWs were specifically designed to enhance performance through worker involvement in waste elimination, area organization, assembly of kits containing specific parts and tools required for specific jobs to increase worker efficiency, and process improvements. Essentially, the timing of the improvement effort and availability of the AIW acted as a conduit for the entrance of the CCPM innovation.

The Boeing F/A-22 improvement team endorsed the generic concept of Accelerated Improvement Workshops (AIWs) to overcome the range of problems readily apparent in the F/A-22 manufacturing area. These problems ranged from poorly designed work areas, to tool and part delivery, to difficulties gaining access to tightly packed work areas, to ineffective work force organization and tasking, to deteriorating cost and schedule performance.

Importantly, even though others on his staff were neutral, the factory manager provided solid support for inclusion of the CCPM methodology because he was familiar with its success elsewhere in Boeing (personal communication, Christ, 2002). As a result, solidly grounded in experience and supported by the factory manager, the Critical Chain approach became one of the several initiatives the Lean Manufacturing Manager integrated into the AIWs. In fact, with the exception of Critical Chain, the processes implemented through the mechanism of the AIWs were familiar parts of lean engineering, an approach to improvement patterned after that of the Toyota Company (Womack et al, 1991; Womack and Jones, 1996).

To the benefit of the CCPM innovation, a key element of the F/A-22 tailored AIWs was the effort to standardize work by building networks to identify all the tasks to be done in a particular assembly area. The networks also included the precedent relationship between and among the tasks.[49] The precedent diagram (PD)[50] networks revealed conflicts between and among tasks that had to be resolved through rewriting of orders and procedures or resequencing of work or both. In addition, durations and resource requirements (people, parts, and procedures) were estimated for each task. At the core of network validity was the direct involvement of working level supervisors and key specialist mechanics across working shifts; their credibility became embedded in the product. Given these facts, it becomes clear that the very detailed precedence network were very specifically developed by the AIW facilitators to permit transformation of the information into a Critical Chain schedule which they were confident could effectively take full advantage of all the other changes implemented as the result of AIWs.

Innovation Decision

Given the responsibility for development and integration of the several initiatives that became part of the AIW, the Lean Manufacturing Manager did not mandate the use of CCPM from the beginning of the improvement effort. Instead, a reasonably objective

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[49] It should be noted that networks previously developed by the industrial engineers had been constrained by management direction that the work had to be structured to support the EVMS reporting, i.e., evenly divided across the build period. Schedules lacking in credibility due to this direction resulted in lack of respect for posted schedules (or the system that produced them), non-standard build sequences, poor schedule performance and poor cost performance. The combination of the AIW initiative and the CCPM orientation permitted the industrial engineers to lead the effort toward far more credible, worker-supported networks.

[50] PD is the term preferred in the Boeing application. However, PD, precedence network, task dependency network or simply project network are essentially synonymous terms for purposes of the dissertation.

assessment led him and other members of the F/A-22 factory improvement team to the conclusion that CCPM should be used. It was then included with little fanfare and from a purely logical perspective, as opposed to the more emotionally laden advocacy of external TOC proponents (personal communication, Christ, 2002).

Implementation

The overall implementation phase of the organizational innovation process consumed nearly two years but solidly established the CCPM innovation which, in combination of the other initiatives embodied in the AIW process, led to consistently outstanding on-time performance.

Because of the AIW-generated task dependency networks, rigorously developed with the help of the assembly area[51] supervisors and workers responsible for the jobs, minimal tailoring of the CCPM innovation was required. There was physical restructuring associated with implementation of the AIW results, e.g., new workplace layouts and process/procedural changes. All of these changes contributed to an environment that favored CCPM by emphasizing disciplined adherence to the precedence-ordered tasks that is a central tenet of the CCPM methodology.

One element of the new structure attributable to the CCPM innovation was the requirement for new computer software to facilitate the implementation of the Critical Chain approach and methodology. Because of its newness as a project management innovation, there were few choices available. One software package was manufactured by ProChain and chosen as most compatible with Boeing's current practices. It was essentially a "bolt-on" addition to Microsoft Project™ (MS-Project™), long a leader in

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[51] Any particular "assembly area" on the F/A-22 assembly floor is technically called an Area Control Code (ACC) at the Boeing plant or a Sequenced Work Breakdown Sequence (SWBS) at LM Aero's Marietta and Ft Worth plants. The total manufacturing operations work on the assembly floor at any of the plants is broken down into roughly equivalent work content and spans to permit simultaneous moves in all areas to the work on the next aircraft serial number in each assembly area.

project management software employing the Critical Path Method as mentioned earlier. ProChain essentially used the same input information, but produced a Critical Chain schedule through the use of different mathematical algorithms.

Given the raw material of the task dependency networks that evolved from the AIWs, actual application of the CCPM methodology occurred in a sequence of three applications to different assembly areas: Wingtip, Fuel tank, and Wing Systems Installation. Due to the heavy demand on resources and pressure from the schedule, AIW efforts were initially directed away from major problem areas to avoid disrupting their intense build efforts. Each application required a slightly more tailored version of CCPM innovation than the previous one and all converged on a contingency decision to either terminate or continue/expand use of CCPM.

First CCPM implementation: Wingtip Assembly area

The initial application of Critical Chain, tailored for the Boeing applications was applied to the Wingtip assembly area along with the other improvement initiatives that evolved from the AIWs. The network diagram was developed through several iterations with the guidance of two experienced factory mechanics; agreement on the final version was gained after two days (Christ, p. 7, 2001). When implemented, evaluation of results by following the schedule generated “best-to-date” cost and schedule performance.

“However, the contribution of the Critical Chain scheduling tool to the performance improvement was not recognized” (Christ, p. 9, 2001). As a result, a new supervisor decided to reject the CCPM part of the integrated AIW solution in favor of traditional scheduling approaches with which the supervisor was more comfortable. These traditional scheduling approaches (using bar-charts, based on MS-Project™) were adopted for subsequent wingtip assemblies. When performance deteriorated again parts shortages ware blamed rather than less rigorous scheduling (Christ, p. 8, 2001).

Second CCPM implementation: Fuel Tank area

The second F/A-22 program application using CCPM, involved an F/A-22 fuel tank. The tailored plan for execution using CCPM was built on the knowledge gained in completing the Wingtip network diagram and schedules. The help of line *and* lead mechanics led to a substantially improved network precedence diagram. Even clearer in this instance was the importance of the coordination between representatives on the first and second work shifts in reaching consensus on the network. The revisions in application of resources that resulted from the AIW accounted for limited access[52] during the fuel tank assembly process, thereby leading to a more realistic schedule.

In addition, the CCPM change agents created a buffer status chart (Figure 24), which they dubbed "the fever chart," to help the assembly area floor supervisors understand progress with respect to project completion due date. The chart was a simple variation on the common three-zone depiction of Critical Chain buffer status concept (Figure 19). In practice, this display along with other ProChain reports gave the area supervisor a clear picture of project status and where attention was needed.

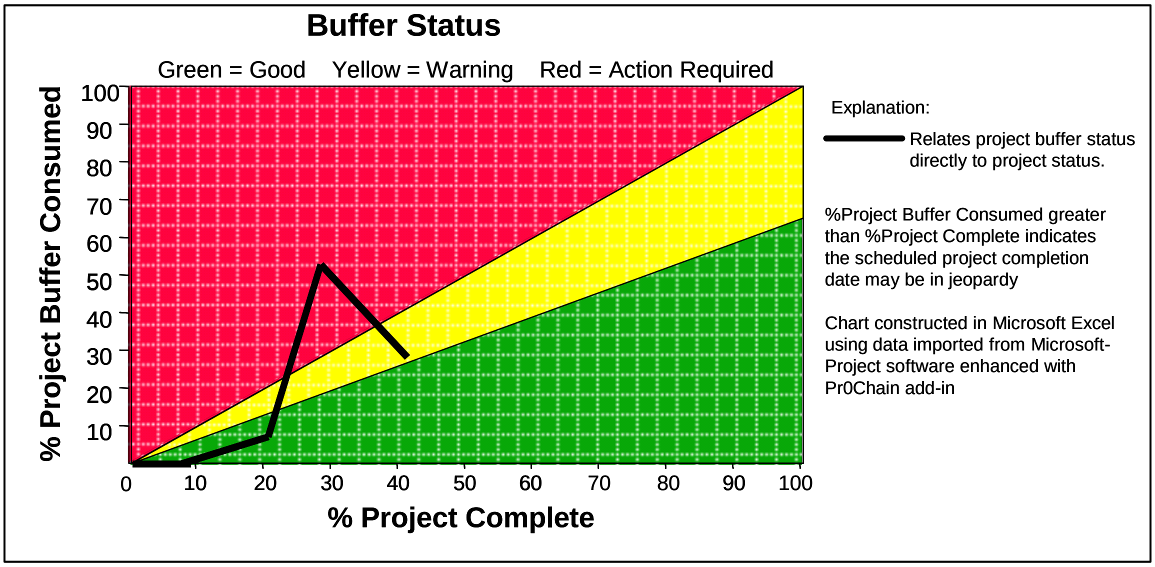

Figure 24. Buffer status chart using Critical Chain data. (Christ, p. 19, 2001).

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[52] Limited access in this instance means the tight space associated with the assembly of the fuel tank. Given that only one or two mechanics could physically be working on the assembly, the task duration could not be reduced by assigning other personnel to the task

In the first application of these tools and in response to a management request that two assemblies be built within the schedule normally associated with one, a Critical Chain schedule was built with aggressive durations equal to 50 percent of the traditional task spans without consultation with the mechanics. Besides receiving an informational briefing on Critical Chain concepts and schedules, workers were told that task durations were aggressive estimates (not mandatory targets) and advised to complete the tasks in network precedence order with their best possible effort (Christ, p. 10, 2001).

The evaluation of results showed that the combination of the AIW and Critical Chain led to dramatically improved performance and met management's challenge. However, in a reprise of the first (wingtip) application, area supervision changed and, without unequivocal evidence of the contribution of Critical Chain, the new supervisor rejected CCPM and decided to adopt a more traditional scheduling approach. Follow-on performance deteriorated, but not significantly enough to return to use of CCPM.

Third CCPM implementation: Wing Systems Installation Assembly

Because of its importance in gaining full recognition of substantial Critical Chain benefits, the third employment of the CCPM innovation requires more attention here. This CCPM application involved the area called Wing Systems Installation Assembly where hydraulic aircraft control systems actuators and lines are installed on the leading and trailing edges of the wing and sensors and power and cooling lines for avionics components and power lines for navigation lights are installed inside the wing.

The application of Critical Chain to this assembly area was considered an excellent test of the innovation, because the planned work for the assembly had never been completed in the Boeing plant. Instead, nearly 40 percent of the work undone in Seattle was "traveled"[53] to the aircraft assembly area in Marietta, Georgia.

To solve these problems, the factory manager and the assembly area supervisor agreed to evaluate CCPM. An AIW was conducted and led to many improvements in the organization of workspace, parts and tools. At the same time, the CCPM approach was followed to complete a network precedence diagram with the involvement of mechanics and supervisors from the first and second work shifts. Figure 25 depicts the results to illustrate the complex nature of a precedence diagram. Once the task relationships were established, the mechanics were polled and provided "aggressive" durations equivalent to about 70 percent of the standard durations. The mechanics also assisted the Critical Chain facilitators in assigning appropriate resources to each of the tasks.

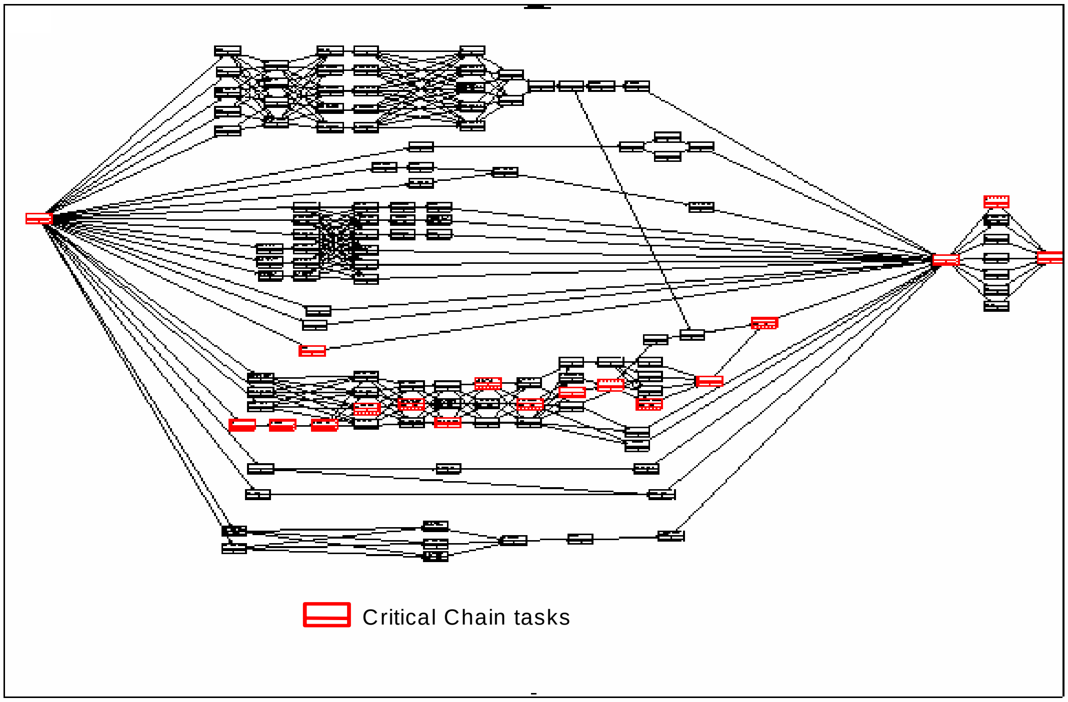

Figure 25. CCPM network diagram for the F/A-22 wing systems installation.[54]

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[53] Any work requiring completion in an area other than originally planned is called "traveled work" and applies whether the work "travels" one assembly area to another or to a different location.

[54] When the diagram is expanded to that the text is readable, each of the tiny boxes reveals task details (e.g., task name, ABP and HP durations, resource names, etc.).

In the first Wing Systems Installation assemblies affected by the AIW/Critical Chain improvements (Figure 26, Units 2 and 3), problems associated with network diagram inaccuracies were encountered and overcome, but the improvement over the previous assembly was credited to generally following the better work sequencing rather than Critical Chain. Despite a labor strike affecting Unit 3, it was essentially complete and shipped to Marietta, GA, while systems installation work was suspended on another wing that had just started.

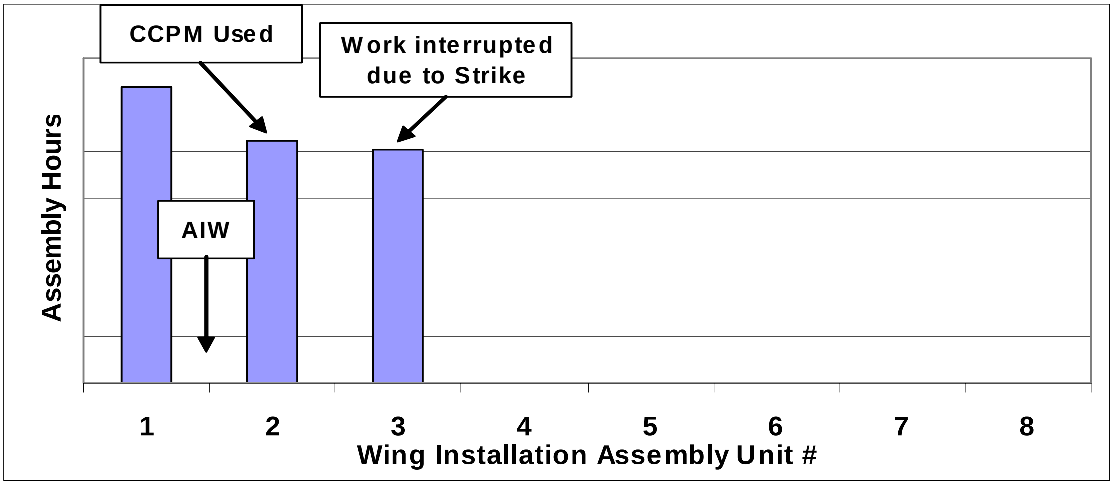
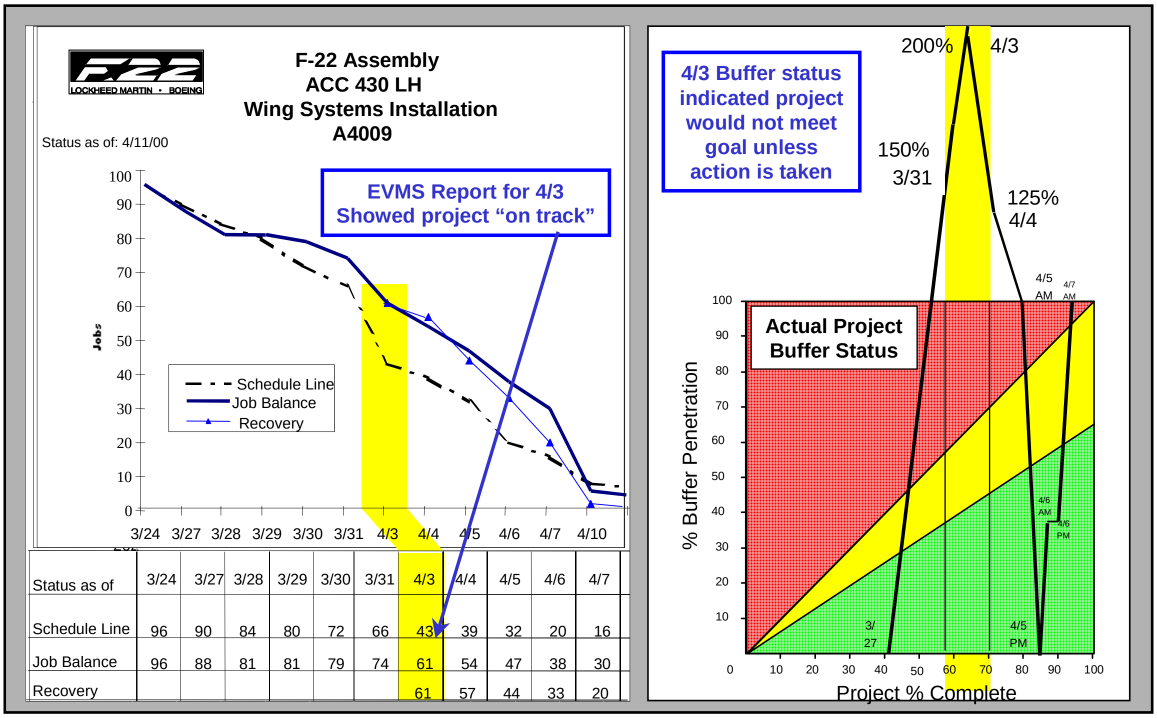


Figure 26. Initial application of CCPM to wing systems installation (Christ, p. 16, 2001).

When the workforce returned to work after the strike, there was considerable pressure to deliver the next wing on time, an extremely challenging goal. In response, the AIW facilitators prepared a Critical Chain schedule, incorporating improvements from lessons learned on the wingtip and fuel tank applications as well as the experience from the first two units in the Wing Systems Installation area. At the same time, a traditional schedule, based on Earned Value Management System (EVMS) was also prepared using the MS-Project™ form of the same precedence network diagram on which the Critical Chain schedule had been based. As work began on the third assembly, both Critical Chain and the EVMS schedule showed the project was on track (Figure 27.)

Just days later, the two reporting systems began to sharply differ. The EVMS reports (left side of Figure 27) indicated the project remained on track, but the Critical Chain buffer report at the time (right side of Figure 27) showed a dramatically different story.



Status as of	3/24	3/27	3/28	3/29	3/30	3/31	4/3	4/4	4/5	4/6	4/7
Schedule Line	96	90	84	80	72	66	43	39	32	20	16
Job Balance	96	88	81	81	79	74	61	54	47	38	30
Recovery							61	57	44	33	20

Figure 27. Comparison of EVMS and buffer reports for wing systems installation, Unit #4 (derived data obtained from Christ, June 2001).

With the help of the CCPM scheduler, the Wing Systems Installation area supervisor concluded that the reason for the difference was that the focus of the work force was *not* on the most important tasks—those on the Critical Chain—even though sufficient work credit was being "earned" to meet the EVMS "on-track" criteria. As a result, the supervisor decided to put his faith in the buffer reports. In fact, by following the information derived from the CCPM schedule, the wing systems were installed on time and the wing was delivered by the cargo aircraft on schedule.

The evaluation of this application (Unit 4 in Figure 28) showed that by using Critical Chain as the primary reference, the schedule goal had been met with full content *and* with the lowest budget and least traveled work to date. The results met the company objective and the implementation was considered a breakthrough by CCPM proponents since results were clearly credited to CCPM as the critical difference.

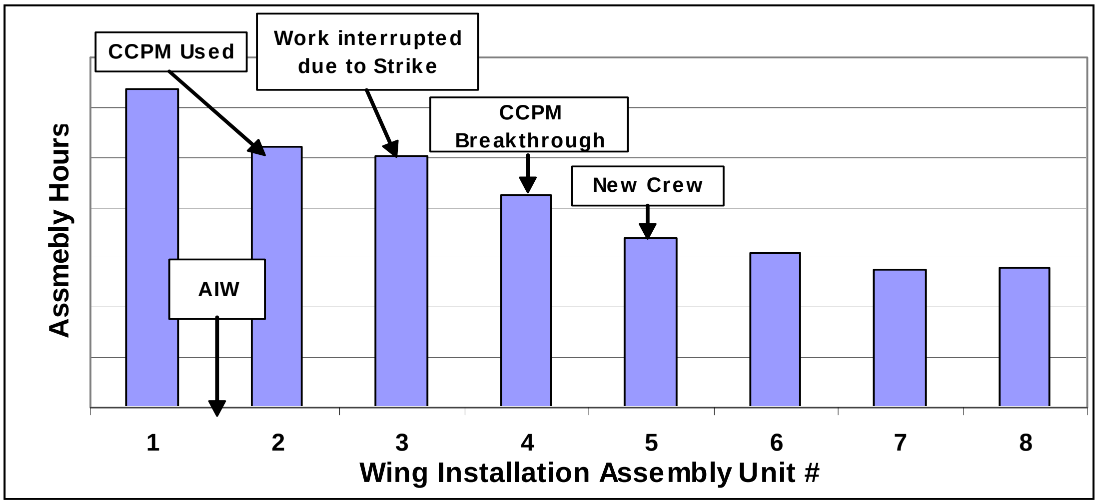


Figure 28. Continued application of Critical Chain to wing systems installation (Christ, p. 16, 2001).

From the supervisor's perspective, the results were so compelling that he became a vocal advocate for expanded employment. He described the multiple benefits to management as shown in Table 2. He was particularly enthusiastic about buffer management, which consistently provided facts and help with "what-if exercises"[55] to decide where to focus his efforts (personal communication, June, 2000).

BENEFITS OF CRITICAL CHAIN FOR LINE SUPERVISOR

- The ability to do a quick analysis of Work-Around scenarios and determine their impact
- The ability to ensure that next available mechanic works the job most critical to project
- Supervisors don't have to touch every job, every day to know the job is on track
    - More time to focus only on the jobs that need help.
    - Ability to prioritize based on data instead of a "gut feel" for which delays will impact delivery.
    - Knowledge of which jobs have buffer impact and need attention.
    - Recognition of Buffer impact on shift focus reports, thereby providing time to recover
    - Atmosphere of trust, team attitude, even across shifts.

Table 2. Highlights of wing system installation supervisor's view of Critical Chain benefits (Trip report, Boeing-LM Aero TIM, June 2000).

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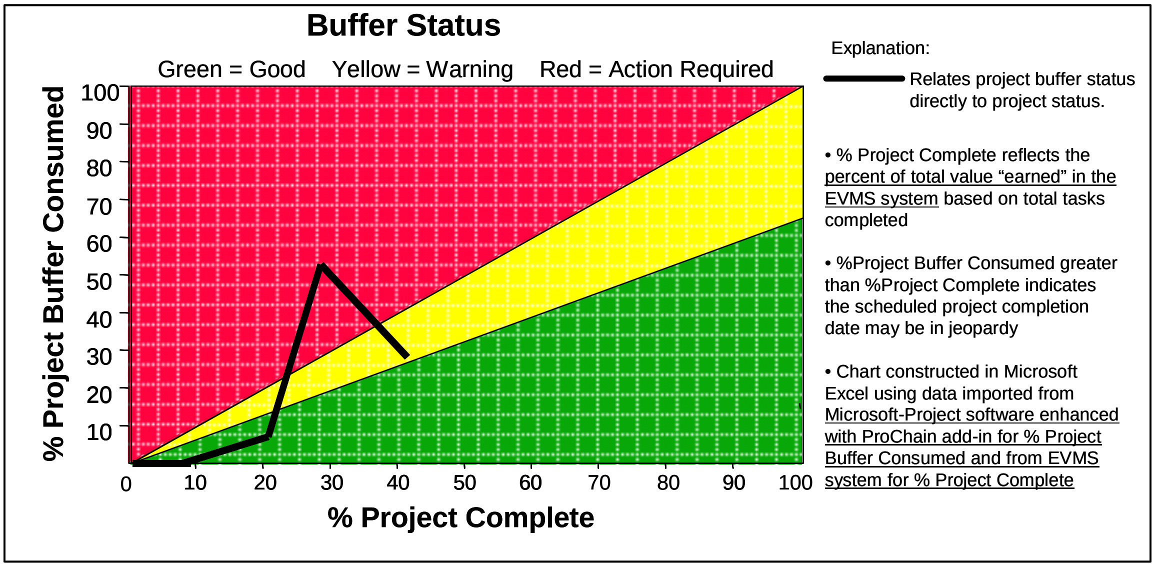
[55] "What-if exercise" is the colloquial term for what is essentially a sensitivity analyses. With the help of the CCPM scheduler, the supervisor could assess the impact on project completion by asking "what if"—e.g., What would happen if changes were made in work flow and resource assignments? These exercises could be run very quickly using the software and produced options based on reality (vs. intuition-based decisions of the past).

The evaluation process continued with the next units (Figure 28) in order to continue validation of the impact of CCPM. During execution the supervisor used Critical Chain reports as his guide for prioritization of tasks and disregarded the work-flow indicated by the EVMS reports. The crew working Unit 5 had never performed the tasks in this assembly area, yet achieved a 30 percent reduction below the previous unit. On time deliveries with additional labor savings continued (Christ, p. 15, 2001).

Before expanding the use of Critical Chain to the rest of F/A-22 assembly operations, the utility of Critical Chain for monitoring the schedule and guiding actions to assure on-time delivery had to be reconciled with the contractual requirement to report progress using EVMS metrics. The solution to the apparent dilemma was an elegantly simple one: a change in format of the “fever” chart (introduced earlier, Figure 24). The change (shown in Figure 29) was to retain the use of ProChain data to report project buffer status (i.e., the amount of project buffer consumed) on the vertical axis, and import data from the EVMS system to depict the percent of the project that was complete on the horizontal axis. Though this change meant that the “% Project Complete” would



Relates project buffer status directly to project status.

- % Project Complete reflects the <u>percent of total value “earned” in the EVMS system</u> based on total tasks completed
- %Project Buffer Consumed greater than %Project Complete indicates the scheduled project completion date may be in jeopardy
- Chart constructed in Microsoft Excel using data imported from <u>Microsoft-Project software enhanced with ProChain add-in for % Project Buffer Consumed and from EVMS system for % Project Complete</u>

Figure 29. Revised buffer chart using Critical Chain and EVMS information (Christ, p. 25, 2001).

be more approximate than exact, this was found to be “good enough”.[56] The value of consistency with EVMS tracking was much greater than the exactly correct CCPM percent complete (personal communication, Christ, 2002). Especially important was that the CCPM process forced attention to the critical chain asks, and discouraged the temptation to work easy tasks to earn value.[57]

Effectively, agreement reflected in the construction of the Buffer Chart resolved the conflict between the CCPM and EVMS systems and permitted the strengths of both to be used where needed. The CCPM information was most critical at the working level, because it provided solid, decision-support assistance on where best to focus efforts to remain on track to project completion. Simultaneously EVMS information was reported to upper management where the metrics could be compared across all areas.

Based on the foregoing agreement, the factory manager directed expansion of the CCPM process to the entire F/A-22 manufacturing operations floor during the remainder of the year 2000. This meant that the CCPM process was applied in a total of 37 assembly areas. The approach to schedule development, reports, CCPM-EVMS “fever charts” and execution in other areas mirrored that used in the later applications in the wing systems installation area. The supervisors are provided the buffer charts updated on a daily basis by industrial engineers who support the various assemblies.

Part B: Analysis

The purpose of this section of the chapter is to assess whether or not evidence supports the construct validity of anticipated improvements related to schedule performance in the Boeing manufacturing assembly area. In addition, the analysis examines the CCPM innovation to gain insights on the adoption of the innovation using

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[56] Close scrutiny during execution of active projects showed a maximum difference in “% Project Complete” from EVMS and that from the ProChain tool to be 2-3 percent, insignificant for improvement team purposes.

[57] If the supervisor chose to disregard the critical chain and work easy tasks to earn value, the impact would be quickly reflected in the “% Project Buffer Consumed” and penetration of the yellow or red zones in the Buffer Charts. As a result, the supervisor would likely be directed to refocus on critical chain tasks.

the lenses provided by CHIP model. S*tructural levels and actors* will be referred to in discussion of the CHIP model as well as summarized in a separate section.

Assessment of CCPM-driven Changes in the Boeing Assembly Area

The sections above establish, quantitatively, that two of the changes noted in the earlier discussion of construct validity, namely: Change 1 “on-time achievement of CCPM schedules” and Change 3 “improvement in schedule performance compared to the past.” A top-level review suggests that CCPM “delivered” in each implementation.

However, quantitatively establishing the exact share of credit due to CCPM within overall performance improvement achieved in each implementation is difficult because CCPM was just one element of the Accelerated Improvement Workshop (AIW) initiative. Essentially, the difficulty segregating the CCPM contribution from other AIW-driven improvements reflects the impact of the technology cluster described in Chapter 3. Actually, the technology cluster acted as a two-edged sword. On the plus side, the AIW requirement to build an accurate network diagram was an advantage for CCPM and made its inclusion somewhat transparent among other initiatives. Even introduction of sharply reduced task times prompted by CCPM was somewhat masked as part of the “standard” use of precedence diagrams. Worker perception of the network diagram itself as more important than task duration estimates was reflected in acceptance of 50 or 70 percent reductions in durations with only mild skepticism (vs. outright rejection).

As expected, even though making it a part of the AIW implementation permitted introduction of CCPM with little fanfare or focus, the negative edge of the technology cluster phenomenon made establishment of the unique value added by CCPM problematic. Without unequivocal, compelling proof of its value, the supervisors in the first two applications in the wingtip and fuel tank areas “rejected” CCPM and returned to traditional scheduling methods (in the wingtip and fuel tank assembly areas).

Finally, however, in the presence of a near crisis, when data from the EVMS and the CCPM systems differed, the value of the CCPM innovation was established. Here there is evidence of support for the second change anticipated as part of construct validity: "Improved ability to anticipate and mitigate difficulties in schedule execution." In particular, the value of CCPM was recognized in CCPM reports of status which forced attention to the tasks most important to overall goal accomplishment—delivery on time with full content—even in the face of difficulties. This very helpful prospective guidance provided by CCPM stood in stark contrast to the only other tool management had depended on—EVMS—which accurately recorded completed work, but provided little help, and sometimes conflicting signals (as in the third, wing systems installation) to the supervisors and managers on the factory floor regarding what to do next.

Results, both quantitative (on-time deliveries, budget savings) and qualitative (supervisor comments) reinforce the expected value of the CCPM innovation. Negative behaviors such as Parkinson's Law and student syndrome seemed to be avoided by the frequent updates and status reports and by the fact that the workers began to treat the aggressive times as the goal. Workers also took responsibility for and were interested in the schedule because they knew their information was its foundation.

Overall, from the Boeing factory management perspective, there was virtually no doubt that CCPM was the dominant factor aiding prudent decision that led to success. The factory manager's decision to direct expansion across the remaining 37 assembly area underscores his conviction that CCPM value was unequivocal and compelling.

Though interview data was sought when details on the CCPM implementation were obtained for purposes of the dissertation, most of those involved in the initial applications were not available, having gone on to other assignments or projects. The author was able to obtain survey responses from only three of the managers/ supervisors. For an overall perspective, those available were asked "How do you assess the utility of the Critical Chain approach to planning, scheduling, tracking and managing compared to others on a scale of 1-10 (10 being the best)?" The responses were two "10s" and an "8." Though clearly inconclusive, these responses suggest strong support for CCPM. As to "why" Critical Chain "works", the following were the responses:

- Eliminates excess time from existing scheduling methods.
- Focuses on early variation detection and allows time for proactive recovery.
- Places focus on the proper place, and provides clear feedback to managers.

Again, not conclusive, but indicative that the implementations achieved success in embedding the strengths claimed for CCPM—use of "aggressive" task durations, focusing on and reacting to knowledge about variability, and focus on the important tasks, i.e., those on the critical chain of tasks.

Analysis from the Perspective of the CHIP Model

Within the framework of the CHIP model, besides the initiation and implementation stages and the innovation decision that separates these stages, we are interested in other areas. The motivation for adopting an innovation is of interest to assess whether, in the acquisition environment, the theory that a performance gap or crisis is required to generate interest in an innovation. Also the number, nature and level of the decisions made during the process is of interest is assess these characteristics are affected by the IPT environment;

Motivation for Innovation

From a top level, the residual effects of the F/A-22 survival from Congressional threats of program cancellation, the awareness of the product delivery delays and the need to respond to the serious schedule challenges facing the F/A-22 program at all locations essentially represented at least a performance gap, if not a crisis, which forced both Program and Operational-level organizations to recognize the need for a change.

That change was clearly needed was validated by Program-level groups, from F/A-22 Team leadership at (Tier 1) direction to fix the problem, to local management and labor organizations' intent to meet commitments (Boeing Company level). In this case, the response to the crisis—the initiation of the AIW process—essentially forced the innovation of interest, CCPM, into an "innovation within a change process", a fact that eventually made it hard to assess the effectiveness of the innovation.

Initiation Stage

In this application of CCPM, top management at the Boeing plant was largely responsible for what might be described as an integrated *agenda setting/ matching* phase. Leaders perceived and decided to react to the problem, provided the overall strategy, direction and motivation for the more encompassing use of the proven (within Boeing) AIW process for change that eventually included the CCPM innovation. Because of the experience of the leader and another member of the Lean Improvement Team with CCPM, there was some analysis that could be characterized as *matching*¸ but use of CCPM was almost a foregone conclusion.

Innovation Decision

Within the overall IPT organizational framework, the decision protocol—generally delegating more authority for decisions on processes to the F/A-22 Integrated Product Team at the Operational level—was not reflected very clearly in the initiation stage. Essentially, that is because the Program level mandated (an authority decision from the CHIP perspective) implementation of the AIW innovation, a radical innovation for all assembly F/A-22 areas. Within that overall AIW mandate, CCPM was an incremental innovation, and the initial decision to employ the CCPM innovation was also made at the Program. Though nearly a "non-event" in comparison to the CHIP model expectation of a fairly visible process and go/no-go decision, this "optional" innovation decision seems consistent with the findings of the Minnesota Studies reported by Schroeder et al (1986) as reported in Rogers (2003). The finding suggests that receptiveness to an innovation is facilitated when the innovation is initially developed “inside” the user organization. In this case, CCPM inclusion in the AIW was decided by the Lean Improvement Team “inside” the broader F/A-22 team. However, even though the Operational-level IPT CCPM did not get a vote on the *initiation decision* to use CCPM, it was almost thwarted by a kind of “outsider” problem akin to that affecting the participant observer role as described in Chapter 3, when the Operational-level IPT did assert its decision authority.

Implementation Stage

The specific “outsider” problem that became apparent during the implementation stage was that despite their Program-level confidence in CCPM supported by what seemed positive results using CCPM, the improvement team was “outside” of the Operational organization doing the work in the first two areas of application. As a result, the policy of delegating authority-responsibility to the Operational-level unit responsible for the work, permitted two successive “contingency” innovation decisions by “inside” supervisors to reject the innovation. The real breakthrough decision favoring CCPM required both another crisis and a real “inside” decision maker at the Operational level. Only when the second “crisis” arose during the intensive post-strike efforts to deliver wings to meet a highly visible Boeing commitment *and* the decision-making supervisor on the “inside” experienced the benefits of CCPM was the innovation on solid ground. The positive value added of CCPM, especially relative to the “old” EVMS system, truly put the innovation on the road to success. Subsequent, very positive performance compared to, and reconciliation with, the EVMS data provided the foundation for the final decision to routinize (in Rogers’ taxonomy) the CCPM innovation at Boeing.

From the perspective of expectations based on the CHIP model, the process was not exactly consistent with the idea of a straight-forward series of implementing-clarifying-routinizing steps following the innovation decision, with perhaps one follow-on contingency decision. Instead, this implementation stage revealed an iterative process, involving several attempts to employ the innovation and a series of what might be characterized as several contingency reject/try-again decisions, capped by the supervisor's solid endorsement and the factory manager's authority decision for expansion across the factory.

Analysis from the Perspective of the Structural Levels and Actors Construct

From a broad perspective, the reality of the Boeing use of CCPM seems generally consistent with expectations arising from the structural levels theory of innovation. The Program level did initiate the innovation of which CCPM was a part and promulgate it top-down through the CCPM experienced engineers acting as the Program champions/change agents to support the application from initiation through implementation. Though the initial innovation decision was made by the Program as part the larger, mandated AIW radical innovation, other innovation decisions were made and implementation did occur at the Operational level. In this case, the perseverance of the change agents, the quantitative success (on-time, minimum-budget delivery), and the qualitative success (enthusiasm and real decision support benefits) were sufficiently compelling to gain acceptance of the CCPM innovation, promulgated by a final top-down directive from the manufacturing manager.

Regarding organizational actors, both groups and individuals were heavily involved in the application of the CCPM innovation. Besides the external actors, groups and individuals, the F/A-22 team leadership groups—the SPO, LM Aero and Boeing—all affected initiation of the AIW change and, by association, the CCPM innovation. The

Lean Improvement Team was the key group regarding the details of the AIW strategy inclusion of CCPM. From the beginning, including advocating approval for including CCPM in a mix of AIW improvement initiatives, the primary roles played by the individual actors were those of the two-engineer CCPM change agents and those who played the champions on either side of the change agents. On the working level side of the change agents, the Wing Systems supervisor became convinced of the value of CCPM and then transitioned a kind of grass-roots-level champion advocating expansion of CCPM. Clearly there was evidence of the "anti-champion" role, the supervisors who could have killed the innovation had it not been for the perseverance of the change agents. On the management side of the change team was the factory manager, who acted as a champion by encouraging the use and refinement of the CCPM innovation, and who eventually directed use of CCPM across the factory via an authority decision.

Summary

In Part A, the data derived in the case study demonstrates that CCPM was a very important component of the Accelerated Improvement Workshop (AIW) promulgated under the mantra of Lean Improvement. After some uncertainty, and even rejection because inability to validate the value of CCPM within a cluster of technologies, CCPM proved its value in a crisis situation by supporting the on-time delivery of a product that would have been delivered late if traditional (EVMS) tracking tools had been used.

In Part B, Analysis, construct validity was verified in that the changes expected with the implementation of CCPM did occur and were supported by quantitative evidence. The very limited survey data on the utility of CCPM for anticipating problems tends to provide some evidence for strength of CCPM in explaining the changes.

The perspectives of the CHIP model and the *structural levels and actors* construct for organizational innovation assisted in both organizing and analyzing the case study of CCPM use in the Boeing F/A-22 manufacturing assembly area. Most interesting regarding the CHIP model was the iterative nature of the implementation and the multiple, occasionally contradictory decisions that were involved before the innovation was finally declared a success. This observation might be explained as the result of fundamental differences between the acquisition environment and other public and private industry organizations where similar models and constructs were developed. However, it also seems very likely that the pervasive influence of the policy regarding delegation of authority and responsibility to the IPT actually responsible for the work is the driving factor.

The application of the CCPM innovation was shown to be quite consistent with the *structural* construct focusing on Program and Operational *levels.* Similarly, the *actors*—both groups and, even more so, the champion and change agent roles—were quite consistent with the expectations of the innovation theory. In particular, the application showed that thought the change agents originated from the Program-level, they were key advocates and facilitators of the eventually successful innovation at the Operational level. The foregoing observations are summarized in Table 3.

Construct validity: expected changes found?			
Change	1	2	3
short description	meets CCPM schedule	better ability to foresee & deal w/ difficulties	better than past
overall answer	yes	yes	yes
supporting evidence	some data clouded by technology cluster; other data unequivocal; limited survey support		

Structural Levels: Program and Operational
Program-level initiation & support for Operational-level implementation
Organizational Actors
group actors @ initiation; external champions & change agents throughout

Casey Hybrid Innovation Process (CHIP) Model				
Element of Interest	Motivation	Initiation Stage	Innovation Decision(s)	Implementation Stage
short description of application	performance gap; external pressure	external identification of CCPM	initial-authority; intermediate-contingent; final-authority	iterative process & decisions; CCPM impact initially unclear

Table 3. Analysis summary: CCPM case study in manufacturing operations.

Chapter 5: CCPM INNOVATION at F/A-22 PROGRAM LEVEL

Overview

This chapter describes and analyzes the initiation of the CCPM innovation at the F/A-22 Program level. Essentially, the Program level is the "top" of the organizational *structural levels* construct and expected to be the source for "top-down" initiation of the kind of process innovation that CCPM innovation represents (Daft 1978). It was the top of the Program level (Tier 1 in terms of the organizational hierarchy, Figure 13) where problems emerged that prompted senior leaders to direct a search for additional options for schedule management on the F/A-22 acquisition program. The chapter describes how Program recognition of CCPM's potential to deal with the problem led to a decision to facilitate demonstration of CCPM, not an irreversible "authority" decision as might be expected in most hierarchies and implied by Rogers (Chapter 2, p. 142).

In fact, there was not an implementation phase at the Program level. However, as described here and reflected in other case studies, the absence of a true implementation did not discourage further, on-going CCPM-related activity at this higher levels. In fact, Program-level encouragement and decisions fostered and continued to support the CCPM innovations on the F/A-22 program that are documented in following chapters. In that light, this chapter is useful in adding documentary "flesh" to the spare "bones" of the Integrated Product Team wiring diagrams of Chapter 3, thereby providing context and another level of insight for understanding the implementations to follow.

Part A of this chapter describes the initiation of the CCPM innovation at the Program level prompted by a failure in an initial solution to a flight test related schedule management problem. Part B presents analysis of the CCPM innovation using the lenses of the CHIP model and the *structural level and actors* constructs for organizational innovation.

Part A: Description

Initiation

In the spring of 2000, leaders of the F/A-22 program became increasingly concerned about worsening schedule management and product cycle time problems**.** In fact, these concerns were highlighted by problems that had begun to emerge in the summer of 1999 in the flight test phase of the program which was being conducted by the F/A-22 Combined Test Force (CTF) at Edwards AFB, California. At the time, the flight testing was falling short of objectives and a draft government study projected that F/A-22 Development Test and Evaluation (DT&E) flight-testing would not finish until August 2004, two years *later* than projected by the program. Responding to this urgent problem, the top technical leaders of the F/A-22 program, the government's Technical Director of the F/A-22 System Program Office (SPO) and LM Aero's F/A-22 Program Integrator jointly directed formation of a Flight Test Working Group (FTWG), with government and contractor representatives from across the F/A-22 program.

As one of two key FTWG actions, the author, a senior systems engineer/analyst for LM Aero, Casey, and a similarly experienced analyst from the SPO, Pennington, were assigned responsibility to review the government study. Their review led to discovery and correction of fundamental errors in the use of historical data and changes to substantially improve model accuracy and flexibility. In addition, Casey and Pennington expanded the model to permit projection of flight test hours based on a variety of factors, e.g., test aircraft deliveries, weather, estimated periods of time test aircraft would be in non-flight status—"down-time"—for modifications and upgrades.

Parallel FTWG efforts were undertaken to establish minimum flight test requirements for the two major components of the flight test program within the CTF: flight envelope expansion, under the supervision of the Flight Sciences Flight Test Operations IPT manager, and mission avionics testing, under the supervision of the

Mission Avionics Flight Test Operations IPT manager.[58] The envelope expansion effort streamlined and integrated the testing required to safely fly the F/A-22 throughout the speed, altitude and maneuver parameters (together called the "flight envelope") for which it was designed. Similarly, the mission avionics effort accelerated an effort already underway to streamline and integrate the flight-testing required to validate the avionics and weapon system capabilities for which the F/A-22 was designed.

Total flight-test hours and total numbers of separate flights (referred to as "missions" or "sorties") estimated to be required and all the other factors developed by the team were employed in the revised flight test program model produced by Casey and Pennington. All these factors were exercised over a wide range of closely scrutinized cases and sensitivity analyses to produce a proposed, team-validated program test plan, and metrics to track the plan when approved.

Just before Christmas, 1999, with the support and agreement of the primary IPTs and the CTF leadership, the System Program Director (SPD), at the F/A-22 SPO, and his counterpart, the LM Aero Vice President and F/A-22 Program General Manager (VP/GM), directed the implementation and monthly tracking of the proposed program.

In January and February 2000, the metrics for tracking actual flight-test progress against projections showed the program on track. However, it was clear by March that even with margins intended to conservatively account for uncertainty in the many factors included in the model, the flight test program, at that time involving only envelope expansion, was again falling behind projections. The F/A-22 team leadership regarded these early warnings with alarm because of the potential to compress the time available to complete development testing (DT&E), the most important factor in predicting success in Operational Test and Evaluation (OT&E) independently conducted by the Air Force. Because reduction in content or a slip in completion of DT&E could reduce confidence in

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[58] Hereafter the organizations are referred to as the Flight Sciences IPT and the Mission Avionics IPT.

successfully “passing” OT&E, the early warning of flight test slippages provided the catalyst to initiate a look at a better way to manage the flight test program.

To carry out this effort, the SPO Technical Director and LM Aero’s Program Integrator tasked Casey and Pennington to look beyond the F/A-22 program at an approach to improve planning, schedule development and execution called the Theory of Constraints/Critical Chain Project Management (TOC/CCPM). The SPO technical director had seen it applied within the Edwards AFB flight testing component of the C-17 program, the program he had been assigned to before the F/A-22.

With the endorsement of this idea by the LM Aero Program Integrator, Casey and Pennington aggressively pursued this direction. Their efforts revealed that the TOC/CCPM approach had been successfully applied in many military and civilian areas with consistent success in generating and executing schedules, often with significant reductions in cycle times. There were some government test program applications,[59] but none of the reported applications of CCPM appeared to have occurred during the development phase of a major acquisition program like the F/A-22. Even so, prior results provided strong evidence that TOC/ CCPM had the potential to deal with scheduling challenges wherever on-time completion or system deliveries (up to and including the test aircraft) were a problem.

To help transform the concepts into a technical application on the F/A-22 program, Casey and Pennington sought advice on sources of technical support from several CCPM-experienced organizations as well as from Major Ross McNutt, lead for Air Force initiatives for Acquisition Cycle-Time Reduction in the office of the Under-Secretary of the Air Force for Acquisition (SAF/AQ) at the Pentagon. A technical support

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[59] At their Langley Research Center, VA, National Aeronautics and Space Administration (NASA) reported 35-50% reduction in wind-tunnel project durations, one-third fewer workers and much less overtime within a more efficient and technically sound plan. (A.G. Hageman, unpublished briefing, *The Critical Chain Project Management Technique,* March 2000).

contractor (TSC[60]) was selected from many identified as being familiar with development programs and Air Force processes.

In April 2000, initial discussions with the TSC representative made it clear to Casey and Pennington that CCPM could be evaluated in an F/A-22 development program demonstration. To that end, the TSC offered to provide introductory training for management and help in designing a program to demonstrate the CCPM innovation for the F/A-22 program, assuming a program decision to do so. The best period for conduct of the training course, the first step for a CCPM demonstration, was late-July/early-August, 2000, timing that forced aggressive arrangements for a detailed initial "education" session for selected program personnel.

This initial education program was conducted by the TSC representative as a one-day session at Marietta to explain CCPM concepts to a larger group and to gaining understanding, "buy-in," and assistance in identifying a locus for the demonstration or pilot program[61] within the F/A-22 program and, potentially, other programs within LM Aero.[62] The six-hour training session convinced attendees that use of CCPM had significant potential for improving F/A-22 planning and schedule management.

Most important, after the training session, a meeting was arranged for Casey, Pennington and the TSC representative with LM Aero's F/A-22 Program Integrator. Though the meeting lasted less than an hour, the Program Integrator immediately endorsed the idea of a CCPM pilot as the quickest way to evaluate and, hopefully, prove the value of CCPM. He directed Casey and Pennington to lead the effort to demonstrate

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[60] Hereafter, the acronym "TSC" is used as a generic reference to a CCPM-expert individual or company that provided assistance with CCPM applications; TSC is not the name of a company.

[61] For purposes of this study the terms "demonstration" and "pilot" are used interchangeably.

[62] The primary participants in the TSC training were Casey and Pennington, the Master Scheduling IPT leader and two members of that IPT, and two representatives of the System Engineering functional group at LM Aero-Marietta, invited to assess possible application of CCPM to other programs at Marietta or elsewhere in the LM Aero structure. Though Edwards AFB F/A-22 Combined Test Force (CTF) Mission Avionics flight test program seemed the most likely host for a at the time, higher priorities at the CTF prevented travel for participants from Edwards AFB in the meeting.

the CCPM innovation and expand use elsewhere in the program if the approach worked as well as other experience indicated. He strongly encouraged efforts to establish a contract mechanism and find a funding source to facilitate the demonstration and to simultaneously and aggressively press efforts to find a host IPT for such a CCPM pilot. Importantly, though the perceived CTF schedule management problem was the catalyst leading to CCPM as a possible solution, the Program Integrator's direction broadened the range of potential implementations to any suitable area of the program with an identifiable schedule problem. By encouraging the search for external funding, the Program Integrator anticipated the need to eliminate initial costs as a barrier to implementation by any IPT willing to sponsor a demonstration of the CCPM innovation.

Acting on the direction involved two parallel paths by Casey and Pennington: (1) an effort to detail a demonstration program using an appropriate contract mechanism and supported by appropriate funding, and (2) an effort to identify a specific program area to host and evaluate a demonstration of the CCPM approach to schedule management as a basis for expanding use of CCPM to other F/A-22 program.

Structuring a Generic Project to Demonstrate the CCPM Innovation

On the contracting/funding path, Casey and Pennington worked with the TSC to structure a program and then translated that structure into a contract document which permitted cost estimation for the proposed approach. Based on the TSC's extensive experience in other locations involving both development and manufacturing situations, Casey and Pennington designed a generic pilot program that could be carried out in one area of the program and quickly expanded to other parts of the program as suggested by the F/A-22 Program Integrator's vision. The program included a two-week training course in a state well away from F/A-22 facilities[63] for both the group tasked to

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[63] Though logistically less attractive than conduct of the course at Marietta where most attendees were

implement CCPM in any demonstration program at a particular site and others that might support the initial demonstration or follow-on expansion of CCPM use to other areas of the F/A-22 program. The generic pilot program also included on-site TSC support for the development of the demonstration in a particular area and its evaluation for potential expansion to other parts of the development program. All of this information was quickly translated into a Statement of Work (SOW) for the pilot program. To officially initiate the study/evaluation of CCPM, Pennington helped draft a contracting letter sent to LM Aero requesting a proposal and estimated costs for accomplishing the effort.

With the support of the LM Aero Program Integrator, Casey generated a proposal responsive to the contracts letter and provided a Request for Proposal (RFP) to the TSC for a cost estimate of the training and technical support components of the pilot program. Because of earlier discussions, the TSC quickly responded. With the TSC input, total estimated costs of $250K included F/A-22 contractor tuition, labor and travel for training of 10 personnel at the TSC's headquarters and for TSC pilot implementation support.

Supporting the cost of the CCPM pilot required a search by the Casey and Pennington for funding from a source external to the program because F/A-22 funds would not be available until the beginning of October 2000 (the beginning of the government fiscal year), thereby “missing” the training window established by the TSC. After failing to find a source within a number of offices and organizations assigned to Air Force Materiel Command (AFMC), parent of the F/A-22 SPO, at Wright Patterson AFB, OH, attention turned to the Pentagon in Washington, DC. Because of earlier conversations about CCPM in general, Casey and Pennington found Major McNutt to be an understandably supportive ally after they described the F/A-22 program situation and the need for funding to support a demonstration of the CCPM innovation. The generic description of the demonstration contained in the Statement of Work, the cost estimates

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located, avoiding the risk that attendees would be pulled out of training for other priorities justified the plan.

and proposed approach for the pilot were translated into the Pentagon-preferred outline ”talking paper” format. After a relatively short internal coordination process, Major McNutt reported optimism that needed funding could be provided within that part of DOD Acquisition Reform focused on Cycle-Time reduction for which he was responsible.

Finding a Candidate for a Project to Demonstrate the CCPM Innovation

Along the second path, finding a host for the conduct of a CCPM pilot project, Casey pursued several possibilities. As a hedge against reluctance or inability of the CTF to host a CCPM demonstration, the area of structural testing was identified as a possible pilot program venue.[64] The objective of a CCPM demonstration in this area would be to help responsible IPT leaders (and the program) avoid emerging delays in the ground structural testing of the F/A-22. To help the leaders evaluate the potential value of the CCPM innovation to support timely structural testing, Casey scheduled a series of meetings to introduce them to CCPM concepts. Unfortunately, while it was clear to the Structural Test IPT that the CCPM approach could very effectively deal with these and other problems, a mismatch existed: The time-line for resolution of the test schedule management problems was shorter than that required to properly train staff members on CCPM concepts and supporting software and actually initiate a CCPM demonstration project within structural testing IPT area.

With structural testing eliminated from further consideration as a CCPM demonstration host, there was renewed motivation to gain interest in the use of CCPM at the Combined Test Force at Edwards AFB. Since flight testing was a top program priority, CCPM success could bring both great benefits for the team and recognition of

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[64] This testing involved two full-size F/A-22s that were built to be exactly like the flying aircraft or, where appropriate, to faithfully represent the structure and mass of the flying aircraft.[64] One, F/A-22 S/N 3999, was built for static testing to assure that the ultimate strength of the F/A-22 structure met specifications. The other, F/A-22 S/N 4000, was built for fatigue testing to assure that the aircraft could absorb the dynamic loads representative of those expected during the life of the aircraft. Information from these tests was required by the CFT to assure ground testing was sufficiently consisted with analytic predictions to permit flight-testing to the outer limits of the F/A-22 performance envelope.

the utility of the CCPM innovation. In addition, delivery of the first test aircraft equipped for avionics flight test was several months away from the May-June 2000 period when a demonstration candidate was being sought, so there was sufficient time for CCPM training and schedule development before Mission Avionics flight testing would begin.

To permit the face-to-face discussions required to gain an understanding of the potential value of CCPM for flight testing, an all-morning meeting was arranged for 23 May 2000 at Edwards AFB with the Mission Avionics IPT leader and key personnel from the CTF organization. To complement the planned CCPM overview presentation by the TSC, representatives from C-17 and F-15 organizations at Edwards AFB that had experience and success with CCPM were invited to demonstrate to the Mission Avionics IPT members that CCPM concepts could be applied to the flight testing environment.

Before the meeting, the Mission Avionics IPT manager was invited to begin the meeting by briefly describing what he saw as the primary challenges to successful execution of the Mission Avionics flight test program. The intent was to provide a backdrop for the CCPM overview, during which the TSC could explain how various aspects of CCPM might deal with the problems identified.

Unfortunately, the extensive detail in the Mission Avionics manager’s remarks extended more than half of the four-hour morning meeting. Noting he had some familiarity with Goldratt’s work, he saw several roadblocks to use of CCPM:

- Projected delays in the delivery of test aircraft and stretch-outs in the functionality of the aircraft when they were delivered presented limitations that made it unclear to him how any approach to scheduling could mitigate the effects of these factors.
- The dynamics of constant change in thousands of tasks of varying length, hundreds of individual flights, and a myriad of planning and execution factors in the CTF environment, made CCPM less appropriate for flight test than more stable environments (e.g., manufacturing operations).

- Based on his extensive experience he did not see the potential payoff of—and could not afford the labor associated with—what he expected would surely be a several-week Critical Chain schedule development effort.
- The offer of CCPM assistance was too late to convince senior management of realistic constraints and, therefore, of debatable value (like other management approaches—“techniques du jour”—such as Management by Objectives (MBO), Total Quality Management (TQM), Lean, etc.

Overall, the Mission Avionics IPT manager did not think CCPM could work in the F/A-22 test environment and “we’re way far away from changing behavior—it’s already bad.” He did note that he felt quite strongly about the inapplicability of CCPM to flight test operations, but acknowledged it might work in the maintenance modification area (personal notes from the meeting, 23 May 2000).

In the limited meeting time available to emphasize a few salient points of the Critical Chain approach and respond to some of the manager’s strongest reservations about the utility of CCPM for Mission Avionics, the TSC presentation was unable to reverse opposition to development of a CCPM pilot in the Mission Avionics flight test arena. The Mission Avionics IPT leader was not moved either by the offer of a “fresh look” at program challenges using the Critical Chain that might, indeed, discover some economies that would help. In response, the Mission Avionics IPT manager strongly suggested that the best thing the program could do with CCPM would be to apply it elsewhere to overcome schedule delays and assure timely delivery of the test aircraft, avionics hardware and software and data from other ground tests needed for successful execution of the test program.

Essentially, the Mission Avionics IPT leader’s argument was that he understood the flight test requirements and if required resources were provided, he could execute the program. In addition, he confidently indicated he could satisfy the requirements without external help, since those without specific relevant experience would not understand nor likely contribute to operating in the unique and dynamic development flight test environment.

The reluctance of the CTF to initiate a CCPM pilot project dealing directly with the flight test program at Edwards AFB prompted program leadership to accept the CTF suggestion to apply CCPM to one or more parts of the program that directly supported the flight test program. As a result, given that flight test aircraft delivery was an overriding determinant of flight testing pace, Casey's attention turned to IPT responsible for delivering the aircraft to flight test, the Build IPT, or simply "Build Team" at Marietta as a possible setting for demonstration of the CCPM innovation.

The Build Team included subordinate IPTs for Manufacturing Operations and for Flight Line Operations. Prior to delivery to Edwards, the IPT was responsible for the fabrication and assembly of major components built at the Marietta plant (forward fuselage and empennage)[65] and for final assembly, ground and initial flight-test of the entire aircraft prior to delivery to Edwards AFB for further flight-testing by the CTF. Logically, if CCPM could be applied in this area to reliably assure on-time or early test aircraft delivery, chances for timely, successful completion of DT&E would be enhanced.

At the time of the initial contact with Build Team leaders in early June 2000, a total of three test airplanes (serial numbers 4001, 4002 and 4003) had been delivered to Edwards AFB to begin flight-testing to expand the flight envelope to full capability. Aircraft 4004 was in being prepared for ground testing (initial engine runs prior to taxi and initial flight-testing) on the flight line at Marietta. Other aircraft (4005-4007) were in various stages of assembly in the Marietta plant. In the dynamic aircraft development environment, there was no shortage of interim and final delivery challenges associated

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[65] The empennage consists of the the horizontal stabilizers and vertical stabilizers with the integral rudders.

with virtually every aircraft. In fact, delayed test aircraft deliveries to Edwards AFB had been the primary factor in the failure to track to flight test goals set in late 1999.

Build Team leaders already had an initial appreciation for the concepts and efficacy of CCPM because they had attended an early-May Enterprise Lean Team (ELT) Video Teleconference (VTC).[66] At that meeting a representative of the ProChain[67] Company provided an introduction to CCPM principles and examples of reports generated by the supporting software developed by ProChain. Boeing representatives also presented an overview of the positive results achieved in applying CCPM to the installation of wing systems.

With some interest in CCPM already established, the Build Team leader readily agreed to Casey's request for a meeting on 12 June 2000, for key personnel to permit an introductory briefing on CCPM and a discussion of possible applications in the Operations IPT at Marietta. Besides the Build Team leader, there were several of the most influential F/A-22 program IPT leaders, including those for the Air Vehicle (design), Manufacturing and Flight Line Operations, Composite Assembly, Operations Support Systems, Utilities and Subsystems, Master Scheduling, and Lean Engineering Initiatives.

At the meeting, Casey presented an overview of CCPM concepts and the outline of the generic process for developing a demonstration of the approach within the Build Team area of responsibility. He also noted the urgency to make a decision because of the tight CCPM training window in July-August 2000. A spirited discussion followed the briefing. On one hand, the Build Team leader expressed serious concern that the visibility of the buffers would make the team very vulnerable to more intense scrutiny than was already being felt. In addition, he viewed it as quite possible that the buffer

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[66] ELT VTCs were set up by the F/A-22 Program office to serve as a catalyst and monitor for team-wide lean engineering initiatives. Tthe VTC forum provided the opportunity for team-members from across the country to share results of improvements in manufacturing operations initiated under the umbrella of Lean.

[67] As noted in Chapter 3, ProChain, Inc. is one of the first companies that developed computer software to enable the application of Critical Chain concepts to projects.

would be viewed as “management reserve” and removed from Build Team control by higher management, making an already difficult job virtually impossible. On the other hand, the Air Vehicle leader was enthusiastic about the CCPM system approach. He especially liked the visibility of the buffer and expressed his strong belief that it was smart to put buffers in critical places. He noted, “We already use a lot of ‘buffers’ without calling them that. It’s not a huge leap to regularly communicate the information in this [CCPM] form” (authors notes of meeting, 12 June 2000).

Recognizing the potential for diversity of opinion within the group, a fact-finding Technical Interchange Meeting (TIM) at Boeing was recommended so that Marietta personnel could meet with the people—from floor supervisor to managers—directly involved in Boeing’s CCPM application and get answers to detailed questions. The Build Team leader agreed to sponsor the trip, subsequently scheduled for 28-29 June 2000.

With that agreement made, the discussion immediately turned to potential demonstration areas if the TIM results warranted such action. Schedule planning and management problems were identified in the final assembly area of the factory, the flight line operations area as well as the finishes area (which had failed expectations on the first aircraft to undergo full stealth finishes). Though as noted by the Build Team lead the real payoff would eventually be in the factory, a consensus began to emerge that the most immediate need was in the post-assembly area, i.e., flight line operations. Within that area, aircraft finishes appeared to best combine need, timing and scope factors to serve as a demonstration venue.

Before the trip to Seattle, given optimism that a potential pilot was within reach, Casey and Pennington intensified efforts to pull together the other elements required to meet the timeline for initiation of the pilot. Besides working to finalize the demonstration project contract, discussions continued with Major McNutt, who reported that tentative approval of the funding had been obtained and he was working to “push” the required paperwork through the Pentagon's fairly complex financial system. Pending completion of that action at the Pentagon, F/A-22 team-level contracting actions were processed through both contractor and government procurement systems to the point that only funding and a decision by the Build Team remained open.

Convincing Evidence to Complete Matching at the Team Program level

The fact-finding TIM at Boeing's assembly plant outside of Seattle, Washington, officially began on the afternoon of 28 June and lasted through 29 June. Besides Pennington representing the SPO, LM Aero attendees included Casey, the Air Vehicle and Flight Line Operations IPT leaders, the Finishes IPT lead engineer, and the lead Industrial Engineering functional representative from Marietta. The Boeing hosts included the Industrial Engineering Manager for F/A-22 Assembly Operations, the Lean Manufacturing Manager for F/A-22 Assembly (and primary Critical Chain expert) and the Manufacturing Research and Engineering (MR&D) process engineer primarily responsible for Critical Chain implementation planning and execution support.[68] The one and a half day meeting was as comprehensive as the Marietta visitors had hoped. The most compelling briefing was by the supervisor of the Wing Systems Installation assembly area. He readily admitted he felt his job was on the line, and he was badly in need of help to assuring on-time delivery of the wing completed during the pilot. His glowing comments about the value of the Critical Chain information were very convincing. During the factory tour, supervisors and workers were uniformly supportive of the approach, some humorously recalling how ridiculous and unrealistic they considered the schedule built with aggressive task times. However, they noted that being able to focus on their tasks and following a plan they had a part in building worked out very well. As one lead put it, "I know how we're doing, what to focus on, and that

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[68] The Lean Implementation Manager and the MR&D process engineer were referred to as Boeing's CCPM change agents in Chapter 4.

we're going to finish on time. Life is good!" (Christ, p. 24, 2001) The TIM concluded with informal wrap-up discussions with all the Boeing and Marietta participants. When asked by Boeing managers what they thought, the team lead indicated that what made CCPM particularly appealing was the contribution to teamwork, the support for the supervisors and the buffer reports that helped stay ahead of problems.

Innovation Decision

Casey and Pennington led a discussion within the traveling group at end of the TIM at Seattle. The discussion produced consensus on a recommendation that Marietta proceed with a pilot, preferably in the area of F/A-22 finishes. In the words of the Flight Line Operation IPT leader: "We're sold! Our biggest fear is that top management will grab the pad [buffer] as soon as it's identified" (Casey, 2000).

On return to Marietta, the results of the trip and discussion were presented to the Build Team IPT leader and the Manufacturing Operations IPT leaders who agreed with the recommendation to move ahead. Build and Manufacturing Operations Team leaders also agreed that if the leader agreed to host the demonstration, the Finishes IPT was a prime candidate for two reasons. One reason was related to the claim that CCPM could capture and help deal with a substantial amount of variability. The leaders noted that the experience with 4004 had demonstrated that considerable variability remained in the materials, procedures, and the capabilities/qualifications of the final finishes workforce. The second reason was that the span required for application of final finishes for the full aircraft had been planned for 60 days and had taken 86 days for aircraft 4004. The leaders noted that because this span was the longest span after aircraft assembly, it had the greatest leverage in reducing the time for delivery of the flight-test aircraft.

The Build Team leader's endorsement of the Boeing TIM recommendations and view that the finishes area had excellent potential as host for the CCPM demonstration was necessary, but not sufficient for a final decision. Consistent with the F/A-22 IPT philosophy, the Finishes IPT leader had the final go/no-go decision, and he had not personally been able to attend the fact-finding TIM in Seattle. The Finishes IPT decisions became part of an initiation process at the working level in the finishes area prompted by the Program-level initiation process described in this chapter. The Operational-level innovation process—initiation, innovation decision, and implementation is described in detail in Chapter 6.

Part B: Analysis

The purpose of this section of the chapter is somewhat different than the other case study chapters, Chapters 4 and 6-8. Following brief comment on construct validity, the focus is on use the CHIP model and *structural levels and actors* constructs of innovation theory to examine the *initiation* stage, the motivation for innovation and the key *actors* involved in the CCPM innovation process at the “top” Program level.

Assessment of CCPM-driven Changes at the F/A-22 Team Level

Though there are no quantitative measures of construct validity generated by the Program-level activity associated with the CCPM innovation, these measures were considered by the team leadership. In fact, *the potential for* on-time achievement of CCPM schedules, improved ability to anticipate and mitigate difficulties in schedule execution, and improvement in schedule performance compared to the past were exactly the driving factors, demonstrated and reported by Boeing and reflected in other reports of the use of CCPM that were key factors in initial and follow-on support for the innovation by the program leadership.

Analysis from the Perspective of the CHIP Model

Within the framework of this model, the motivation for innovation as well as core initiation stages and the innovation decision are the primary interests. Though there was no implementation at the Program level, the activities there laid the foundation for the implementations that did take place at the Operational level.

Motivation for Innovation

The failure to establish and maintain the flight test program pace projected by the Flight Test Working Group at the end of 1999 certainly reflected the kind of performance gap expected to be involved based on the innovation framework. More than that, the urgent motivation to pay immediate attention to the “gap” was prompted by the surprising speed with which the end-1999 plan veered off course, despite the fact that all were convinced that the plan was able to absorb considerable variability. In the face of a potential crisis, the situation convinced the leaders that internal schedule management tools were insufficient and it was time to look outside the program for solutions. Virtually all levels of the F/A-22 formal organization reflected what Zaltman described as an “impetus for innovation” that “arises when organizational decision makers perceive that the organization’s present course of action is unsatisfactory” (p.55, 1973).

Initiation Stage

Once motivated to look outside the program, the search for a solution to the problem facing the F/A-22 team was fairly brief. Considering leadership direction to look into the potential of CCPM to help the F/A-22 program, the primary option for dealing with the identified problems seemed almost as given as the problem itself. However, following traditional bureaucratic protocol, Casey and Pennington aggressively completed the staff work, including many comparative results checks, conversations with those experienced in the use of CCPM and engagement of top subject matter experts.

Once the innovation was found attractive, most of the initiation stage was spent developing a contractual program, finding funding, and finding a host to support a demonstration of the innovation, thereby seeming to validate March’s observation that innovation in organizations “often seems to be driven less by problems than by solutions…Answers often seem to precede questions” (March, p. 568, 1981). However, while the attractiveness of the CCPM “answer” did precede the exact F/A-22 program problem it was used to solve, there was no shortage of problems. The issue was finding which particular “problem” was the right size, timing and importance to provide a good venue for solving the particular problem for the host, while at the same time providing credible assessment of the general CCPM capability to meet program needs.

Innovation Decision

The F/A-22 IPT decision process seems to conflict with the implication in the Rogers innovation decision structure (p. 49, accepted in the CHIP model) that the decision can occur at any level and is usually a “yes” or “no” decision to proceed to the implementation phase. By policy in the F/A-22 IPT organization, the decision to proceed can, in general, only be made by IPT leader responsible for implementation. At upper tiers of the IPT organization, the conclusion of the initiation phase is, effectively a gating decision[69] regarding the potential of the innovation for success in the program. At worst, the decision could reject the innovation or at best permit further consideration, i.e., adoption conditioned on an Operational-level IPT leader’s decision to proceed. For the F/A-22 program, the Program-level conclusion was that the CCPM innovation did have potential for further consideration by the working IPT leaders at the Operational level.

Analysis from the Perspective of the Structural Levels and Actors Construct

In the context of the *structural levels* construct, the Program level was unquestionably responsible for the initiation of the CCPM innovation. The description makes it clear, however, that in a complex IPT structure like that of the F/A-22 program,

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[69] This seems at first to fit with Rogers' innovation decision taxonomy (p. 403, 2003), but by his definition, a contingent decision only occurs after a *prior* decision to implement or reject the innovation. In the IPT setting, the higher level gating decision *is* that “prior” decision.

completing the initiation process requires very extensive staff actions, though they only lead to a gating decision. Thereafter, the activities at the Program level are almost wholly that of encouragement and infrastructure support for all the Operational-level implementations. While not as decisive or directive as expected in a hierarchical structure, these activities and on-going support are very important and well beyond the metaphor of cheerleader one might be tempted to suggest for the post- initiation role

These considerations lead to the observation that within the F/A-22 integrated product team structure, the initiation stage is different at the Program level versus the Operational-level IPT. At the team level the considerations are more strategic and the problem more general, so that short of mandating application of the CCPM innovation to a particular problem, it is unclear which of many similar problems might be the best one to demonstrate the innovation. At the Operational IPT level where the innovation is implemented, the issue must necessarily be specific and urgent and it is clearer whether the innovation has the potential to successfully address the problem or not.

Regarding the innovation *actors* that operate in and across *structural levels* the F/A-22 Program-level innovation process involved a number of organizational groups and individuals. Organizational groups were involved in the process in several ways. The F/A-22 IPT team structure provided the framework that permitted Program leadership to proceed through the *initiation* stage of the organizational innovation process, at least to the point that the CCPM innovation seemed conceptually matched with the program schedule challenges.

Another organizational group involved was the office of the Under Secretary of the Air Force for Acquisition (SAF/AQ). That organization’s formulation of policy interest in cycle-time reduction at the headquarters Air Force level led to a program that could support the needs—particularly funding—of acquisition programs when needed. From the author’s perspective as a participant observer intimately involved in the innovation initiation process, it is absolutely clear that both the policy interest and funding from outside the program was a constant source of motivation and support for all those interested in establishing the basis for a CCPM demonstration on the F/A-22 program.

Because the Program-level activities were equivalent to a screening step in any selection process the Program staff was also an important organizational group *actor*. Besides vetting the innovation process, staff groups had to complete the administrative “spade-work”, e.g., contractual and funding searches and documentation, required to establish timely infrastructure support for the organizational innovation, should the gating decision be positive and the process proceed to the working level IPT.

Regarding the individual organizational members involved, as expected, the most important individual actors were those who played the role of *champions*—the SPO Technical Director and LM Aero Program Integrator—and the *change agents*—Casey and Pennington.[70] The SPO Technical Director’s suggestion to assess CCPM’s potential to meet the F/A-22’s needs and his continuing support as demonstrations of the innovation unfolded were initially and continually important. Likewise, the LM Aero Program Integrator’s guidance and support for efforts to find funding and broaden the search for other demonstration venues beyond the Combined Test Force was essential.

The transformation of a new idea in mid-April to an almost certainly funded, ready-to-implement program by early July would have been difficult for Operational IPTs. This is especially true considering the required navigation of the complex organizational structures of the government reaching to the Pentagon, and of the contractor reaching to several locations around the country. The fact that Program-level champions supported consideration of CCPM employment was made clear to IPTs at Tier 2 and below and opened the minds of several IPT members as well as several organizational doors to

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[70] Colby was not heavily involved in this program initiation phase, but became a crucially important change agent in the case studies described in subsequent chapters.

introduction of the CCPM innovation. Actions by the SPO Technical Director and the LM Aero Program Integrator champions seemed to validate another of Rogers' observations, that when a very attractive innovation emerges, leaders see a “good chance that the innovation will match some problem faced by the organization” (Rogers, p. 423, 2003).

Summary

The innovation process at the Program level is an important part of the overall innovation case studies presented in the dissertation. Part A described the innovation initiation process in detail; including the many activities required at the Program level before there was a sufficiently solid foundation on which to build toward an incremental demonstration of CCPM. In Part B, the CHIP model and *structural levels and actors* were useful lenses. In fact, the expectation in *structural level* construct that the Program level would initiate the organizational innovation was solidly validated, with the initiation stage activities occurring in fairly rapid succession. Both groups, champion and change agent *actors* were vital to execution of the process which led to a different kind of decision, a gating decision, than those described by Rogers. During initiation, the Program-level members searched for expertise, screened the CCPM innovation, developed infrastructure support and searched for a demonstration venue, all activities essential to laying the groundwork to effectively implement a real demonstration of the CCPM innovation at the Operational level.

Overall, within the context of the complex organization previously described, this chapter helps provide an appreciation of the scope and complexity of the process required to arrive at a decision to encourage use of the CCPM innovation. Actions and decisions literally and metaphorically provide a “gate” to all implementations documented in the research of this paper (except for that in Seattle, described in Chapter 4). Table 4 summarizes the analysis and observations for the Program level. Chapter 6 provides the first description of the application of the CCPM innovation at the Operational level encouraged and supported by the Program level.

Construct validity: expected changes found?			
Change	1	2	3
short description	meets CCPM schedule	better ability to foresee & deal w/ difficulties	better than past
overall answer	N/A - but believe potential changes all positive		
supporting evidence	Belief in potential to improve in all areas based on Boeing results & substantial data from outside F/A-22		

Structural Levels: Program and Operational
Program level initiation = important pre-cursor to Operational level efforts

Organizational Actors
many internal & external group actors; Program champions & change agents emerge

Casey Hybrid Innovation Process (CHIP) Model				
Element of Interest	Motivation	Initiation Stage	Innovation Decision(s)	Implementation Stage
short description of application	performance gap intensified by failure of previous solution	dominated by staff work to facilitate use, find funding, market idea of CCPM	not "contingent" but *gating* decision: OK for IPTs to consider CCPM use	N/A

Table 4. Analysis summary: CCPM case study at the F/A-22 Program level.

Chapter 6: CCPM INNOVATION IN A MANUFACTURING PROCESS

Overview

This case study of the LM Aero application of the CCPM innovation at its plant in Marietta, GA, is the first of several F/A-22 applications following the Program-level initiation phase in the F/A-22 program described in Chapter 5. More descriptive detail and analytic detail is provided because the application was both an effort to solve a serious manufacturing problem—span time of the manufacturing finishes process—and to provide an incremental demonstration of the CCPM innovation. The study demonstrates CCPM success in a manufacturing-process area and provides an important example of the emergence and solution of serious implementation stage problems. Despite positive results, the study also shows that even a successful innovation can be terminated, though many valuable lessons were learned about the CCPM innovation and process that were eventually applied in other implementations.

Part A: Description

Initiation

In the spring of 2000, the Finishes IPT was struggling to complete the application of stealth finishes on the first F/A-22 that required these finishes, Serial Number (S/N) 4004.[71] The personnel in the Finishes IPT had developed key processes and gained extensive experience in applying finishes to major components (e.g., wings, aft-fuselage, vertical stabilizers), and to a full-scale test aircraft “pole-model”.[72] Even so, the span

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[71] Stealth finishes were not required for aircraft 4001, 4002, and 4003 because they had been designed for evaluation of the Flight Sciences aspects of the F/A-22 design, i.e., to evaluate and confirm that the F/A-22 was capable of performance throughout the flight envelope specified by the Air Force. As a result these aircraft were provided finishes that assure the aerodynamic continuity of the surfaces as well as durability and rain erosion coatings. Aircraft 4004 was the first of the remaining aircraft intended to verify the F/A-22 combat operational capabilities, including stealth characteristics, so it was also the first aircraft to require full stealth finishes.

[72] This model was one of the two prototype F-22 aircraft which had only conventional aircraft paint finishes during the Demonstration-Validation (Dem/Val) system acquisition phase of the ATF program which preceded EMD. The prototype aircraft was modified to F/A-22 production configuration and, after surfaces

required for the first final finishes application to aircraft 4004 was a disappointing 86 manufacturing days, unacceptable if test aircraft delivery commitments were to be met.

In fact, even before the disappointing performance with 4004, the Finishes IPT leader had become frustrated with the tools available to help him manage schedules for the several work areas in the finishes facility. He and his engineers had even designed a unique system for automatic statusing of finishes work, but had been unable to obtain required funding to institutionalize the system. Still, his vision was to have "waterfall" charts (i.e., milestone or Gantt charts) for all the different components to which his workforce was tasked to apply stealth finishes.

In early July 2000, following the meetings with the Build Team leader (described in Chapter 5), the Finishes IPT leader was contacted by the author to explore the possibility of a CCPM pilot. The Finishes IPT leader first described the work for which he was responsible, noting that except for the forward fuselage and small parts, every major component goes directly to a finishes facility for the initial phase of stealth finishes process. Eventually, all are transferred to the F/A-22 area of the B-1 assembly building where the components are mated together to form an individual F/A-22. After initial system checks are completed, the full aircraft is towed to the specialized L-64 facility for application of final coatings and stealth finishes to the entire aircraft. Figure 30 below depicts the major components and L-64 at the LM Aero plant at Marietta, GA.

Given this background about the IPT tasks, the author introduced the Critical Chain innovation and reviewed the Boeing success using CCPM. While the IPT lead readily declared his willingness to "try anything to get a better schedule for the final finishes work", he simultaneously indicated skepticism that Critical Chain was the right solution.

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were coated with stealth finishes, the full size aircraft was literally mounted on a "pole" so it could be extended several feet off the ground for evaluation and risk reduction at a classified test range.

Given the IPT leader's uncertainty about CCPM, an informal Technical Interchange Meeting (TIM) was arranged for the Finishes IPT leader, his lead engineer who had been attended the meeting at Seattle and TSC representative who had provided technical help on CCPM at the team level (Chapter 5).

Figure 30. Major components and primary finishes facility, L-64.

At the meeting, the Finishes IPT leader explained his needs and concerns, emphasizing his frustration that the preliminary finishes work on major components could not be completed prior to delivery to the assembly area. Since completion of that work was necessarily required before final finishes on the entire aircraft could be initiated, it appeared almost impossible to meet the span objectives for the full aircraft finishes. Not infrequently, already-committed work was pre-empted by new work labeled "top priority" by upper management,[73] but he had no way to show management the impacts. He expressed frustration that most of the time, "the only way to set priorities is

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[73] An example of overriding unplanned-but-top-priority work would be the requirement to return to full stealth configuration a horizontal tail that had been shipped from the CTF at Edwards AFB to Marietta for repairs. While "top priority" for this work is understandable to return test aircraft to flying condition, the work was imposed on a workforce already fully- or over-tasked with stealth finishes on parts needed in the B-1 plant.

to fight the fire that is burning the brightest right now, and when that seems under control, to move on to the next fire" (personal communication, 8 July 2000).

In response, the TSC representative described the CCPM approach in depth, emphasizing the very detailed planning, excellent visibility of the right priorities, resource allocation and interdependencies, and built-in planning and execution safeguards. The TSC also explained that the mathematical algorithms implementing CCPM concepts in available software programs related task and resource dependencies and could include resources of any kind, including skills, equipment, parts, and even space.[74] The TSC further explained that because of the visibility provided, the process could generate an assessment of the impact on loading and capacity of new priorities and quantify the impact on previously committed work.

Further discussion concluded that a CCPM pilot project in the final finishes area embodied the right scope. It was especially attractive to the IPT leader because a detailed network of tasks for the full aircraft had not been developed, and the CCPM process would assure that one would be developed. The TSC representative agreed, noting that the typical CCPM implementations revealed repeating patterns of work or "templates" that could be applied elsewhere, certainly to the other components requiring similar work sequences.

Innovation Decision

The meeting concluded with the declaration by the Finishes IPT that "I'm dying to try this" (personal communication, 8 July 2000). The urgency of the need to compress the finishes spans combined with this enthusiastic response by the IPT leader solidified the plan to conduct the pilot project in the final finishes area of the Build Team,

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[74] "Space" in this context means the physical area adjacent to a particular part of the aircraft. In many areas where finishes must be applied, there is limited access that constrains the number of people who can be working at any one time. An example of the impact is that adding additional people cannot shorten a two-day task in a limited access area because they cannot all be working at the same time.

specifically on the first full aircraft finishes effort for 4006. As noted earlier, because of the F/A-22 policy on Operational-level IPT decisions, if the Finishes IPT leader decided against a CCPM demonstration, the Program would have accepted the decision.

Implementation

Following the IPT leader's decision: several actions were undertaken: (1) planning, funding, and conduct of initial training, (2) adapting CCPM to the chosen pilot project, and (3) expansion to other major components and developing the tracking process, (4) finalizing/executing the initial implementation plan (4006), and (5) adjusting/executing the final implementation plan (4007). These last three steps required transformation of the product from step (2) into useable schedules and then tracking progress of final finishes for components and the two aircraft for which the full project schedule was eventually developed. The evaluation phase described in Chapter 2 is broken out here as a separate focus to assist understanding of CCPM in Finishes.

Setting the Stage: Planning, Funding, and Conduct of Initial Training

As efforts to reach agreement on conduct of the demonstration project were concluded, Casey and Pennington continued work on the details of pilot project initiation, including tailoring the generic Statement of Work (SOW) for a pilot program in the Finishes IPT. Once the final training dates were finalized as 31 July – 10 August 2000 other details included personnel selection, software to support the implementation, and, finally (and very importantly), the funding arrangements.

The selection of 10 personnel to be trained followed the concept embodied in the SOW. To focus on the Finishes IPT as host of the pilot, the Finishes IPT leader, his engineering technical lead and his lead industrial engineer (IE) were chosen. To permit their role as leaders and facilitators of the pilot in final finishes and any follow-on implementations, Casey and Pennington and a third individual, the Marietta F/A-22

Master Scheduling representative Colby, were also chosen. The other four were chosen to represent other areas and gain sufficient knowledge assess applicability to their own areas and lead implementations if directed after a successful pilot in the final. In all cases, as anticipated by the F/A-22 Program Integrator, the fact that outside funding would be provided to cover the tuition, labor, airfare and per diem costs made it easier for the supervisors to approve course attendance .

Another implementation item on which a planning decision had to be made concerned the choice of software required to enable the application of the Critical Chain during the pilot project. Of the three options then available, Project Scheduler, Version 8 (PS8™) produced by the Sciforma® Corporation, was chosen, based primarily on PS8™'s multi-project capability,[75] moderate cost, and the potential for later cooperative preparation for OT&E with AFOTEC (who had successfully used PS8™). To facilitate a late-August pilot start-up and avoid the kind of delays experienced with procurement systems of other large corporations like LM Aero, the Sciforma® Corporation representative committed to provide demonstration copies of PS8™ with full functional capability and technical support through the end of CY2000.

The final arrangement requiring closure was the funding from the Pentagon that had seemed very secure. Unfortunately, six days prior to travel, things began to unravel. Despite extensive efforts by Major McNutt, it was clear that Pentagon funding would not be available in time to support the planned demonstration project. Facing impending termination of the pilot because of funding that would delay or, possibly, preclude a re-start until early in 2001, Casey urgently requested alternate funding at a meeting with the program business manager and the Build Team leader. With CCPM unquestionably representing a new process technology to achieve both schedule and cost performance,

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[75] When the decision on software was being made, it was not clear if or when the ProChain software would be available. Boeing's application of CCPM required only single project capability, so ProChain offered all the capability needed in the Seattle assembly area.

approval was given to use available production funds. This information was conveyed to Major McNutt, along with the request that if at all possible, the funding problems be resolved so that the $250K could be "fenced" for possible evaluation of CCPM in another area of the program.

The training class at the TSC location convened on 31 July 2000, and was exclusively made up of the group from the F/A-22 program. Except for one day of orientation to the PS8™ software, the TSC representative who supported the exploratory efforts to date conducted all training with help of a knowledgeable assistant. The course focused on the mechanics of the Critical Chain Project Management process and touched on broader aspects of the Theory of Constraints on which CCPM is based.

Adapting CCPM to the Finishes IPT pilot project

Following the two-week TSC training course planning for the pilot project at Marietta began in earnest at facility that had been reserved by Casey and Colby.[76] The facility was suitably equipped with computers on which the Sciforma® PS8™ software was loaded[77] and separated from the finishes facility by some distance to permit total focus on the final finishes project. There was also adequate space to hang the 36-inch wide, sometimes several-feet-long, plotter paper used to print out the iterative versions of the network diagrams that depicted the precedence order and interrelationships of the tasks required to accomplish the objective.

As part of the start-up activities in the dedicated location, the TSC provided a day-long introduction to the concepts for the supervisor who was to become part of the core team described below and three other supervisors who would be involved in

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[76] During the final stages of pre-training coordination and during the training at the TSC, it became clear that the contractor CCPM innovation needs required Colby, the F/A-22 Master Scheduling IPT representative, to join Casey and Pennington as change agents for the F/A-22 program.

[77] CCPM network development was not delayed in order to get software training for LM Aero personnel from Sciforma® experts. Instead, the TSC facilitators accepted primary responsibility to use available documentation and to conduct frequent telecons with Sciforma® personnel to stay ahead of project requirements.

validating the number and types of personnel, aggressive and safe durations, interdependencies, and other resources included in the task dependency network.

Simply put, the objective was to plan, schedule, track, and successfully verify the application of final stealth finishes to a complete F/A-22 aircraft, specifically, the next aircraft scheduled for stealth finishes, aircraft S/N 4006, then expected to arrive at the Finishes facility, building L-64, in late November or early December 2000. The success criteria was a minimum 30 percent reduction in the span required to accomplish the final stealth finishes compared to aircraft 4004, the first fully stealthy F/A-22 test aircraft. Achievement of the 30-percent reduction goal would require that the work be accomplished no more than 60 days[78] versus the 86 days taken to successfully complete the finishes on aircraft 4004.

The first step in the process was to build the network for final finishes of the full aircraft. The CCPM core team that accomplished the development of that network was composed of the Final Finishes lead and industrial engineers and the supervisor responsible for directing the work. The supervisor was key because he knew most about the specialized techniques for applying the multiple layers of finished materials as well as the specific, individual tasks for each of the layers. Two personnel from the TSC, the TSC representative who had supported the effort from the beginning and another well-experienced CCPM technical expert, facilitated the work of this core group. Casey and Colby also participated.

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[78] Sixty days was the span that had been estimated in the F/A-22 Master Schedule and represented management's expectation. Though the core planning group realized that the span would be a fallout value from the network building process, the group used 60 days as a benchmark for comparison of results.

Beginning work on 22 August and finishing on 3 November,[79] the group produced an initial, detailed, resource-loaded precedence network for the full aircraft capturing some 1116 tasks to be accomplished. Figure 31 shows the entire network in miniature to reflect the complexity, interdependencies and integration points among the tasks, each represented by a box, or "node" on the diagram. Worth noting is the center of Figure 31, where the multiple, parallel series of nodes represent exactly the same series of steps, but applied to different panels or parts of the aircraft. This common series of tasks represents a "template" for that particular process, which can be electronically copied and used in other networks if that same serial process is applied elsewhere (e.g., the parts or panels of one of the major components such as a wing or mid-fuselage).

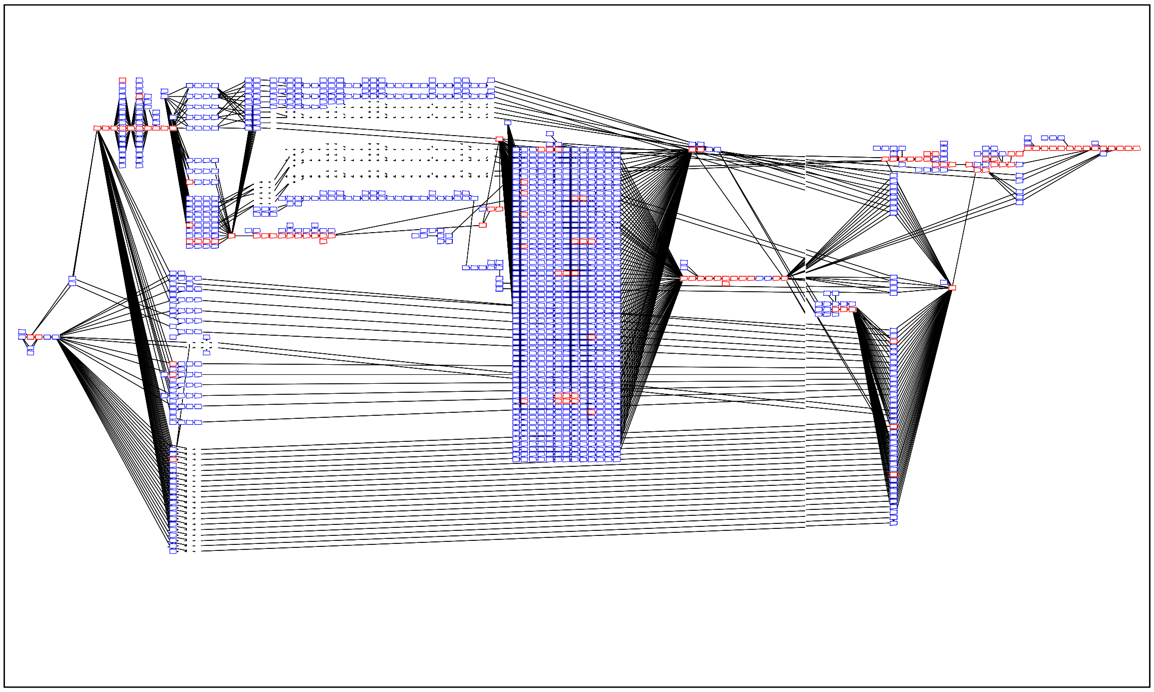

Figure 31. Representation of the full aircraft final finishes network (Finishes IPT 4006 project file archives, November 2000).[80]

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[79] Delays in completion from the end-September target to 3 November were due to the lack of 100 percent availability of participants because of other duties, incorporation of finitely detailed information to satisfy the needs of the industrial engineer, and substantial learning associated with the use of the new Sciforma® PS8™ software. The fact that Sciforma® representatives were extremely accommodating and generous with their time to assist the start-up accelerated the learning a great deal and defused some of the frustration.

[80] When the diagram is expanded to that the text is readable, each of the tiny boxes reveals task details (e.g., task name, ABP and HP durations, resource names, etc.).

After the core team drafted the network, a validation process was followed whereby other individuals were given an overview of the CCPM methodology and asked to identify missing dependencies and to correct resource assignments and task duration estimates so the network diagram could be refined. When the software was exercised to generate the Critical Chain and insert buffers, the span for the entire project was just under 60 days. However, the core group recognized that because of a substantial amount of "traveled work" that would have to be integrated just prior to arrival of 4006 at the finishes facility, this initial product realistically represented only the starting point for the plan that would later be translated into a schedule for execution.

At this juncture, two new personnel were assigned to important roles in the Finishes IPT and the CCPM demonstration project. The first was a new Finishes IPT leader chosen to replace the previous leader (who had made the CCPM innovation decision and attended the TSC training).[81] The other new person was from the LM Aero Master Scheduling organization assigned as a normal part of the expansion of the Finishes IPT to meet the demands of increasing rates of test aircraft development and production. The new master scheduler was to be assigned responsibility for day-to-day updates of the Critical Chain schedule during execution according to the plans. Because of their key roles, the introductory briefing presented by the TSC was particularly important. Both quickly understood the power of the CCPM process and expressed enthusiasm for the time when the execution phase of the demonstration would begin.

While the details of the network and schedule were being developed for the full aircraft and as a step toward expansion of the innovation if successful in Finishes area, CCPM concepts and the demonstration plan were presented to key members of the Build Team and to members of supporting organizations within the larger F/A-22 team

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[81] The original Finishes IPT leader was still involved by virtue of elevation to temporary responsibility for both finishes and assembly of parts made out of composite materials.

and LM Aero organizations. Attendees included the F/A-22 Program Integrator, the F/A-22 lead for “affordability”,[82] the Marietta finance area leader and representatives of contracts, procurement, and financial management. These introductory meetings were carefully tailored to focus on the specific issues of concern to each different group. Where possible, the other members of the group trained at the TSC were included by speakerphone in these meetings.

Expansion to Other Major Components & Developing the Tracking Process

With the initial network and wider team briefings complete in early November, the pilot project entered a period of reduced activity. This occurred primarily because of a delay in the arrival of 4006, the aircraft that was the objective of the CCPM pilot. However, the respite provided time to develop project networks for the major components listed in Figure 30 during the November-December lull. The core team industrial engineer worked with the lead supervisor to accomplish this work. Just as anticipated, the processes, materials and labor resources for many parts of these components were very similar or identical to those on the full aircraft. By using the templates from the 4006 network, other networks were pieced together for all the major aircraft components in a total of only two weeks. In another two weeks, the networks were reviewed and validated following the process described earlier. By mid-December, the group had a library of all the resource-loaded task dependency networks that were needed to accomplish finishes on the major components.

At the same time major component schedules were set up, Casey and Colby worked with the master scheduler in the Finishes IPT to set up the software and process

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[82] Operating under LM Aero’s F/A-22 VP/GM, “Affordability” was a staff function established to help focus intense, on-going efforts to wisely control costs across the team. This office became the lead for prioritizing cost reducing improvement proposals made by IPTs, The office also coordinated expenditure of funds to deal with the loss of suppliers who chose to withdraw from the F/A-22 team when production numbers were reduced (from the original production estimate of 650 aircraft to some 300 by 2003) and budget reductions forced the program to be stretched out in time. This generic problem was called “Diminishing Manufacturing Suppliers” (DMS).

for tracking, and monitoring the project(s). In addition, large Gantt charts were posted in the separate bays of the finishes facility and the overall objective of the project, the meaning of the spans and the importance of maintaining the proper work sequence were all explained to the workers.

At the twice-weekly status meetings that were set up for the supervisors responsible for the work in-process, the IPT leader quickly settled into a routine for schedule reviews which centered on laptop-projected views and paper copies of Critical Chain information provided by the master scheduler. After quickly reviewing the work accomplished for the day prior and the work scheduled for the current and next few days, the IPT leader would quickly move to the final page of the component schedule and look at the project buffer status, i.e., appropriate buffer penetration in relation to project completion. If it seemed reasonable, he would quickly move to the next schedule. If the buffer status showed “yellow” or “red” (middle or last one-third of the total buffer span, respectively) and the project was still early in the total planned span, he would quiz the responsible supervisor regarding plans to assure on-time delivery would be achieved. The IPT leader also would ask if his direct involvement or support from other organizations was needed to assure the success of required actions. This process was repeated for each component in play at the time.

This on-going scrutiny and cross-examination of supervisor’s schedule status and plans by the IPT leader, the emerging tendency of the workers and supervisors to treat the “aggressive-but-possible” spans as the objective, and quick reaction to any eroding buffer status resulted in nearly always positive status and invariably resulted in completion of all planned work prior to delivery of the required components. In addition, besides helping the Finishes IPT establish a consistent record of on-time deliveries, they established the process and discipline that would be important for success on the “real” target of the finishes CCPM demonstration project, full finishes on aircraft 4006.

Finalizing and Executing the Initial Implementation Plan (4006)

As noted earlier, the initial core-team network and 60-day schedule for completion of the finishes on 4006 was idealized in that it included none of the “traveled” work, i.e., work resulting from the failure to complete the initial finishes work on one or more components. As reflected in Table 5, below, the traveled work essentially doubled the total work[83] that was part of the optimum plan for the full aircraft. Actually, the total is even higher because of off-aircraft fabrication of panels and canopy finishes work, as well as restoration of engine inlet areas after a structural repair directed by engineering. The nature of the traveled work was quite varied and occurred across all components as determined by a physical inspection led by the IPT leader and a total records inventory conducted by the IE just days before the scheduled arrival of the aircraft at the Final Finishes facility on 14 February 2001.

	Estimated Standard Labor Hours	
Description of Finishes Area	**4004**	**4006****
Planned Air Vehicle Final Finishes work	**721.3**	**670.8**
Traveled Work		
Major Section Mate Areas	**447.0**	**371.0**
Mid Fuselage	**24.4**	**120.1**
Aft Fuselage	**76.5**	**113.1**
Wings	**11.3**	**28.5**
Horizontal stabilizers	**0**	**0.0**
Vertical Stabilizers	**15.1**	**29.6**
Edges*	**117.8**	**3.9**
Tot Traveled	**692.1**	**666.2**
Total Planned+Traveled = Actual Work to be completed in Final Finishes	**1413.4**	**1337.0**
Ratio of Planned to actual work in Final Finishes area	**2.0**	**2.0**
*Edges are components attached to other major assemblies (e.g., leading edge flaps are "finished" then attached to the Wing		
**4006 Excludes Canopy, & required rework of already complete inlets		

Table 5. Comparison of full aircraft planned and traveled finishes work (derived from Finishes IPT 4006 project file archives, January 2001).

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[83] The metric for the work shown is “estimated standard hours,” which is the number of total hours estimated by engineering analysis that remaining tasks should take when completed by a competent (i.e., trained and experienced) worker employing a stable process. Though not all these characteristics were true of the finishes tasks, the relative size of the numbers is sufficiently accurate to support their use in context here.

To incorporate the traveled work, the core team reconvened and began to expand the original, optimal task dependency network by adapting, with only minor changes, the many templates for the work originally planned for the full aircraft finishes effort. The additional work was extensive enough that it significantly increased the number of tasks and the span/duration for the total effort to an initial maximum of 2800 tasks and 112 days, including all the buffers. In the process of finalizing the network, some flaws in the original network were discovered and corrected.

What followed then was an intense effort to transform the task dependency in to an acceptable and credible schedule. With the very responsive and sometimes intensive telephone assistance from Sciforma® technical support, the software was proven extremely flexible and powerful, permitting rapid exercise of as many “what-if” scenarios and modified networks as the core team members could structure.

When adjustments resulted in a span that was still in excess of 100 days, the supervisor member of the core team directed sharp reductions in the spans for which his coaters were responsible by as much as 50 percent. When it was suggested he intentionally “padded” even the aggressive-but-possible times, he defended his conservatism based on technical uncertainties about both the CCPM methodology and the crew. He believed the new, shorter times to be achievable because he was now more confident in the capabilities of his crew than he was when the estimates were provided during the initial network construction nearly three months earlier. These changes brought the total span down to approximately 80 days.

The final effort exercised the software’s capability to assess changes in crew loading and shift spans. The traditional approach to reducing nearly any manufacturing span was tried first, namely, to increase the number of workers per shift, in this case from 12-man shifts to 15-man shifts. However, as discovered using the “what-if” capabilities of the PS8™ software, the increase in the length of each shift from 8 to 10 hours was more effective. After several iterations, a final 67-day schedule emerged which the IPT leader declared to be “good enough” even though longer than the desired 60-day span. The Build Team leader (who had originally sponsored the pilot project) and the LM Aero leader for Assembly Processes were briefed on the plan, agreed that the CCPM process had much to offer, and approved its implementation.

On arrival of 4006 at the Final Finishes facility on 8 February 2001, the crew assigned to 4006 began to follow the baseline plan, using the same updating, reporting and reviewing process used for the components during Tuesday and Thursday meetings led by the IPT leader. Unfortunately, difficulties began to emerge by the third week of execution. The problem was that even a schedule that had been collapsed from nearly 3000 tasks to just over 1000 was still too complicated and detailed for the projected 67-day span, especially combined with problems that forced revisions in the sequence of work. These revisions required that some downstream work be done earlier, while other work had to be delayed pending resolution of coating material difficulties. While the software accommodated these changes via flexible update techniques, it was clear that some of the dependencies thought to be “hard” or unchangeable were, in fact, more flexible. As a result, the supervisor began to raise questions about the veracity of the overall plan and even CCPM core team members were concerned about the risks of project failure.

Before these questions could be resolved, a fortuitous program leadership decision provided time to adjust and possibly avoid failure for the CCPM demonstration. The program leadership decided it was imperative that the pace of the flight-test program be accelerated, particularly Mission Avionics flight-testing. The only way to achieve that goal was to accelerate the entry into flight test of 4006 by foregoing the full stealth finishes process. Therefore program leadership directed that work be suspended on the original objective—full stealth finishes—and the work plan converted to apply coatings and finishes for aerodynamic smoothness and rain erosion, i.e., the same finishes and processes used for the first three flight test aircraft. This direction caught the workforce in mid-stream, but the master scheduler used the PS8™ software to implement team direction and produced a plan overnight that the supervisor could follow. The plan was quickly approved, and when implemented facilitated on-time compliance with management direction. However, since the objective of the project remained the use of the Critical Chain schedule for the completion of full and validated stealth finishes on an F/A-22, the utility of the Critical Chain innovation remained to be proven.

Adjusting/Executing the Final Implementation Plan (4007)

The next airplane, 4007, became the "real" pilot project test aircraft. The traveled work for 4007 (Table 6), was as extensive as for 4006 and this extra work had to be integrated into the plan as well. By now, though, the core team felt they could confidently make changes to simplify and consolidate the network. This confidence was based on the understanding of the work and all the associated dependencies at the very

	Estimated Standard Labor Hours	
Description of Finishes Area	4006 Stds*	4007 Stds*
Planned final finishes work for full aircraft	670.8	745.6
Traveled Work		
Major Component Mate Areas	371.0	371.5
Mid Fuselage	120.1	110.5
Aft-Fuselage	113.1	153.6
Wings	28.5	2.3
Horizontal Stabilizers	0.0	0.0
Vertical Stabilizers	29.6	0.0
Edges**	3.9	0.0
Tot Traveled	666.2	637.9
Total Planned+Traveled work = actual work to be completed in final finishes	1337.0	1383.5
Ratio of Planned to actual work in finishes area	2.0	2.2
*4006 & 4007 Excludes: Canopy, inlet repairs and fabrication work on 77doors, panels, seals		
** Edges are generally leading or trailing edges of other components (e.g., wing leading and trailing edge flaps, ailerons, etc.)		

Table 6. Comparison of full aircraft planned and traveled finishes work (derived from Finishes IPT 4007 project file archives, February 2001).

finite level of detail captured in the original network, combined with the experience gained in the execution of component and 4006 plans and schedules. With the help of the new supervisor responsible for 4007, the team made changes to recognize that some tasks scheduled in series in the plan for 4007 could, in fact, be completed in parallel. The resulting network was developed into a Critical Chain schedule with feeding and project buffers and included just fewer than 100 tasks, or 10 percent of the original network. More important, the total span for the full finishes activity, including verification, was 39 days, less than half the time used for 4004, the first stealth aircraft.

On arrival of 4007 at the finishes facility on 24 April 2001, the execution and tracking of the plan began, following the same process as outlined earlier. The effort clearly benefited from the earlier experience of collapsing the 4006 network and schedule, and the process went very smoothly. The status meetings on Tuesday and Thursday involved the same scrutiny from the IPT leader and actions were taken in response to difficulties as required to maintain reasonable project buffer status and to avoid crisis. The actual span for full final finishes and a 3-day span in another facility for verification of stealth characteristics was 37 days. After all the ground and flight-testing required at Marietta was completed, the aircraft was returned to the final finishes facility for permanent restoration tasks before delivery to Edwards AFB. This work was completed in approximately eight days. In total, the combined time for completing final finishes on 4007 that was “apples-to-apples” the same as for 4004 (including the post-flight restoration) was 45 days.

Evaluation of the CCPM innovation in the Finishes IPT

Overall, the application of the Critical Chain Project Management innovation in the F/A-22 Finishes area was quite successful in the preliminary areas of application, the major components, as well as in the formally selected pilot area, the full aircraft.

For selected major components, Figure 32 shows that although CCPM plans and schedules were initially applied to the major components to permit "practice" in tracking CCPM schedules before the *real* CCPM pilot—the full aircraft—the impact of using CCPM appears to be quite beneficial. *Before* CCPM, none of the finishes work for the last three aircraft serial number components of each type was fully completed before their transfer to the B-1 building where they became part of the full aircraft. Essentially this was the source of the "traveled work" that had to be finished later, generally when the aircraft returned to the finishes facility and prior to application of the final, full aircraft finishes. *After* Critical Chain, the first three aircraft serial number components of each type were 100 percent complete in the case of Aft Fuselage and Wings and nearly complete for the Mid Fuselage components.[84] Essentially, after the implementation of

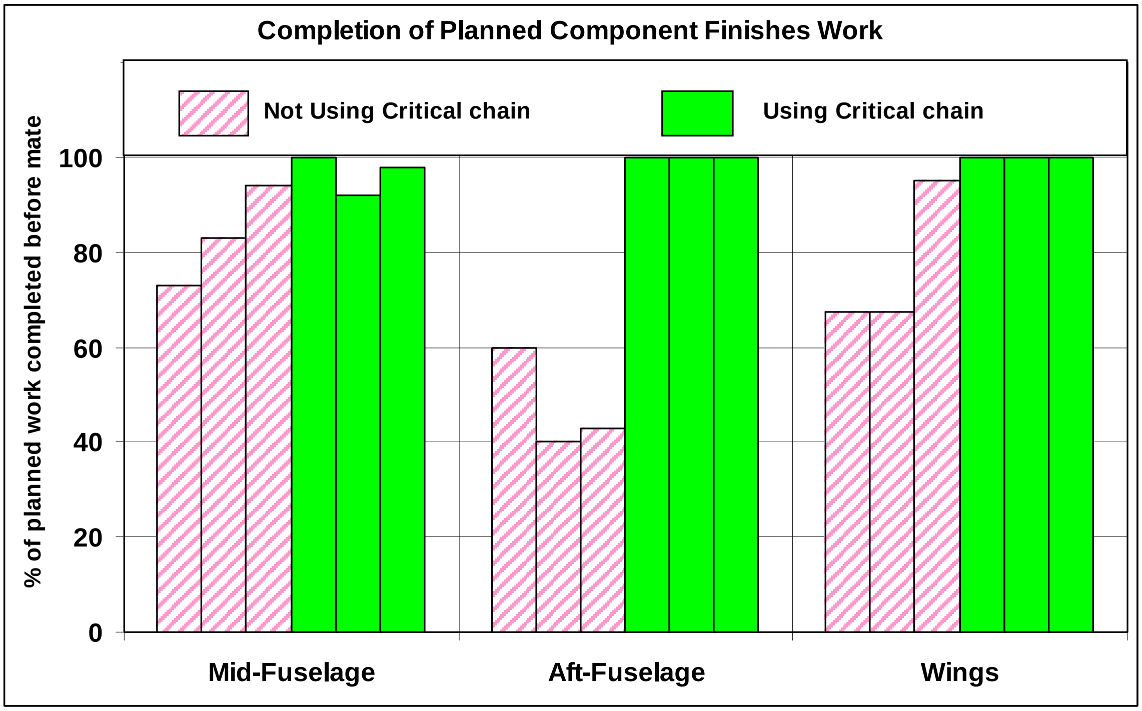

Figure 32.Percent of planned component work completed before mate (derived from Finishes IPT 4006 project file archives, June 2001).

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[84] The comparison for the Mid-Fuselage before and after Critical Chain is included for completeness, but is tantamount to comparing "apples and oranges" since the technical process was different before and after Critical Chain. During the first two Mid-fuselages for which CCPM was used, the process was changing from a completely manual process to one that employed robotic application of finishes. As a result, "process

CCPM, all delivery commitments were being met with 100 percent of the work done. Because the components represented in Figure 32 were associated with aircraft 4008-4014, the reduction in "traveled work" did not benefit aircraft 4006 or 4007. Even so, these reductions in traveled work for the full aircraft final finishes suggest a solid contribution to the eventual reduction of that span to 21 days as required by plans for increasing the production rate to 32 aircraft per year.

As encouraging as the post-CCPM picture for components is, it is not obvious that CCPM is the only or dominant factor in meeting the finishes objective—100 percent of the work completed on time. A classic way to look at results is through the lens of the learning curve calculation, a mathematical assessment over time of the extent of improvement or reduction in the amount of labor required to execute a stable, repeatable manufacturing process. However, though this was exercised (Appendix D) changing processes, materials and increasing proficiency on the part of the workers preclude the assumption of stability for the process. At the same time, because these changing factors could have contributed to the improvement—along with Critical Chain—it appears that the "technology cluster" mechanism was again at work and precludes certainty regarding the contribution of each factor to the improvement in the results before and after the adoption of the CCPM methodology

However, data for the *real* test for CCPM—final finishes for an entire aircraft, in this case, 4007—is more encouraging. Figure 33, below, reflects the comparison among the first three aircraft for which stealth finishes were intended. As was noted earlier, 4004 required fully 86 days (including a five-day restoration period after initial flights) erosion coatings sharply reduced the span to 28 days. Though not comparable to the full

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proofing" with uncertainty about the "best sequence" precluded accrual of the substantial reduction of span time for the mid-fuselage components that was achieved with aft-fuselage and wing components.

finishes, it is worth emphasizing that the Critical Chain approach and tools did help to convert the plan to accommodate the change to aero coatings only in minimum time.

Finally, Figure 33 shows the improvement achieved for aircraft 4007, the aircraft that became the instrumental demonstration pilot for use of Critical Chain Project Management. As indicated in the Figure 33, the Finishes IPT crew accomplished the job in 45 days, including the 8 days of restoration after ground and local flight tests and maintenance. That the job was accomplished in just under half the time that was required for 4004 was a solid demonstration of the value added by Critical Chain.

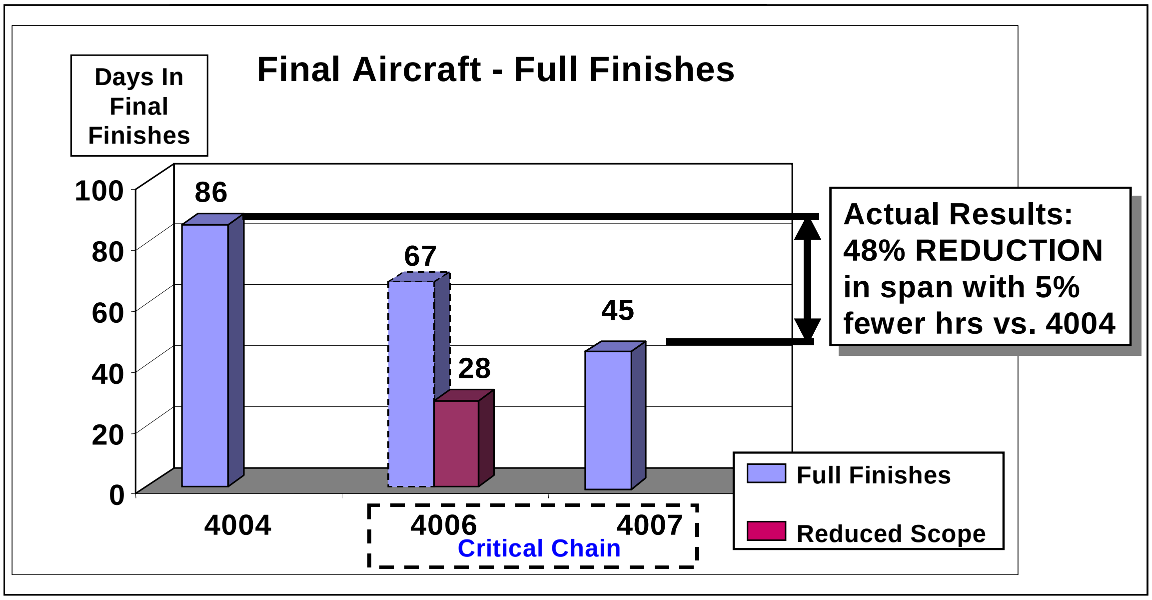

Figure 33. Comparison of stealth finishes spans for aircraft 4004, 4006, 4007.

Whereas the mix of factors in the major component CCPM projects made it difficult to quantify the specific contribution of CCPM to the results, here it is clearer. Though improved materials and crew experienced from working on 4004 stealth finishes could contribute to the improvement, those factors would mostly affect the labor hour reduction, which was approximately five percent. Where the Critical Chain improvement focused was planning, scheduling and executing to assure that the order and integration of the work was much more efficient than the much less detailed plan for 4004.

The most important CCPM contribution was a substantially reduced span. The payoff for this reduction can only be crudely estimated. However, at the time of 4007's delivery to Edwards AFB, the per-day cost for flight test operations was approximately $1M. As a result, the savings generated by 4007's arrival approximately 30-40 days earlier than would have occurred if the 4004 plan had been followed suggest that the savings generated to be several million dollars.

Overall, the quantitative evaluation of the impact of the CCPM innovation in the case of the *components* is generally positive but equivocal regarding the dominance of CCPM as a factor. In the case of the *full aircraft*, however, the quantitative evidence is quite compelling, and CCPM does appear to be the dominant factor in achieving a nearly 50 percent reduction in the cycle time.

Completing the Implementation Stage

The continued application of the networks and schedules for the components and the full aircraft was done with very little change in the networks or schedules. Other than some changes to accommodate supervisor refinements in the case of the F/A-22 canopy plan, the only changes required to use CCPM for follow-on components and other aircraft were to change the title of the schedule and the target completion date. At the same time, a very desirable behavior change was that the "aggressive" dates became the goal, perhaps one of the most positive results of the implementation of CCPM.

The other change was that the original, TSC-trained IPT leader again assumed primary responsibility for oversight of the Finishes IPT work.[85] Initially, he continued the twice-weekly review of CCPM schedules with the supervisors. However, tracking, updating and management of CCPM schedules became so routine that actual meetings were scheduled only when needed. Essentially, the master scheduler worked with the

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[85] The original IPT leader had completed his interim assignment overseeing both Finishes and Composite IPTs and the other IPT leader was reassigned to a job from which the incumbent departed unexpectedly.

supervisors to baseline, track, update, and report the schedules for the components and full aircraft. When comparison of buffer penetration and project schedules suggested the need for assistance from the Finishes IPT leader, the master scheduler would highlight that fact and the leader would either take or direct action to relieve the situation.

Of course, the original intention of the Build Team and F/A-22 program leadership was to expand use of CCPM beyond the Finishes IPT. Essentially, the hope and expectation was that the results of any success in the finishes area would “sell” themselves to leaders in other areas. These leaders, vested with the IPT responsibility and authority for their product, could then initiate the innovation process in their areas at any stage of the innovation process depending on the similarity with the Seattle assembly process or the Marietta finishes process.

Final Decision Rejecting use of CCPM in the Finishes IPT

Though the apparent *routinized* use of CCPM within the finishes area seemed to bode well for expanded use of CCPM in the F/A-22 manufacturing area, other factors led instead to the suspension of the CCPM process innovation in the Finishes IPT. At the time the positive results became clear, the manufacturing final assembly area at Marietta was undergoing a substantial reconstruction process to permit implementation of a Lean Engineering process called “single-piece flow.” The turmoil associated with the needed changes made it virtually impossible to attempt a CCPM implementation until, literally, the “dust settled” on the physical changes. In the flight-line area, another potential target for CCPM expansion, the Flight Line Operations Manager accepted a job with another company, and his replacement was unfamiliar with Critical Chain. The intensity of demands on the new leader and his team for delivery of airplanes to Edwards AFB precluded in-depth orientation to the CCPM processes and potential benefits.

Similarly, as the changes in the manufacturing final assembly area reached completion, other changes in factory management represented a substantial turn-over in personnel, particularly in leadership positions as part of the personnel cross-flow initiated in transition to a "single company" structure.[86] Many of the new personnel possessed substantial experience in the F-16 fighter production processes, and infusion at Marietta was expected to accelerate the transition from development to production.

However, these new leaders were unfamiliar with the Critical Chain process, totally absorbed with the responsibilities of their new positions and simultaneously committed to expanding the use of other proven and company-endorsed processes, of which CCPM was not one.[87] In particular, the manufacturing manager decided that he would employ only established, LM Aero functional core-sponsored methodologies to execute his responsibilities, at least until the production process was stabilized. Therefore, he directed the Finishes IPT to convert to the use of Microsoft Project™ as the primary planning and reporting tool. Fortunately, the learning and much of the discipline from the CCPM process was embedded in the new Microsoft Project™ networks and schedules, so not all the benefits of the CCPM innovation were lost.

As a result of all these factors and decisions, what was a solid success in the execution of the Critical Chain pilot in the final finishes area was not transformed into new projects or rapid expansion into other areas of LM Aero's Build Team operations at Marietta.

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[86] In 1999, a new LM Aero president initiated a major overhaul to dramatically "flatten" the corporate structure. This change replaced a structure of cooperating but largely independent companies at several sites, each with their own set of vice-presidents, programs and core functional organizations with an integrated single company. This single company, headquartered at Ft. Worth with several operating sites, had one set of vice-presidents, one set of programs across the several sites and one set of core functional organizations responsible to promulgate one set of "best practices" across all sites.

[87] In particular, having been initiated from within a program (instead of a process sponsored, staffed and sustained by functional core groups at the LM Aero corporate headquarters), CCPM was considered somewhat of an experimental—and therefore *unproven*—methodology.

Part B: Analysis

The purpose of this section of the chapter is to assess whether or not—and why—the types of anticipated changes did occur and to assess the CCPM innovation in the manufacturing process area of F/A-22 finishes from the organizational perspective. In addition, the analysis examines Insights gained on the adoption of the CCPM innovation using the lenses provided by the CHIP model and *structural levels and actors* constructs of organizational innovation.

Assessment of CCPM-driven Changes in the Finishes Area

A top-level review suggests that CCPM "delivered" in each implementation regarding two of the changes noted in the earlier discussion of construct validity, namely: Change 1 "on-time achievement of CCPM" and Change 3 "Improvement in schedule performance compared to the past." However, in a very real sense, the line between success and failure was perceptively narrow.

Essentially, after nearly foundering because of the complexity built into the initial project schedule, quantitative evidence supports the conclusion that the CCPM innovation was a technical success on the instrumental demonstration project, the final finishes on the full F/A-22 aircraft, 4007. In fact, results reflect a dramatic reduction in cycle time. In addition, application of CCPM to support the finishes process for the major aircraft components was also successful. In the cases of major components, the measure of CCPM success was not so much a reduction in cycle time as assuring that deliveries met the commitments to support the overall Master Assembly Schedule with full content.

To some degree, credit for the improvements in the cycle time CCPM innovation was somewhat uncertain because, as noted in the evaluation section earlier, other improvements—materials, processes and increasing proficiency within the work force—

were also factors in the success. In addition, regarding Change 2, “Improved ability to anticipate and mitigate difficulties in schedule execution,” there was no specific quantitative measure of the impact of CCPM in assisting management in the face of adversity. As a result, in the face of uncertainty regarding CCPM’s added contribution and value, a series of discussions was initiated to serve the dual purposes of (1) the F/A-22 program need to better understand the first Team Program Office-sponsored use of the CCPM innovation and (2) its value and the dissertation research need for more insight into the “whys” of any benefits or penalties perceived by the using organization.

The number of discussion participants was relatively small because the intent was to get a representative cross-section of views on a number of subjects from those most knowledgeable about, or directly involved in, applying the CCPM innovation. Primary interest areas were as follows:[88]

- Management towards goals using buffers and buffer management. Of interest because the treatment of variability and the use of “buffers” to account for and absorb variability is unique to CCPM.
- Recommendations regarding CCPM itself. Here the interest was in finding out what the people involved in the process thought were the key lessons and strengths/weaknesses of CCPM as well as their recommendations for future use.
- Comparison of operations “before and after” CCPM. These were included to provide a relative sense for CCPM compared to Finishes IPT operations before CCPM.

As reflected in Table 7, participants had a range of experience in LM Aero and the Finishes IPT and were considered representative of those who were vital to updating and producing status and buffer reports and using the information. Of particular interest

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[88] Another subject not addressed here but of interest to the program was the quality of the training and tools. Training was of interest to provide a basis for future implementations in the event CCPM would be expanded to other areas. Tools—both the software and the products it produced—were of interest to see if the finishes team found them usable and useful.

CCPM Role	Position in Finishes IPT	CCPM Training		Experience at LM Aero & Finishes IPT
		Concepts	Software	
Manager	Manager (M1)	2 weeks	2 days	18 yrs LM Aero; 5yrs Finishes IPT Manager; 6 mos as Finishes & Composites IPT Manager
	Manager (M2)	1/2 day	.5 day	20 yrs LM Aero; 3 yrs Finishes IPT Manager
Planner	Lead Engineer (LE)	2 weeks	1.5 days	8yrs LM Aero; 2 yrs Finishes IPT lead engineer
	Industrial Engineer (IE)	2 weeks	4 days	10 yrs LM Aero; 2yrs Finishes IPT IE
Implementer	Production Supervisor (PS)	1/2 day	not trained	10yrs LM Aero; 2 yrs Production Supervisor; 5 mos as Supervisor in Finishes
	Master Scheduler (MS)	1/2 day	2.5days	3yrs in LM Aero; 8 mos in Finishes IPT

Table 7. Characteristics of participants in CCPM Discussions.

was the potential difference in perspectives based on the role of the individual—manager, planner, implementer—in case changes were needed in the approach of those with similar roles in future implementations.

The structured discussions followed the same sequence of subjects (Appendix C) and were conducted by Casey and Colby who recorded notes during the discussions, documented the answers in a draft form, and finalized the record after receiving comments on the draft from the participants. Where appropriate, tables capture salient points made followed by the author's observations as they relate to general areas.

Management toward Goals

The questions here examined the nexus of general management concerns and expectations that CCPM could help in the areas of concern—confidence in meeting goals and reducing cycle times.[89] Regarding confidence in meeting goals the managers and planners strongly agreed that CCPM helped, as reflected in manager M1's comment that "without a doubt CCPM has improved our confidence." The lead engineer went even further, saying that Finishes IPT "Credibility is a lot better. Finishes is [perhaps the only] major organization that consistently meets its commitments." Regarding cycle times, five of six interviewees were unequivocal or quite positive in

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[89] Words and phrases in quotations in this paragraph were extracted directly from the documentation.

saying “yes”—that CCPM had, in fact, reduced cycle time. Only the production supervisor indicated that he saw no direct correlation between CCPM and cycle times.

Buffers and Buffer Management

Questions in this area were important because the concept of buffers and their actual use in influencing decisions were two of the most significant aspects of operating under CCPM. Because of that, answers to two questions on this subject are presented in Table 8. In fact, all responses indicate that the buffer concept and use were totally consistent with related training and the overall intent of buffer management. Though there was a mix of responses regarding the impact of strategically placed buffers on schedules, there was unanimous agreement that they were sized “about right.” The responses in Table 8 indicate that the meaning and impact of buffers were well understood. With the exception of the IE, all responses are completely consistent with the concept, so much so that some of the responses are almost “right out of the “book” on CCPM. Buffer management was used “to verify ‘health’ of the project,” “as catalyst for action,” and “as a means to communicate.” Unequivocal “yes” responses from five of six interviewees leave no doubt about CCPM living up to “advertised promises”

BUFFERS AND BUFFER MANAGEMENT		
		How did you use Buffer Management?
Manager	M1	I used CC buffer management to verify “health” of the project and to communicate overall status
	M2	Helped determine project health, catalyst to take action, provided project status, improved flow of information up (to leaders) and down (to the team in weekly meetings)
Planner	LE	Finishes management does a good job of using Buffer Management as designed--as catalyst for action, as recognition that no action is required, or as reason for extra pressure
	IE	Not applicable (decisions based on buffer status were made above my level.)
Implementer	PS	Provided an indication of overall health of the project.
	MS	As a warning of the need to take action. As the reason to assign more labor to a job, sometimes from another crew if necessary. As a means to communicate to higher levels where we were in the process.
		Did Buffer Management live up to advertised promises regarding early warning and impact of actions on delivery?
Manager	M1	Yes, provided early warning assessment.
	M2	Yes! Most satisfied with this aspect of CCPM.
Planner	LE	Yes! Definitely the main advantage. I really like that aspect of CCPM.
	IE	Yes!!
Implementer	PS	Did provide early warning indication of likelihood of completing on time
	MS	Yes. The Green/Yellow/Red [buffer status] concept works effectively.

Table 8. Comments in discussion of buffers and buffer management.

regarding early warning. Even the production supervisor's response, somewhat equivocal elsewhere, amounts to very positive agreement with this aspect of CCPM.

Recommendations on CCPM

These general questions on Critical Chain related to perceptions of why it works, strengths and weaknesses, and lessons learned for future work were quite instructive. The "why it works" responses consistently mentioned the benefits related directly to dealing with human behavior, variability, reducing chaos and to providing challenges to the workforce. These responses were complemented by the perceived strengths, namely, "better understanding," "good visibility," "solid measure," "helps organize," and "whole strategy." In combination, the responses reflect both understanding of the CCPM concepts and confirmation that the concepts do, in fact, work.   Responses to two other questions in this section are summarized in the following "checklist" of cautions or advice on future implementations from those interviewed:

- Provide a dedicated team (free of other duties) to conduct CCPM implementations.
- Start with simple projects then build to more complex ones.
- Conduct up-front software training.
- Make sure "aggressive-but-doable" durations are realistic (or workers will disregard).
- Dedicate manpower to daily/frequent updates.
- If action is not taken on buffer status, chaos will quickly return.
- Do a good job educating and implementing CC at the first line supervisor level.

Before and After CCPM

Here, discussions focusing on the nature of the CCPM approach, process and tools and their utility imply that CCPM led to improved performance.   Two questions explicitly asked for a judgment on how the conduct of Finishes IPT operations with CCPM compared to operations prior to the use of CCPM. Because the responses strongly bear on the impact of the CCPM innovation on all questions of construct validity, responses are provided in Table 9. With the exception of the production supervisor,[90] comments are all quite positive. Manager M2's comment is the most unequivocal endorsement of CCPM as a true decision support system. He characterized the new CCPM process as more than a picture of project status, because he could use it to allocate responsibility for status and analysis to the staff and more time for the manager to make decisions.

BEFORE AND AFTER CCPM		
		How does decision-making based on CCPM and associated schedules compare with decision making before CCPM?
Manager	M1	Decision making more obvious with well-defined networks.
	M2	Before CCPM, team used simple/manual Gantt to make decisions. With CCPM and it's system of buffers and automated updating of ECDs, [estimaed completion dates] status and analysis delegated to staff and I can focus more on decision making. This is how it should be!
Planner	LE	CCPM significantly improved the structure and accountability over the previous process that used simple, often-manually-generated Gantt charts.
	IE	Definitely better than the Gantt charts that had been used.
Implementer	PS	Provides a better sense of crew assignments, durations and timing for tasks
	MS	Hard to answer since I started in Finishes about the same time as CCPM was initiated.
		How has your overall credibility with internal/external customers been affected by CCPM?
Manager	M1	CCPM has had a positive impact – extremely confident we can deliver finished aircraft and assemblies on promised dates.
	M2	Improved. Since I arrived (about same time as CC which began tracking projects in Dec) we've met our delivery goals! Tough to break out what the impact of different factors—people vs process—on results.
Planner	LE	Much improved credibility--has a lot to do with management using CCPM schedule as an enabler to insist on schedule discipline and accountability
	IE	Definitely improved.
Implementer	PS	None
	MS	I think the credibility has gone up. We reliably make the Line Need Date. We show [management] where we are with the buffers and make our dates.

Table 9. Comments in discussion of comparison: Before and after CCPM.

For the most part the results of discussion reflected in Table 9 reinforce the argument that CCPM was, indeed, the dominant factor explaining the successful reduction of span-time for the pilot project and generating improved performance, decision making and credibility with the customers.

The discussions with this elite group of CCPM innovation personnel were also very useful in helping to refine the implementation process in terms of its structure and in capturing opinions and observations to help those in other organizations assess possible use of the CCPM innovation in their organizations. Independent of length of training or

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[90] The production supervisor joined the IPT at the outset of the execution phase of the CCPM pilot. As such, he was only aware of the consistent, on-time/full content deliveries that occurred during the pilot, so he did not personally have relevant experience to make a "before and after" assessment.

role (manager, planner, or implementer), responses led to the following general conclusions:

- Longer formal training can be focused on fewer participants.
- Software training (at least three days) needs to be conducted early.
- CCPM helps understand the work and interdependencies.
- Influence on resource management is not as heavy as anticipated.
- Management to meet commitments is definitely enhanced.
- CCPM can assist in reducing cycle times.
- Buffers and buffer management works and is the most compelling CCPM advantage.

Overall, the discussions were very useful in providing insight for program leadership on the nature and value of CCPM as perceived by the users, especially in combination with the sharply improved performance in all areas of the Finishes IPT employing the CCPM innovation. The discussions also provided solid support for Change 2 among those associated with construct validity, “Improved ability to anticipate and mitigate difficulties in schedule execution.” Especially the responses in Tables 8 and 9 seem to verify that CCPM and its buffer management information were especially valuable in sensing problems before they became crises and very helpful in deciding what action to take. In general, despite other things that might have been going on, the preponderance of information derived from the surveys suggests that CCPM was regarded as a major factor in improving performance and dealing with problems.

Analysis from the Perspective of the CHIP Model

Within the framework of the CHIP model, the discussion will focus on the motivation for adopting an innovation, the core initiation and implementation stages and the innovation decision that separates these stages. Prompted by greater descriptive detail for the implementation stage, more detail is provided in the analysis of this stage.

Motivation for Innovation

Virtually all levels of the F/A-22 formal organization reflected what Zaltman described as an “impetus for innovation” that “arises when organizational decision makers perceive that the organization’s present course of action is unsatisfactory” (p.55, 1973). Chapter 5 documented the emergence of perceptions of unsatisfactory performance regarding the completion of finishes on the first full aircraft, 4004, at levels above the Finishes IPT. At the Operational level, the Finishes IPT organization, the performance gap between the IPTs expectations and performance had also been clearly recognized. Not only was there the very negative visibility of the pre-CCPM final finishes span for aircraft 4004, the first aircraft produced by the F/A-22 EMD program with full stealth characteristics. In addition, the working level IPT leader’s recognition of, and frustration with, the inability to manage his work had prompted the search for corporate or commercially available tools to assist management. When that search failed, the IPT developed its own tool to overcome the schedule management problem. In combination, the broader organizational situation and the IPT circumstances combined to provide an organization context that enabled and motivated and encouraged movement toward the innovation that occurred and was pursed to success (Van de Ven et al., 2000).

Initiation Stage

The initiation stage of the CCPM innovation in the Finishes IPT was consistent with expectations based on the CHIP model. It happened, but required limited time because of the screening activity at the Program level (Chapter 5) and the problem identification and search for other solutions already underway in the Finishes IPT. As it happened, the matching stages in the Finishes IPT level revealed a specific problem/CCPM solution match, sweetened by the Program’s offer to fund and facilitate the CCPM innovation at a time when the IPT leader had become frustrated with the inability to obtain or develop a solution to his schedule management problem. In this case, success in the use of CCPM at Boeing in a manufacturing environment and confidence engendered by the TSC all led very quickly to the positive conclusion by the Finishes IPT leader that CCPM was a good match for his problem.

Innovation Decision

The decision protocol of the F/A-22 Integrated Product Team was clearly reflected in this implementation. The F/A-22 Program leadership provided at least preliminary validation of the CCPM innovation for the Finishes IPT leader. Program leadership also allowed the Finishes IPT leader to make what was for him an “optional” innovation decision and take the time needed to “reinvent” the CCPM innovation to meet the working level management needs. The only other innovation decision was the final one, the “authority” decision by the manufacturing manager to direct termination of the CCPM innovation in the Finishes IPT area. In this case, the decision protocol which facilitated initiation of the CCPM innovation also proved to be key to its suspension.

Implementation Stage

From the beginning, the plan was for an incremental demonstration in the Finishes IPT embedded in a strategy that envisioned fairly quick success leading to, essentially, radical innovation, i.e., rapid expansion of the CCPM process to fuller implementation in the manufacturing assembly area at LM Aero’s plant in Marietta and, perhaps, Ft Worth, TX. From the prospective of this overall objective and retrospect, the validity of the consensus decision that the best project for the demonstration of CCPM was the full aircraft final finishes is debatable. Technically, it was certainly the most challenging objective within the candidate projects in the Finishes IPT. Success in the full aircraft project certainly had the potential to prove the merits of the CCPM approach for more general application in the Marietta manufacturing area. However, the

TSC facilitators and the LM Aero CCPM implementation team did not fully appreciate the time required to build or modify the 1000+ node network or recognize that the result might be unmanageable because of relative size and complexity for a project of roughly 60 days. Even using the status reporting and buffer management process established during the major component efforts, it was extremely difficult to manage the much larger, more complex full aircraft project. In fact, the accuracy of the buffer status—the sine qua non of the CCPM process in comparison with other scheduling approaches—was highly questionable by the third week of the 12 week process for 4006.

A better strategy for implementation, especially when the arrival of 4006 was delayed, would have been aggressive conversion to a building block approach, starting with the major components which involved smaller, less complex networks. Such a building block approach would have permitted the core team to gain proficiency in the use of the software, and templates produced by this process could have been used on the larger, full aircraft process (instead of the other way around, as happened in reality).

Expanding the potential benefits of early success with components further, it is possible that the Build Team might have initiated another demonstration in the factory at an earlier time. By the time some success was achieved with the components in early February 2001, the CCPM core team was consumed with the demonstration of CCPM on 4006 (largely because of its size) and there was insufficient time before construction supporting “single-process flow” in the factory began to initiate another demonstration project even if there had been an invitation.

Had it not been for an unrelated management decision to terminate application of full stealth finishes on 4006 to accelerate delivery to Edwards AFB for flight test, it is quite possible that the demonstration of CCPM in the finishes area would have ended in failure. Instead, the management decision effectively permitted an almost complete reversal from imminent failure of CCPM to a significant success. The powerful CCPM software permitted a virtually overnight conversion of the full stealth finishes plan to a highly accurate two-stage plan to meet deadlines established for the new plan to provide only aerodynamic finishes for 4006 finishes plan. Then, the interval between the modification of the plan for 4006 and the arrival of the new CCPM demonstration target, aircraft 4007, allowed time for a sharp reduction in the level of detail for scheduling and managing the full stealth finishes on aircraft 4007.

The dramatically streamlined schedule for aircraft 4007 was much better suited to the finishes environment. Daily updates provided sufficient insight to support buffer management and the overall project was completed in just over half the time of the original project aircraft, 4004.   The success with 4007 combined with the success of meeting line need dates in finishes on the major components permitted the routinization of the CCPM innovation with virtually no change in the Finishes IPT.

To emphasize an earlier point, the decision to delay formal software training for LM Aero personnel is questionable in retrospect. The failure to provide direct software training from Sciforma® for the LM Aero participants resulted in frustration when TSC facilitators were not directly available. In addition, the absence of software proficiency likely slowed the development of the initial full aircraft network and schedule. The need for LM Aero implementation team software proficiency was even more apparent when the “traveled work” had to be added to an already huge and very complex network for the initial demonstration aircraft, 4006.

The evaluation within the implementation stage was quite straight forward in terms of the simple quantitative assessments to determine if the CCPM innovation worked, though somewhat problematic regarding establishment that CCPM dominated other factors that changed during the demonstration (materials, labor proficiency, etc.). The more elaborate evaluation involving the discussions with Finishes IPT members enriched the understanding of the qualitative aspects of the innovation, particularly regarding the advertised benefits of the innovation and the perception that CCPM was, indeed, critical to the reduction in finishes span time in the view of IPT members.

As a final point in this section, in spite of all these potentially “better” decisions in light of the goal of a quick transition from incremental to radical innovation, the evidence is that the implementation in the Finishes IPT was an overall success at the tactical level, in the military vernacular. At the strategic level, it has to be judged a failure, because the use of the CCPM innovation in the finishes area was terminated and the full potential of the CCPM innovation was not realized by rapid expansion of the innovation to other manufacturing areas. In effect, the window of time when the Build Team organizational context was very supportive of the CCPM innovation closed by the time that the innovation achieved success in the demonstration.

Analysis from the Perspective of the Structural Levels and Actors Construct

Overall, the implementation in the F/A-22 finishes manufacturing process area can be characterized with the *structural levels* construct. It involved top-down initiation and support from the Program level in terms of identification of the innovation, funding and encouragement. Besides Program-level initiation, there was an identifiable *initiation stage* at the Operational, Finishes IPT level. The innovation decision authority was held by the Finishes IPT leader, consistent with the F/A-22 Integrated Product Team philosophy. Thereafter, the Program-level office provided the motivation, direction, flexibility, and, in this case, patience for the eventually successful use of the innovation within the Finishes IPT. As was true in the case of the Boeing application of CCPM, success had to be determined at the Operational level.

Regarding innovation *actors,* individuals were most important (versus organizational groups). The champions at the Operational level were both of the IPT leaders. Their enthusiasm for the innovation definitely assisted in the achievement of success, especially when the difficulties caused by the huge schedule for 4006 arose. The Program-level change agents, Casey and Colby, worked across the Program-Operational-level divide to persevere and complete the transformation of an idealized schedule to one that included all the traveled work for 4006 and 4007; they also supported the internal master scheduler efforts to finally generate a truly workable CCPM schedule for 4007. Other than Program leadership group and Build team support and encouragement, organizational groups were not heavily involved or influential in the actual detailed development and execution of the CCPM schedule.

The external TSC change agent played a central role from initiation through the first five months of the nine-month implementation span encompassing the reinvention/restructuring and evaluation phases. Individuals at all levels of the organization placed both trust and confidence in the TSC change agent and followed the TSC's guidance for virtually all aspects of the innovation. Even considering unintended and unanticipated consequences of some of the decisions that the team made, eventual success could likely not have been achieved without the external support.

Summary

The innovation process in the F/A-22 manufacturing process (finishes) area is an important component of the overall innovation case studies presented in the dissertation. Part A described the initiation stage activities were quite compressed due to benefits of the initiation stage at the Program level. In this case, the primary change agent role was played by an external source (the TSC) who very quickly gained the confidence of all involved because of obvious expertise and experience. Though extreme schedule detail and dynamics during project execution undermined the innovation effectiveness and almost caused failure, problems were sorted out fairly quickly and timely solutions developed. Overall, the implementation stage was complex and drawn out, but it led to fairly dramatic success in the demonstration when the innovation was finally tailored appropriately. Evaluation discussions consolidated appreciation for the qualitative aspects of the innovation. Unfortunately, none of these facts was compelling enough to avoid termination of the innovation in the Finishes manufacturing process area.

Table 10 summarizes the CCPM innovation process in the Finishes manufacturing process area at Marietta, GA.

Construct validity: expected changes found?			
Change	1	2	3
short description	meets CCPM schedule	better ability to foresee & deal w/ difficulties	better than past
overall answer	yes	yes	yes
supporting evidence	some data clouded by technology cluster; other data unequivocal; limited, strongly supportive data from discussions with key participants		

Structural Levels: Program and Operational
Program-level initiation & support for Operational-level implementation
Organizational Actors
groups played minor role; internal champions; both internal & external change agents

Casey Hybrid Innovation Process (CHIP) Model				
Element of Interest	Motivation	Initiation Stage	Innovation Decision(s)	Implementation Stage
short description of application	performance gap; internal "pull"	external identification of CCPM	quick initial optional decision to adopt; final authority decision to terminate	iterative process; lengthy start & near failure; tactical success; strategic failure

Table 10. Analysis summary: CCPM case study in a manufacturing process area.

Chapter 7: CCPM INNOVATION IN TEST OPERATIONS

Overview

The application of the CCPM innovation at Edwards AFB, CA in the F/A-22 Combined Test Force (CTF) is different in many respects from the other applications discussed in this paper and, indeed, from other applications outside of the world of defense acquisition. Whereas other F/A-22 applications are concerned with physical products—an assembled wing, a stealthy aircraft, or the aircraft computer—the primary job at the CTF is to produce information. Also the CTF is, in one sense, "at the end of the line." That is, the ultimate test of the weapon system is validation that production representative test aircraft satisfy the performance requirements in terms of aerodynamic, combat capabilities and logistics supportability. While responsible for the requisite testing to produce information that verifies the aircraft does what it is supposed to, the CTF necessarily depends on the rest of the program IPTs and facilities to provide the right assets with the right capabilities at the right time so the testing can be responsibly conducted in a timely manner. These dynamics contribute to the highly variable environment which produces significant unpredictability in virtually every aspect of CTF operations, even more so than in other parts of the F/A-22 development process.

Regarding the introduction of CCPM into this environment, the discussion in Chapter 5 made it clear that CCPM initially appeared to be unsuitable. CCPM was therefore rejected by the cognizant IPT leader based on limited exposure to CCPM and a very strong working-level preference to use traditional methods proven successful on other testing programs at the Edwards AFB Air Force Flight Test Center (AFFTC). In this section, another "chance" for use of the CCPM innovation is described, generated by external pressure emanating from Air Force headquarters at the Pentagon.

The CTF implementation evolved as a somewhat different two-phase application of the CCPM innovation, depicted in Figure 34. The first phase, initiation, formally

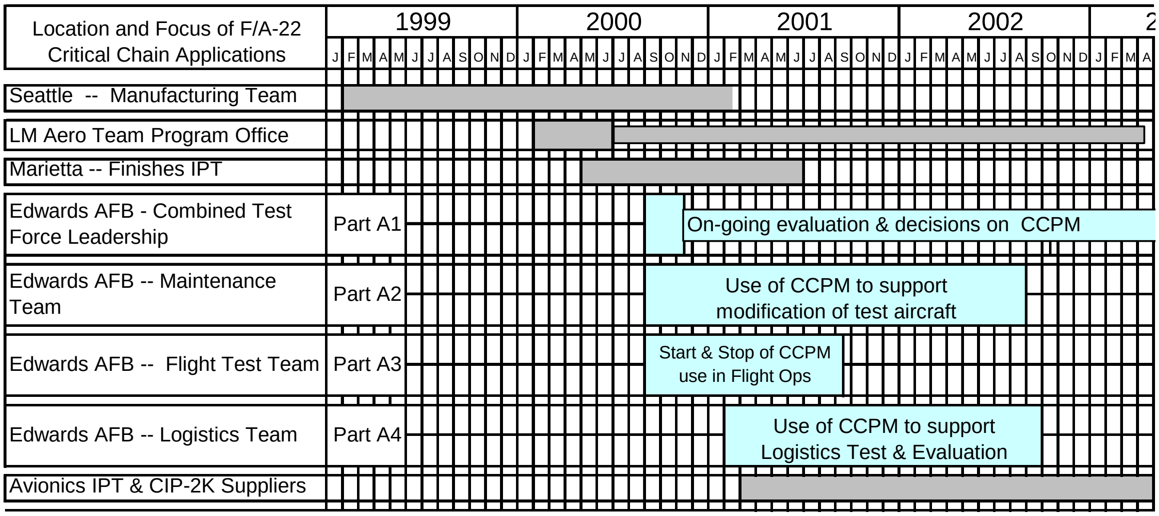

Figure 34. CCPM innovation initiatives at the F/A-22 Combined Test Force.

occurred at the CTF leadership level, where in an exception to the F/A-22 team policy on working level responsibility for no/no-go process decisions, the CTF leadership imposed a top-down decision to implement CCPM. Once the innovation decision was made at the CTF leadership level, the two lower level organizations conducted all or parts of the innovation implementation phase: Flight Test Operations (Flight Sciences and Mission Avionics) by direction and the Maintenance Modifications team (referred to as Maintenance Mods) by desire.[91]

The organization of this chapter is somewhat different than the preceding chapters. Essentially, there are four “Part A” sections, parts A-1 through A-4, as depicted in Figure 34. Part A-1 describes the initiation process and decision at the CTF level. Parts A-2 and A-3 present the description and mini-analysis of the implementation phase in the Flight Operations and Maintenance Mods area. Part A-4 provides description and mini-analysis of both initiation and implementation stages of the LT&E adoption of the CCPM innovation. Following all the “Part As,” a single Part B presents additional analysis considering construct validity and both CHIP model and *structural levels and actors* constructs of innovation (which are also used in the mini-analyses).

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[91] The third element under the CTF leadership umbrella, Logistics Test and Evaluation (LT&E), became involved later with the concurrence, rather than at the direction, of the CTF leadership.

Part A-1: Description: CTF Initiation and Innovation Decision on CCPM

The CCPM-related activity at the CTF leadership level involved the initiation stage through innovation decision parts of the innovation process. Like the initiation process at the higher Program level, there was no "implementation" phase at the CTF leadership level, but the CTF leadership remained engaged in the on-going CCPM innovations at the Operational level and involved in follow-on decisions.[92]

Initiation

As noted earlier, the F/A-22 Combined Test Force located at Edwards AFB, California, was both the catalyst and the first choice (at the Program level) for evaluation of the Critical Chain innovation for schedule planning and execution management of the F/A-22 acquisition program. Though the CTF declined the opportunity to host a pilot evaluation of CCPM when it was offered in May 2000, pressure from a Flight Test Tiger Team[93] caused CTF leaders to reexamine the earlier decision. The Tiger Team, chaired by a two-star general and composed of very senior, seasoned test operations civilians and officers, was chartered by Headquarters Air Force during the late summer in 2000. The team's task was to closely examine CTF operational test plans that projected what appeared to be an unacceptably long flight test period to validate the F/A-22's performance capabilities.

The catalyst for formation of the team was the perception at Headquarters Air Force at the Pentagon of a significant difference between what the F/A-22 program had documented as required testing and what some senior leaders thought was reasonable to meet requirements. Since one of Tiger Team's concerns was planning and execution,

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[92] As a point of emphasis, the CTF leadership was part of the Program level in the *structural level* construct.

[93] "Tiger Team" is a name often used by the Air Force, other Services and aerospace industry organizations in the title ad hoc teams formed to take on a significant problem that have defied solutions with existing approaches. Often manned by top industry or national experts, the team usually employs a multi-disciplined team to attack problems with a fresh perspective and make recommendations for problem resolution.

the government's F/A-22 Technical Director suggested a presentation on Critical Chain as a possible solution during the Tiger Team's first visit to Edwards AFB on 20 September 2000.

The CCPM briefing was thus scheduled and preceded by the CTF Mission Avionics manager's presentation that projected overdue completion of Mission Avionics development testing in June 2003, nearly four months beyond the scheduled beginning of the Air Force's OT&E. What intensified Tiger Team concerns about the optimism of the schedule were the identified "risks to executability" including idealized assumptions regarding aircraft and avionics system deliveries, best-case, sustained high sortie rates, and little allowance for "unk-unks"[94] (extracted from briefing slides, 20 September 2000).

Following the Mission Avionics IPT leader's briefing, Casey presented an overview of the Critical Chain innovation. The briefing described examples of CCPM success, including several in the system test environment, notably the NASA wind tunnel test at the Langley Flight Center, Virginia, and on the C-17 and the F-15 programs locally at Edwards AFB. The briefing also noted that funds originally expected from SAF/AQ to support the Finishes CCPM pilot project in Marietta were now available to support a second pilot project, like an initiative in the CTF area.

The briefing generated extended, spirited discussion of the potential for use of CCPM in many areas of the F/A-22 flight test program. In one exchange (author's notes of the meeting), the Mission Avionics lead pointedly asked the F/A-22 SPO director:

> Sir. If you already don't like the length of testing as we have planned it, how are you going to like the same schedule with Critical Chain buffers added, thereby making the period even longer?

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[94] "Unknown-unknowns" or "unk-unks" is a term that has become common-place in the taxonomy of risk management. "Known-unknowns" are problems that may affect development and explicitly accommodated in the planning. "Unk-unks" are problems that cannot be anticipated in terms of their nature or impact, but experience shows "they *will* happen." This is especially true in flight testing, where less control of the environment makes surprises or "unk-unks" quite common. The only way to allow for them in planning is to reserve funds and development and testing spans to deal with unk-unks when they occur.

The SPO Director immediately responded:

> I'd rather know *now* that what we need to do is only realistically feasible in 18 months, than find out 10 months from now that the 12-month schedule you briefed me will have to slip six months.

In further comments, the SPO director made it clear that he would rather have a schedule he could depend on for three reasons: (1) in the short term, he could more accurately plan to deal with the impacts of a longer than expected test period (if, indeed, that was the outcome of the planning); (2) in the longer term, he could reliably know when the Air Force could begin other activities—such as OT&E—that followed the contractor testing; and (3) overall, he could confidently make commitments to senior Air Force leaders about what would be done when.

As a result of the briefing and subsequent discussion within the Tiger Team and with the CTF leadership, the LM Aero F/A-22 Program Integrator was tasked to form a study group with SPO, CTF and contractor members and carry out the following task:

> Conduct a study to compare Critical Chain Project Management with its supporting software with the current approach, essentially the Critical Path Method (CPM), with its supporting software.[95] Present results and recommend an implementation plan for the selected approach[96] to the next meeting of the Tiger Team, 23-24 October 2000.

Casey and Pennington were appointed study group managers to limit additional tasking on the CTF.

The CTF reaction to the tasking was mixed. In a weapon system testing environment steeped in a traditional culture oriented to engineering evaluation and

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[95] This wording of the action assigned by the Tiger Team corrects the original wording which confused the planning and execution approaches with the software that enables each approach.

[96] Since the "current approach" was already in place, the study group recognized that an implementation plan would only be required if CCPM were adopted to replace the current approach.

problem solving, many CTF members believed that the Tiger Team was pushing for a study to modify a management process not really "broken." There was a general feeling that the current problem was not of their making, and, in fact, the current management approach had played a major role in dealing with the impacts of the schedule crunch.[97] Many pointed out that the current policy requiring detailed planning for only the next two weeks was the result of external factors over which they had little control that forced significant changes by the time the second week began. As a result, there were real misgivings about detailed planning for the entire program as seemed required by CCPM.

These concerns notwithstanding, the study group recognized that available, largely qualitative data would have to be used to support the study because there was insufficient time to develop a significant amount of new data. Furthermore, the group made the overall assumptions that (1) the evaluation should addresses overall management approach (versus just software) and (2) management was interested in knowing which approach offers best value in managing schedule risk.

After the approach and methodology were agreed upon, involvement of the CTF players was problematic, for two reasons. First, study was just one of multiple tasks and a much lower priority than support for planning, executing and reporting on actual flight tests. Second, it was not clear to CTF members of the working group that the time and detail Critical Chain would require offered compelling advantages over parametric planning then used to address longer term planning.

These limitations on availability were largely overcome in extensive discussions via e-mail and video teleconferences. Casey and Pennington set up the administrative process and integrated the iterative results of the evaluation into primary and back-up

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[97] During the previous year, the organization had "done its part" to deal with the impacts of delayed aircraft deliveries and some required changes. At the end of the year 2000, the CTF had "surged" for nearly three months to accumulate sufficient test hours and information to overcome attacks on the program for too slow a flight test pace. Their efforts and other evidence of progress gained Defense Acquisition Board (DAB) support for continued funding of the program.

draft charts to support the agreed presentation form. As detailed in Appendix E, the results of these discussions favored the CCPM solution on all functionality agreed as important when the study first started, namely, project planning, scheduling and statusing, allocation of resources, problem identification and resolution and communication with program personnel at all levels.

As the study findings began to favor for the CCPM solution, Casey and Pennington began developed a CCPM implementation plan and worked with the CTF leads to identify personnel who would require various levels of training to support such a plan. When discussions were renewed with Major McNutt at SAF/AQ, he was able to gain tentative approval for use of the $250K promised earlier for a CTF implementation if and when the decision were made to do adopt the CCPM solution.

Innovation Decision

At the next Flight Test Tiger Team meeting on 21 October 2000, the results of the trade study favoring the Critical Chain approach on utility and effectiveness criteria were presented. The Trade Study team recommended that CCPM be adopted and confirmed availability of SAF/AQ funding to support implementation. At the time, the tight agenda for the Tiger Team precluded extensive discussion, but the general consensus was that the preponderance of evidence supported adoption of the CCPM approach.

Shortly after the Tiger Team meeting, the combined expectation that something needed to change and the strong study preference for the CCPM option prompted the CTF leadership to direct implementation of CCPM in Flight Test Operations (Flight Sciences and Mission Avionics), and in the Maintenance Mods area. In addition, the government Deputy Director of the CTF was designated CCPM implementation lead. To facilitate the process, a statement of work similar to that used in the Finishes IPT implementation of CCPM was developed along with contractual and funding documentation to obtain technical support from the TSC.

The implementation phases of the three CCPM applications resulting from the innovation-decision are described in the sections that follow: Maintenance Mods area (Part A-2), the Flight Test Operations area (Part A-3) and the Logistics Test and Evaluation (LT&E) area (Part A-4). The necessary training in CCPM concepts by the TSC and CCPM software by Sciforma® was the logical first step in the Maintenance Mod and Flight Test Operations area implementations and is covered in Part A-2.

Part A-2: Description: CCPM Innovation in the CTF in Maintenance Mods

The maintenance modification process involves the installation of preplanned hardware or software changes justified as needed by any one of several sources after the initial fabrication and flights of the aircraft.[98] To accomplish these modifications or "mods", one or more aircraft are assigned to ground maintenance status. Because of the intensive flight-testing required of each F/A-22 test aircraft and all of them as a group, it is imperative that these modifications be accomplished efficiently in the shortest possible time. At the point at which the CCPM approach was introduced, some 2.5 years into the flight test program, several mod periods had already been conducted with mod periods invariably exceeding initial projections by upwards of 50 percent and a worst case of 300 percent. At best, planning was based on top level estimates (as opposed to task-by-task details), and execution was manually controlled by use of

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[98] In some cases, the need for modifications is clear too late in the assembly and initial test period for the modification to be made before the aircraft is sent to Edwards AFB. In other cases, engineering structural tests, such as the static and fatigue tests described earlier, or subsystem qualification tests between those required for initial flight and full qualification dictate that changes be made. Finally, new releases of software sometimes requiring additional hardware or permitting the operation of a new subsystem generate the need for changes. While closely controlled by an F/A-22 Configuration Control Board (CCB) and limited to those changes absolutely required, changes or mods do occur and are frequently "batched" for efficiency.

magnetic strips on what was called a “wicky board”—an approach virtually identical to that used by most other flight test programs in the past.[99]

Most appealing about the CCPM innovation was the process and enabling software that supported the execution phase information to better prioritize work and predict ability to meet prior commitments based on progress to date. The promise of CCPM to generate such feasible and relatively immune schedules and finish the modification at a predictable date was particularly attractive to the Maintenance Mod lead planner. In fact, as the responsible working level decision maker, he was not opposed to the CTF leadership direction to implement the CCPM innovation. Rather, he was pleased and actively campaigned for inclusion and priority when the decision was made.

In practice, the application in the Maintenance Mod area became a series of comprehensive, iterative implementations.[100] The description (including evaluation) of the several iterations which follows shows that for a number of reasons it was less than an ideal implementation. Though evidence accumulates to show that CCPM did support the maintenance mod area, it was not as effective as it might have been. Even so, the implementation provides the basis for a number of lessons learned for future applications in similar settings.

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[99] The “wicky board” displays detailed tasking—jobs and personnel assigned--on a day-to-day basis for the current few days. While useful and accurate for current status, the information is subject to substantial interpretation regarding progress toward the completion of the project and/or predicting completion date. As variability and delays accumulate, what tasks are most important to completion within the mod period becomes uncertain. Similarly, the risks and time to deal with integration challenges at the end of the span expands as does the time to deal with them so there is frequently a “surprise” declaration near the end of the span that the schedule will be overrun. In contrast, if properly updated during the project, CCPM forces continuing focus on the Critical Chain tasks that relate to goal; attention to indicators that the completion date is in jeopardy are apparent earlier, thereby permitting earlier action to keep the project within the planned span.

[100] In fact, when the CTF leadership agreed to use of CCPM in the Maintenance Mods area, it was with the stipulation that it was not co-equal with the other implementation areas. (The flight operations areas and LT&E area provided test data, whereas the mod area only supported those areas).

Implementation

The first step in the implementation process was two weeks of CCPM foundation training. The TSC agreed to accomplish the training “on-site” in California instead of at the TSC headquarters. Because of the security concerns and potential conflicts at Edwards AFB training was conducted at the nearby LM Aero facility in Palmdale, California. To reconcile schedule conflicts, the class was split into three days before and five after Thanksgiving Day, 2000. Based on one of the lessons learned in the Finishes IPT implementation, CCPM software training was arranged to immediately follow and reinforce the concept training provided by the TSC.

After the initial training session, the second phase of training for Mission Avionics personnel was deferred because it appeared that aircraft 4004 and 4005 might be delivered to Edwards AFB almost simultaneously in late December, thereby causing an overload situation for support of 4004 and 4005 test missions. While approving that deferral, the CTF leaders directed Flight Sciences and Maintenance Mods personnel to attend and complete the CCPM training on schedule.

First Maintenance Mods Use of CCPM: Single Project

Immediately following the training, work began on the networks for the Maintenance Mod work planned for aircraft 4003, facilitated by the TSC (who had been involved in all F/A-22 CCPM efforts to date) and another TSC associate.[101] Because of both the Maintenance Mod planner’s interest of the in CCPM and the limited availability of Flight Sciences technical people, the Maintenance Mod effort became the “lead” CCPM implementation area for the CTF. Based on another lesson learned in the Finishes IPT, that it was best to start “small” with a simpler project, the first CCPM effort involved the application of the CCPM innovation to a single aircraft project.

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[101] The implementation could not have proceeded without this assistance, though the absence of security clearances for the TSC personnel created an additional administrative burden in terms of paperwork and constant escort.

The Maintenance Mod personnel rigorously followed the network building process with the goal of a complete by 4 January 2001. The concept for initial application of the CCPM approach was to focus on a change to the Main Landing Gear (MLG) door and the surrounding structure (referred to as simply the MLG mod herein). The effort had been estimated by conventional means to require approximately six calendar weeks of aircraft "downtime." However, to take advantage of the maintenance downtime initially prompted by the MLG mod, a total of 29 maintenance jobs[102] were included in the plan. In comparison with the finishes work, which required a rigorous sequence based on stealth technology, network development for Mods involved a sequence of maintenance "jobs" structured to make the most sense, assuming parts and personnel were available to accomplish the tasks. The planners knew that the sequence could be changed "in-process" if any one of a number of contingencies were to arise (e.g., non-availability of parts or specialist, unexpected configuration difficulties, etc.).

Actual work on the project started before network completion during the last week of December and the first two weeks of January. During this time, aircraft preparation work (e.g., removal of panels, etc.) was accomplished, following the Critical Chain network precedence flow while the overall network was being finalized. During this same period the Maintenance Mod planner/CCPM leader trained maintenance supervisors, leads and mechanics/crew chiefs on Critical Chain concepts and gained their help in validating the network. After final refinements, the "critical chain" sequence was identified, buffers were inserted to account for expected variability, and the project (depicted in Figure 35) was finalized on 12 January with a projected completion date of 4 April 2001. Importantly, the schedule assumed eight qualified specialists/mechanics.

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[102] "Jobs" is a generic reference to any one of several tasks that might be completed during a maintenance modification period. Besides the Change Requests, Engineering Inspection Requirements (EIRs) to accomplish periodic, often invasive inspections of a particular area or part, Flight Test Requests (FTRs) generally associated with addition of test instrumentation sensors or wiring, Removal and Replacement (R&R) of parts or equipment, etc.

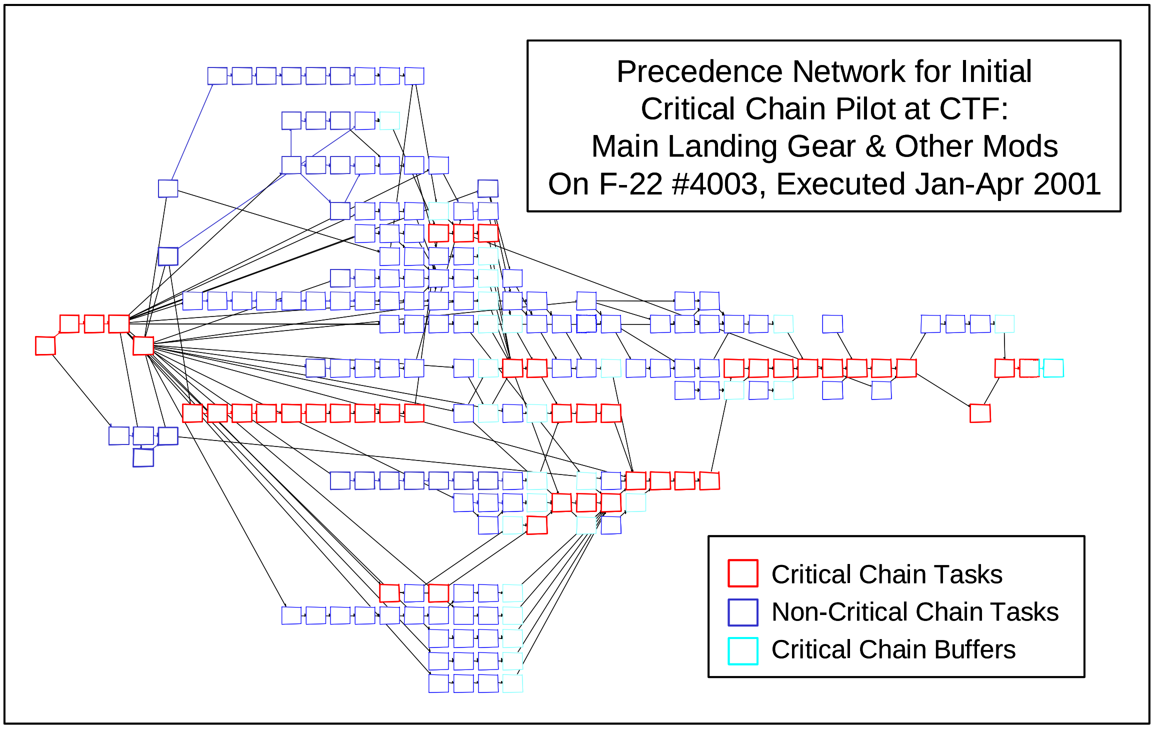

Figure 35. Overview of project network for Maintenance Mod project on 4003 (Maintenance Mod CCPM archives, April 2001).[103]

would be made available temporarily (TDY) from other program sites (Marietta and Ft Worth).

After updating the project for completion of the preparatory work, the tracking process began on 14 January with daily morning meetings in front of a 3- by 6-foot easily-readable version of the precedence network posted on the maintenance hangar wall. Each day, the crew chief would brief the Maintenance Mod planner/CCPM lead on progress of the effort and annotate the network with task starts and completions. This PS8™ software update information was used by the master scheduler (who had been trained in CCPM concepts with the original LM Aero group during the summer of 2000).

Though a combination of key personnel absences and higher priority work caused suspension of the formal updates in PS8™, the work did follow the precedence

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[103] When the diagram is expanded to that the text is readable, each of the tiny boxes reveals task details (e.g., task name, ABP and HP durations, resource names, etc.).

captured in the network (except as precluded by the availability of parts). Failure to use the update and reporting features of the software forced the team to use engineering judgment to estimate the buffer status in reports to management each Tuesday. Even so, the project was completed on 12 April, just beyond the 4 April target.

Evaluation of the First Maintenance Mod Use of CCPM

Though completing later than planned by approximately seven percent, results were better by at least a factor of seven than previous projects of similar scope. Specifically in the case of the primary change in the entire package, the MLG mod was accomplished in approximately 4 weeks--2 weeks or *33 percent short of the projected six-week span based on traditional planning methods*.[104] Though improvements over the past were very positive, the newness of CCPM prompted a post-mod assessment by key participants to fully understand the reasons for missing the target. Results were briefed to the CTF Deputy Commander, overall lead for CCPM implementation, as noted earlier.

The group concluded that at a top-level, four factors negatively affected on-time achievement of the goal: normal variability, availability of parts, fewer support personnel from Marietta and Ft Worth than planned (five instead of eight), and work that represented new scope. From a buffer management perspective, while the buffers absorbed the normal variability and some of the shortfall in support personnel and availability of parts, buffers were not able to completely make up for parts delays and new scope, thereby forcing a later finish than projected. A significant factor was both the addition of added work and the decision not to formally add the work to the PS8™ baseline project. The dual consequence was that the buffer status dependent wholly on

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[104] This "traditional planning span" to "CCPM achieved span" ratio, if applied to the entire project, suggests that the gain in added flying for 4003 was on the order of 40 days. Even recognizing that 4003 was only one of three flight test aircraft at the time, the equivalent dollar savings for potential acceleration of the flight testing was several million dollars (because of the $1M/day cost of operations). The resulting, very attractive return on the investment in CCPM training and technical support could be calculated to be much higher if factors for overruns typically associated with execution of traditional plans were taken into account.

engineering judgment was progressively less accurate and, therefore, judgments on the value of buffer status and management were inconclusive.

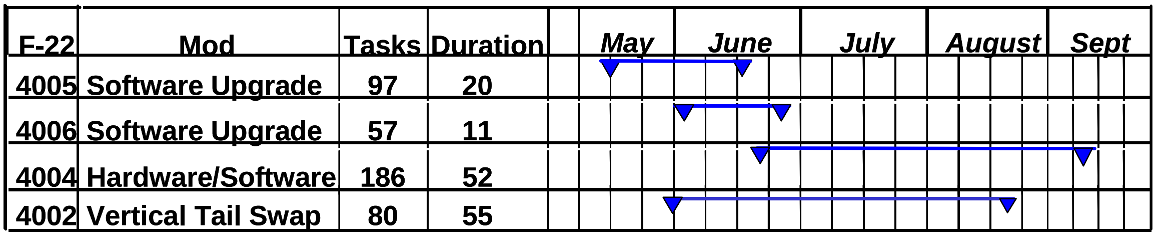
On the positive side, the group felt that the intense planning effort forced by the CCPM approach provided management a better knowledge of the work content, and provided the workers a more orderly, efficient flow of the work. In addition, the CCPM training and execution processes highlighted the unacceptable costs of multi-tasking and helped managers anticipate manpower and other resource difficulties so “borrowing” from other program locations (e.g., Marietta, Ft. Worth) was better justified and there when needed (even considering the reduced manpower from Ft, Worth). It was also much easier to see where to logically add new work, thereby avoiding rework caused in the past by giving new work immediate, top priority as often happened.

On balance, despite the difficulties encountered, the pilot project was considered a success. The Maintenance Mod planner was convinced that the process added significant value the effort by the maintenance community to support the CTF mission.

Second Maintenance Mods Use of CCPM: Multi-Project

During execution of the first project, the Maintenance Mods planner/CCPM leader began planning to mitigate the impact of the need for multiple aircraft to be “down” for modification from May through October 2001 and simultaneously evaluate the multi-project capabilities of Critical Chain. The primary objectives of the modifications of three of the aircraft, 4004, 4005 and 4006 were centered on an upgrade of software and/or hardware associated with new operational flight program (OFP) software for the avionics system. A fourth aircraft, 4002, required the removal and replacement of the vertical control surfaces (generically called “tails”) to overcome a structural weakness discovered in ground testing and permit continued expansion of the flight envelope. As was the case with the MLG mod period on 4003, each of the four aircraft required other "jobs" to be accomplished while the aircraft was down for the primary mod.

The planning for the coordinated efforts to achieve modifications of several aircraft with overlapping spans of downtime was facilitated by employing the CCPM multi-project "synchronizing" technique (described in Chapter 3). This approach resulted in a proposed staggering of the start of the individual aircraft projects based on the most heavily used resource (the "strategic" or "drum" resource in the CCPM lexicon). In the case of this set of projects, the software identified the structural mechanic as the strategic resource.[105] The next most heavily used resources were the avionics technicians, required to accomplish the software upgrades that dominated the overall modification period. Both were used to "synchronize" the projects for this effort. Figure 36 below displays the relationship of the four projects as finalized for the project.



F-22	Mod	Tasks	Duration
4005	Software Upgrade	97	20
4006	Software Upgrade	57	11
4004	Hardware/Software	186	52
4002	Vertical Tail Swap	80	55

Figure 36. Relationship of synchronized Maintenance Mod projects (Maintenance Mod CCPM archives, April 2001).

The actual execution of the modification schedules was very similar to the execution of the initial single project application of the CCPM innovation. There were a number of similar difficulties along the way, including parts and manpower availability. Also problematic was the decision not to modify the CCPM plan when unexpected work was created or discovered in the process of completing the mods or formally added to

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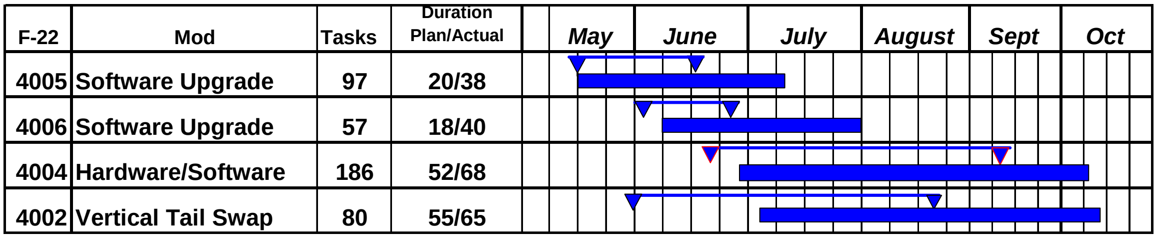
[105] This made sense, since they are the workers who remove panels (de-panel) and disassemble the aircraft to provide access to the modification areas, install or complete many of the modifications, and then reassemble and re-panel the aircraft in preparation for resumption of flight testing.

the scope of the various aircraft projects. Rather than cover these problems individually, the essence of these problems is best described in an overall evaluation.

Evaluation of the Second Maintenance Mods Use of CCPM

The results of the execution of the multi-project plan are shown in Figure 37 were disappointing compared to the positive results with the first use of CCPM on 4003.



F-22	Mod	Tasks	Duration Plan/Actual
4005	**Software Upgrade**	**97**	**20/38**
4006	**Software Upgrade**	**57**	**18/40**
4004	**Hardware/Software**	**186**	**52/68**
4002	**Vertical Tail Swap**	**80**	**55/65**

Figure 37. Comparison of planned and actual spans for synchronized projects (Maintenance Mod CCPM archives, October 2001).

However, the majority of the difference between planned and actual spans was the result of several factors as assessed by the CTF group, with the help of the TSC facilitator and LM Aero change agents.

Despite initial consensus on the plan, once the mod efforts began, supervisors and crew chiefs tended to use the plan as a general guide rather than a near-mandatory sequential checklist. As a result, actual sequences were dictated by exercise of prerogatives based on past experience,[106] updating the Critical Chain schedule became more difficult and the key metric—buffer status—became less accurate.

All aircraft were affected by additional work that was added after the project was begun, generally by 25-30 percent, but as high as 80 percent in one case. The new work was not formally added to the network because the team knew a new span would likely be generated, and they wanted to avoid perception by CTF leadership of a "moving" or unstable baseline—something the Critical Chain methodology was supposed to avoid. As a result, by mid-span in the projects, the buffer status was almost

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[106] This is not unusual. In a study at an Air Force depot responsible for disassembly, inspection and repair of large-body cargo aircraft, Gemmill and Edwards found that "much of the schedule is determined based solely on the experience of the shop floor supervisors or crew chiefs" (p. 44, 1999).

meaningless, buffer management was impossible, and three of the projects predictably overran the originally projected completion date. Until CTF leadership was fully aware that the buffer status was based on middle-management engineering estimates rather than critical chain software algorithms, there was some surprise when the projects exceeded plans.

Exacerbating the problem was the fact that whether for planned or added work, parts, modification kits,[107] and instrumentation equipment delays affected modifications more than anticipated. In addition, parts were often "cannibalized" to support the flying aircraft, negatively affecting the modification activity and often delaying efforts to return the aircraft to flight.

To this point, the multi-project phase of the Maintenance Mod pilot was judged less than successful, but not a failure. The Maintenance Mod planner CCPM lead understood that the substantial difference between the work that was planned and the work actually completed meant that planned and actual were two different projects. Furthermore, some of the myriad problems could be legitimately characterized as "special causes" of variation rather than the "common causes" that Critical Chain is designed to account for.[108]

Third Maintenance Mod Use of CCPM

Applying some of the lessons learned in the single- and multi-project implementations of the CCPM innovation, two more projects that were planned and managed in a third use of the CCPM innovation. Of the two important projects, one of them provides a bridge to section A-4 which describes the Critical Chain implementation in the area of Logistics Test and Evaluation (LT&E).

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[107] To facilitate modifications, all the parts and procedures for installation of changes or other jobs were assembled into complete packages or "kits" by the primary site (e.g., Marietta, Ft Worth or Seattle) and sent to the site where the job was being accomplished, in this case, Edwards AFB.

[108] It is also possible that inadequate estimates of common causes variability associated with the tasks resulted in insufficient buffer capacity to absorb the variability of the work that *was* in the CCPM plan.

The first of the follow-on projects was the modification of aircraft 4004 to assure it was fully and properly configured for execution of the extremely demanding climatic tests in a special facility at Eglin AFB, Florida. This 4004 mod was by far the largest mod planned and executed using Critical Chain. The second of the mods involved 4006 and was centered on the upgrade of the Avionics OFP.[109] At the same time, because LT&E testing had been constrained by intense pressure on the CTF to accelerate flight testing for on-time initiation of OT&E, the maintenance mod and LT&E planners agreed to work jointly during the 4006 mod period. After reviewing the access areas and procedures required to complete the planned mod work, the planners agreed that 46 LT&E test points could be accomplished on 4006. The points were to be evaluated as part of planned mod work or as a dedicated LT&E effort on an area separate and apart from the area on which modifications were being accomplished.[110]

Evaluation of the Third Maintenance Mods Use of CCPM

The results of the 4004 and 4006 efforts are shown in Figure 38, below, in the context of the earlier single and multi-project Critical Chain pilots. The tabular section of Figure 38 shows that after a relatively laudable success on 4003 and a very negative result on 4005, management of the multi-projects improved consistently. In fact, the 4002 and subsequent aircraft were able to "deliver" in terms of planned versus actual span and in terms of buffer use.

Both the tabular and graphic results from use of Critical Chain for the 4004 climatic mod and 4006 software upgrade show *apparent* Maintenance Mod team success in applying the hard lessons learned during the earlier multi-project effort.

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[109] The 4004 mod required six engineering changes (including the MLG mod described earlier) and the movement of gun system components from another aircraft, two major software changes, and nine extensive instrumentation mods to assure comprehensive data monitoring capability robust enough to handle the environmental conditions imposed during climatic testing. The 4006 mod included several other related firmware and configuration changes, two engineering inspections and two instrumentation mods.

[110] Further comment on this cooperative effort from the LT&E perspective will be covered in Logistics Test and Evaluation (Part A-4).

				Project Buffer Info		
Aircraft	Primary Mod	#Tasks*	Completion	Hrs Planned	Hrs Used	% Used
4003	Main Landing Gear + Ground Vibration Testing, OFP Load, etc	208	12-Apr-01	294	380	130
4005	S/W upgrade (Blk 3.0 FT 2.1)	97	7-Jul-01	105	648	617
4006	S/W Upgrade (Blk 3.0 FT 2.1)	57	1-Oct-01	114	412	375
4004	H/W & S/W upgd (Blk 3.0 FT 2.1)	186	8-Oct-01	249	669	339
4002	Vertical Tail Swap	80	19-Oct-01	380	420	110
4004	Climatic Prep+others	313	29-Apr-02	436	~436	~100
4006	S/W upgrade (Blk 3.1) + others	87	30-Apr-02	324	~324	~100

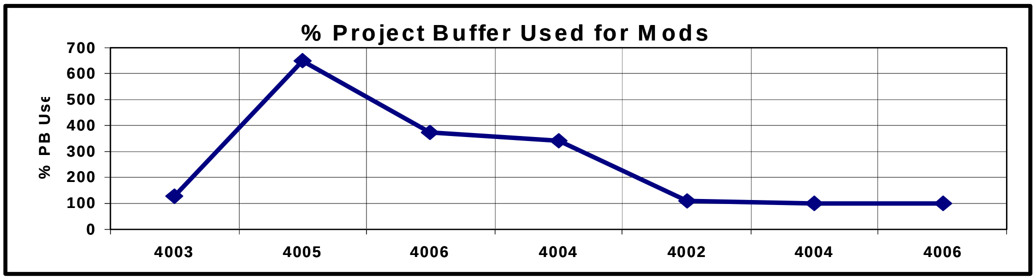

Figure 38. Comparison of Project Buffer use on Maintenance Mod projects.

However, though the team was able to limit (though not eliminate) additional unplanned work once execution of the project began, they also artificially inflated the project buffer (in colloquial terms, added “a fudge factor”) beyond what the critical chain software provided. As a result, other than forcing and providing a way to capture detailed planning, the CCPM process cannot be granted full credit for the success. What share of credit is difficult to assess because of the artificial inflation of the project buffer, the tendency on the part of floor supervisors to treat CCPM schedule work order as a guide, the failure to add unavoidable added work to the Critical Chain precedence network, and dependence on engineering judgments for buffer status reports to management.

After completion of the 4004 and 4006 modifications, the CCPM innovation (almost in name only) had been established and continued to be followed when substantial modifications by the CTF were required. To some extent continued use was a moot point for the F/A-22 mod activity at the CTF. In fact, in order to permit focus on completion of DT&E and support of OT&E, program leadership decided to complete only small mod packages of very limited duration at the CTF. Continuing, more substantial modification activities were transferred to LM Aero facilities at nearby Palmdale, California. However, details on the initiation and continued use of CCPM at the Palmdale facility are beyond the scope of this dissertation.

Mini-analysis: CCPM Use in CTF Maintenance Mods

Analysis regarding the construct validity of the expected changes is nearly a moot point regarding the CCPM innovation in the Maintenance Mods area. While there were some very promising results in some of the applications, the evaluations of iterative projects make it clear that the implementation of the innovation was so flawed as to almost invalidate any overall assessment.

Even so, the CHIP model proves useful for purposes of a mini-analysis. Though adoption was imposed by CTF Leadership, there certainly was a performance gap and, essentially, quasi-initiation and innovation decisions by the Maintenance Mod planner/ CCPM leader. The most interesting and detailed element of CHIP model in play in this CTF use of the CCPM innovation was the iterative implementation/evaluation cycles. As noted throughout the description and assessments, results of essentially merging CCPM innovation planning discipline with traditional intuitive execution practices were mixed at best, but might have been far better if the CCPM approach had been applied more rigorously. While some aspects of the classic application of CCPM protocols for single and multi-projects were applied and did produce improvements (arguably sufficient to pay for the SAF/AQ and program investment several times over), other aspects of the use of the CCPM innovation were seriously flawed. During the use of CCPM by the CTF mod team, several protocols of the CCPM approach were either violated outright or were only loosely followed. Though correcting these flaws would improve performance and strengthen acceptance in the future, actual results experienced in the use of CCPM for maintenance mods prompted cynical references to CCPM as “Critical Pain” from those who preferred the traditional “wicky board” and like approaches for planning and carrying out maintenance mod activities. The detailed Critical Chain plan was regarded as more restrictive than the more traditional approaches that permitted greater use of intuition and judgment when reaction to immediate, day-to-day-dynamics was required.[111] As a result, though experience with CCPM provides some evidence that it can work successfully in the very complex arena of flight test modification activities if properly employed, support for continued use of CCPM at the CTF was far from unanimous.

Part A-3: Description and Analysis: CCPM Innovation in CTF Flight Operations

In the flight operations area, the Flight Sciences and Mission Avionics test operations were managed by two co-equal, non-competitive managers that had distinct responsibilities. The Flight Sciences IPT Manager was responsible for “clearing the flight envelope”[112] for the F/A-22 operations using the flight sciences test aircraft: 4001, 4002 and 4003. In contrast, the “mission” of the Mission Avionics IPT Manager was to conduct testing of aircraft 4004 through 4009 to confirm that the avionics and weapons performance assured full F/A-22 capability to perform the air superiority mission for which it was designed. The connection between the two is that the Flight Sciences group had to “clear” areas of the flight envelope before the Mission Avionics group could schedule avionics systems test profiles in those areas of the flight envelope.

Implementation

Though parallel with, but largely independent from, the Maintenance Mods CCPM efforts, the pace and timing of the flight operations CCPM implementation was

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[111] On the surface this might seem to pose no problems or even be expected. However, the over-dependence on this approach might have been a factor in the consistently poor Maintenance Mods performance in pre-CCPM modification projects, especially when dealing with a revolutionary aircraft development program which generates new problems with no precedents,.

[112] This includes the rigorous, deliberate expansion of the speed, altitude and maneuverability envelope of the aircraft, as well as the required normal and emergency performance of the subsystems—electrical, hydraulic, flight controls and surfaces, etc.

affected by three factors: availability and training of key personnel and initial scope of the efforts. The very experts needed to develop the CCPM networks and plans were quite naturally key to the on-going, active flight testing, so both Flight Sciences and Mission Avionics efforts had to be pursued in the presence of intense demands to support the daily flying schedules. Regarding the training factor, CCPM implementation got under way first in the Flight Sciences area since the Flight Sciences personnel completed training (along with Maintenance Mod personnel) in early December 2000. Mission Avionics planning for use of CCPM had to be delayed until the basic CCPM training deferred earlier could be completed. Efforts in both areas initially attempted to plan for the entire test program, so substantial progress was not made until the effort was scaled back to a reasonable size, as described in the following sections.

Initial Flight Test Operations Use of CCPM

Immediately following the training as described in Part A-2, work began on the networks for the Flight Sciences work. The prime movers in the Flight Science area were the Deputy Flight Sciences Test Operations Manager[113] and the Flight Sciences lead Flight Test Engineer (FTE),[114] working with the TSC, and two TSC associates assigned to the Flight Sciences group.[115] Despite responsibilities and demands that slowed the progress of the CCPM planning compared to the Maintenance Mod effort described in Section A-2, the expertise and experience of the lead FTE and the Deputy Flight Sciences IPT manager made them the right people to be involved.

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[113] The Deputy Flight Sciences IPT Manager supports or acts for the Flight Sciences IPT Manager to execute administrative and programmatic responsibilities for the Flight Sciences IPT.

[114] The lead FTE essentially has the role of overseeing working-level test operations planning and execution for Flight Sciences test flights, both those for which he will serve as the FTE and those tasked to other FTEs. This very time consuming job requires coordination with all the individuals and agencies involved in the test flight, e.g., maintenance, flight operations (including the test pilot), range operations, mission control facility, etc.).

[115] As with Maintenance Mods, the absence of security clearances for the the TSC personnel created an additional administrative burden in terms of paperwork and constant escort.

The challenge in developing a CCPM plan for Flight Sciences was incorporation of numerous test points across the entire range of aircraft flight and aircraft systems performance arranged in four large groups of test points, referred to as “steps.” These large groupings were organized to (1) base testing on the anticipated flow of results from the full-scale structural testing and analysis being conducted at Marietta and (2) provide timely flight envelope expansion to permit flight profiles needed for the testing of the Mission Avionics aircraft.

Satisfying these planning parameters led to several iterations of the Flight Sciences CCPM effort and required frequent interactions with the Flight Sciences Test Operations Manager. Though the effort made only halting progress during the January through March 2001 period, the Deputy Flight Sciences Manager and the lead FTE became increasingly convinced of the potential value of CCPM in the early April time frame. The Flight Sciences team began making good progress due to development of a mission “template” at a meaningful level of detail with sufficient visibility of resource needs and conflicts, and techniques to permit overlap of the missions run by different teams of experts,.

Meanwhile, in early February 2001, approximately a month after the Flight Sciences CCPM team started, the Mission Avionics group completed training with some significant exceptions.[116] Actual planning for the CCPM implementation in Mission Avionics began after a delay to support the Green Team.[117] Thereafter, the group trained in CCPM concepts agreed that because the planning materials involved security classifications for which the TSC was not cleared, the development of the task

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[116] Instead of arriving by end-December, aircraft 4004 arrived January 30, and 4005 arrived March 30, 2001, making earlier deferred training harder to re-schedule. When the training was driven to the only “window” available in January-February 2001, it directly conflicted with aircraft 4004 arrival, prevented attendance by the lead Mission Avionics team planner and limited attendance Mission Avionics Manager.

[117] The F/A-22 program “Green Team” was the technical core of the team that had been convened to identify testing absolutely required to verify that the F/A-22 mission avionics capabilities met specification requirements. As such, it was appropriate to give this effort priority, since results could critically affect the tasks that would be part of the CCPM plan.

dependency network fell to the lead Mission Avionics planner over the next six weeks through the end of March. Since he had structured and exhaustively reworked the MS-Project™ schedule of some 300 nodes/tasks covering all Mission Avionics testing requirements[118] for the Green Team, he used that schedule as the point of departure for development of the CCPM task interdependency network. As individual problems arose, the planner described them in generic terms to the TSC representative or the TSC-trained Mission Avionics scheduler to resolve them as best as possible. In addition, the TSC representative, who had been working with the Flight Sciences team, shared the "template" that team had worked out for a standard mission flow. As the work on the first draft network was completed, the Mission Avionics planner was able to develop formats that effectively excluded classified data, but permitted trouble-shooting of the network. Even so, progress was slow in the Mission Avionics area.

Revised Flight Test Operations Use of CCPM

As both the Flight Sciences and Mission Avionics CCPM planning efforts continued without a clear projected completion date, the Deputy Director of the CTF convened a meeting of both teams in mid-April. He expressed the CTF leadership concern and frustration that progress was falling short of expectations for a full schedule that the team could begin implementing. He advised them that to accelerate the process, the leadership wanted to review progress and, possibly, revisit the decision to use Critical Chain if progress was inadequate or if there were "show-stoppers" associated with the flight test environment that prevented the application of the CCPM methodology. As a result, he directed both the Flight Sciences and Mission Avionics CCPM teams to complete a representative body of work for CTF leadership review at

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[118] Though this schedule methodology had been the representative of the traditional planning that had fared poorly against the Critical Chain approach in the Trade Study described earlier, the planner had frequently noted that the myriad "what-if" exercises he had worked had validated the network and, in his view, made any significant reduction in schedule by the CCPM approach very unlikely.

the end of May, to be followed immediately with a CTF-F/A-22 program leadership meeting to review progress on CCPM implementations. Each CCPM planning group was expected to produce common products, namely, a task dependency network for the work to be done including full resource loading, a detailed schedule, the tracking plan, and a "go-forward" plan, i.e., the plan for going from this set of products to the remainder of testing required to assure readiness for, and success in, conduct of OT&E.

The group agreed that for the Flight Sciences team, this meant completion of a credible CCPM plan for one of the four remaining envelope clearance "step" series of test missions. For Mission Avionics, the team agreed that CCPM plan would have to encompass the series of missions leading to the first guided launch of an AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM).[119]

To most efficiently respond to the revised tasking, the Flight Sciences leads and the TSC focused on refining the CCPM plan and schedule, which was 90 percent done, since they had already been planning in terms of "steps." As a result, they quickly converged on the CCPM plan and schedule for the next envelope expansion. A comprehensive, resource-loaded network and schedule consisting of 1605 tasks was developed and validated for the next major block of the flight envelope expansion effort called "Step 2." A good deal of that team's efforts focused on the presentation to convey results and recommendations regarding continued use of CCPM to the CTF leadership.

Responding to the revised tasking for Mission Avionics was more difficult because the group's effort to date had been less successful. Examining a subset of the initial network pertinent to the first AMRAAM guided launch to understand the task level and resource dependencies was the first step toward satisfying the tasking from the CTF leadership. The challenge of this tasking was to develop a schedule that could be

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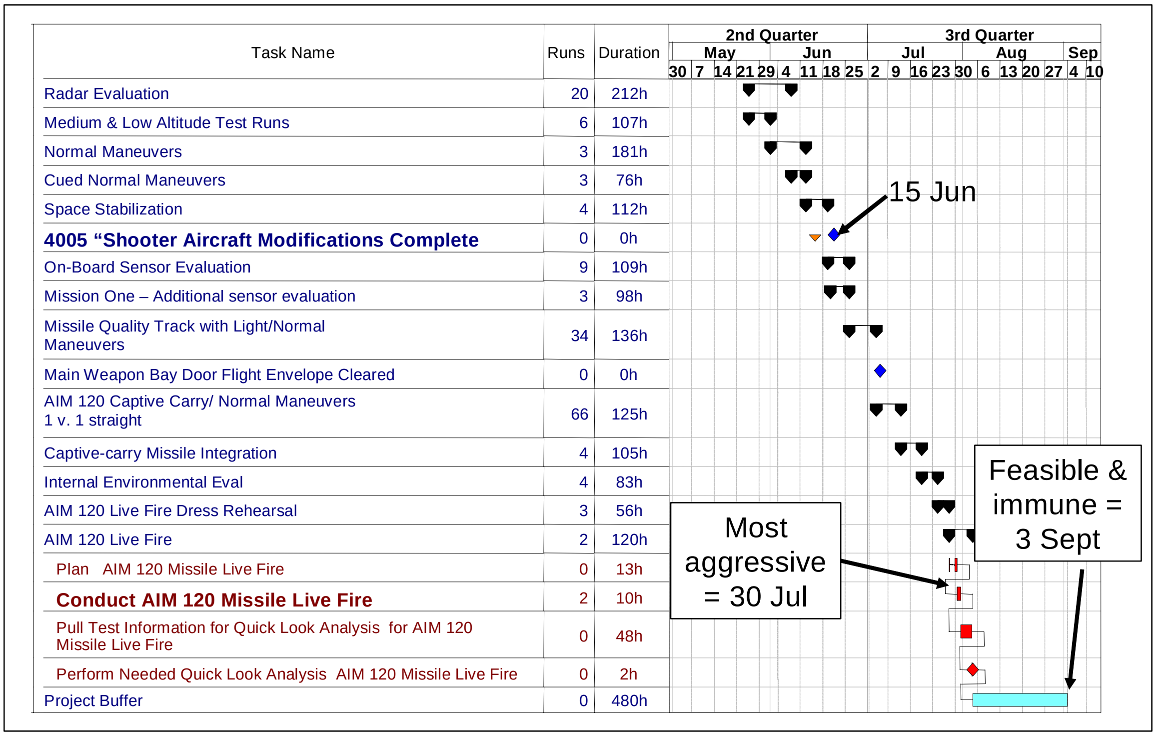
[119] At this point in the program, the first *unguided*, i.e., ballistic, launch of the AIM-120 had already taken place, but the "guided" launch was far more complex, requiring drone flight parameters and relative location to be determined by F/A-22 on-board sensors, missile launch and F/A-22 guidance from the aircraft to the missile, etc..

tracked to the completion of the estimated 17 flight test missions encompassing some 125 intercepts of an airborne target, including two “dress rehearsal” missions and a final mission for the actual launch of a live missile at an unmanned drone target vehicle simulating an enemy aircraft. Even building on that improved understanding, however, led to an initial result regarded as too complicated, unable to handle the dynamics endemic to development flight testing, and potentially manpower intensive for accomplishing needed updates.

To overcome these problems, Casey and Colby augmented the group to develop a streamlined “mission template” that could be tailored as necessary for unique requirements of particular missions. The result (Figure 39) was a network and associated schedule employing mission flow that reflected operational reality. The detailed planning process produced the additional insight that the constraint for the system was not the aircraft, but rather manpower, specifically, operations engineers, and actually permitted more time for completion of the mods than would have been



Task Name	Runs	Duration
Radar Evaluation	20	212h
Medium & Low Altitude Test Runs	6	107h
Normal Maneuvers	3	181h
Cued Normal Maneuvers	3	76h
Space Stabilization	4	112h
4005 “Shooter Aircraft Modifications Complete	0	0h
On-Board Sensor Evaluation	9	109h
Mission One – Additional sensor evaluation	3	98h
Missile Quality Track with Light/Normal Maneuvers	34	136h
Main Weapon Bay Door Flight Envelope Cleared	0	0h
AIM 120 Captive Carry/ Normal Maneuvers 1 v. 1 straight	66	125h
Captive-carry Missile Integration	4	105h
Internal Environmental Eval	4	83h
AIM 120 Live Fire Dress Rehearsal	3	56h
AIM 120 Live Fire	2	120h
Plan AIM 120 Missile Live Fire	0	13h
Conduct AIM 120 Missile Live Fire	2	10h
Pull Test Information for Quick Look Analysis for AIM 120 Missile Live Fire	0	48h
Perform Needed Quick Look Analysis AIM 120 Missile Live Fire	0	2h
Project Buffer	0	480h

15 Jun

Most aggressive = 30 Jul

Feasible & immune = 3 Sept

Figure 39. Critical Chain schedule for the first F/A-22 guided AIM-120 launch.

allowed by an arbitrary “quesstimate.” Finally, the “end of the project buffer” (teal blue bar in Figure 39), was considered the most likely date for completion of the missile firing, both feasible and relatively immune from normal variability. As a result of growing confidence by the lead Mission Avionics CCPM planner and deputy lead, the network and schedule became the core element of the presentation to the CTF leadership.

Reconsideration CCPM Use for Flight Test Operations

To meet the tasking of the Deputy CTF Leader, the government deputy leaders of the Flight Sciences and Mission Avionics teams presented briefings on the results of their efforts to the CTF leadership on 31 May 2001. The USAF colonel commanding the CTF chaired the meeting. Attending were his deputy, the contractor CTF leader and his deputy, and the Flight Sciences Flight Test manager and members of the CCPM planning teams.[120] including both Casey and Colby.[121]

The Flight Sciences CCPM network for the flight envelope expansion, Step 2, was presented first. In addition to detailing the task network and resulting schedule to achieve the objectives, the briefing revealed the results of the detailed resource loading analysis permitted by the CCPM methodology. Specifically, the briefing emphasized the need for extensive augmentation of up to 20 engineers in several disciplines to meet the targeted Step 2 completion date, including structural loads and flutter, vibration, handling qualities, and utilities and subsystems. He pointed out that the methodology generates insight on issues that “your ‘gut’ doesn’t tell you are there” (like shortages of specific kinds of specialists) and noted that once established, the methodology quantified the impact on results of major changes in assumptions or different management decisions.

The Mission Avionics Flight Test Operations deputy lead presented the results of the planning and scheduling for the first guided AIM-120 missile launch, describing it as

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[120] The chief of maintenance, the lead CCPM Mission Avionics planner, and the CCPM-trained schedulers for both Flight Sciences and Mission Avionics. Unfortunately, the Mission Avionics Manager was absent.

[121] All quotes and details of discussion from author’s unpublished notes of the meeting, 31 May 2001

a pilot project to help understand the application of the CCPM approach and overcome problems initially encountered in the attempt to apply CCPM to the entire Mission Avionics program. He carefully explained results of the effort that addressed concerns about level of detail and measures of progress, i.e., cumulative reduction or “burn-down” of pre-live-fire requirements. He noted key assumptions that would affect this or any plan, but described the CCPM plan as workable. He also presented three options with associated pros and cons for moving ahead as depicted in Table 11 below. The options ranged from a full commitment to use of CCPM, to a minimum commitment (with later decision on full commitment), and a middle ground, characterized as a “rolling wave”.[122]

Number	Brief Description of Option	Pros	Cons
1 Full Commit	Apply Missile Modeling Approach to Entire Avionics Program	--Credible Burndown --Improve assessment of executability --Enhanced communication of program information	--2-3 month effort --1.5-2 people + consulting support --Need central CCPM point of contact
2 Middle Ground	Apply CCPM to a 3-6 Month Window (“Rolling Wave” Approach)	--Credible Burndown for near-term --Avoids super-detailed effort for uncertain situation (> 6 mos) --Clearer knowledge of hard- and software availability/functionality --Requires less labor near-term	--requires continuation of parametric approach to project beyond 6-mos. --Periodic spurts of more intense planning (to support rolling wave)
3 Minimun (Test)	Implement and track First AIM-120 Launch	--More clearly establishes validity of AIM-120 plan before expanding --Provides experience with process & execution benefits --Provides basis for converting to new buffer management --Enhanced communication of program information	--Delays implementation of approach to program (as directed)

Table 11. Options for use of CCPM approach for Mission Avionics flight test.

The CTF Commander asked several questions and indicated that it appeared that most of the concerns about CCPM he had been briefed on previously had been dealt with. He, therefore, approved continuation of the planning for Flight Sciences, especially since the effort that was clearly showing positive results.

On Monday, 4 June 2001, a follow-up teleconference connected key personnel concerned with the Flight Test program commitment to the Flight Test Tiger Team on

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[122] The intent of the “rolling wave” was to provide detailed planning for the next 3-6 months with updates each month to extend the planning/scheduling horizon by an additional month.

use of the CCPM innovation.[123] The LM Aero Program Integrator indicated he and the SPO Technical Director had reviewed the 31 May presentations and wanted to understand the CTF plan for moving forward to meet the commitment to the USAF Flight Test Tiger Team for use of CCPM. The CTF commander indicated that the CTF would use CCPM for the Maintenance Mod planning and execution, and expressed his belief that previous concerns about the ability of the CCPM innovation process to handle flight test operations details had been overcome. Though acknowledging that CCPM was a more complex process than traditional planning, he expressed the CTF preference for use of greater detail for the next three to six months, then more aggregate levels of planning for the remainder of the program, thus still providing a total program look.

While the commander's comments were relatively positive, other CTF concerns were expressed about the level of work to be done (even given good mission templates for both flight operations areas), dealing with changes in mission resources, the belief that parametric analysis might be as accurate as CCPM planning with far less work, etc. Because of these concerns, the result of the meeting was to leave the issue of applying CCPM to flight test operations for a follow-on meeting which would focus on the difficulties encountered with CCPM applications and options for dealing with the problems. The SPO Technical Director indicated the results of those discussions could be used to provide feedback to the Air Force leadership in the Pentagon to assure they understood the new plans, and to the rest of the F/A-22 program to possibly inspire their use of CCPM. The CTF commander agreed, but noted he would suspend further detailed planning until a "face-to-face" meeting with the SPO Technical Director and the LM Aero Program Integrator could be arranged.

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[123] Present for the discussion were the F/A-22 SPO Technical Director and Pennington (at Wright-Patterson AFB, Ohio), the F/A-22 Contractor Program Integrator, Casey and Colby (at Marietta, Georgia), the CTF Commander, his deputy and the CTF contractor director, (at Edwards AFB, California). Also participating was the CCPM TSC to the F/A-22 program.
Details and quotes from Author's notes of the meeting, 4 June 2001.

After the 4 June teleconference, the follow-up CCPM discussions at the CTF did not happen for a number of reasons. Lingering reservations among CTF leadership group about CCPM aside, the activities associated with actually preparing to achieve the first live guided AIM-120 missile firing became so intense that it consumed those in the Flight Sciences and Mission Avionics teams that would have been required to accomplish further CCPM planning. Thus, the Mission Avionics CCPM planning team was unable to develop the “rolling wave” approach, and the enthusiasm of the Flight Sciences deputy manger waned as other priorities overshadowed the CCPM effort.

In an attempt to overcome residual concerns, Casey, Colby and Pennington solicited specific concerns about flight test operations (including scheduling and execution) from CTF and other key leaders across the team. The three change agents then worked with the TSC to use Theory of Constraints cause-and-effect logic to develop a coherent, integrated picture of how the myriad concerns related to each other.

On 11 September 2001, the results of this effort were briefed by Casey and Pennington to the CTF leadership via VTC in a meeting chaired by the LM Aero Program Integrator and the SPO Technical Director. Besides describing the “current reality” of the CTF environment in the form of a diagram that revealed the key causes and effects, the briefing suggested how several aspects of the Critical Chain systems approach could mitigate many of the problems identified by the leaders themselves. However, the logic of the current reality diagram was not fully accepted by the CTF leadership and had no impact on the long-standing reluctance to use of CCPM to support flight operations testing.

Final Decision Rejecting CCPM Innovation Use for Flight Test Operations

In concluding the 11 September 2001 VTC discussion, the CTF commander and contractor CTF director advised the contractor Program Integrator and SPO Technical

Director that all things considered, they had decided to maintain the traditional approach to planning scheduling and executing flight test operations. At the same time, they reinforced their commitment to application of CCPM to the Maintenance Mod and add a new area, Logistics Test and Evaluation (LT&E). The CTF leaders believed CCPM was better suited to both areas than to flight test operations.

In a post-VTC discussion with Casey and Pennington, the LM Aero Program Integrator and SPO Technical Director explained that they had accepted the CTF leadership decision for two reasons: (1) without CTF leadership support, there was little chance for CCPM success even if the CTF was directed to use CCPM by team leadership, and (2) that further attempts to prove its worth would only be distracting. The SPO Technical Director and Program integrator tasked Casey and Pennington to suspend further efforts to convince the CTF leaders to use CCPM in the flight operations area. Instead, they directed continued support of the CCPM efforts in the Maintenance Mod and LT&E areas of the flight test program and anywhere else there was both a need and an IPT willing to employ CCPM.

Mini-Analysis of the Aborted CCPM Use in Flight Test Operations

On the surface, the final decision to terminate the use of the CCPM innovation in CTF flight operations seems a result of collective resistance. However, the lens of the CHIP model allows the clearly visible prediction that the CCPM innovation was likely doomed from the outset. First, as discussed in Chapter 5 and reiterated in this chapter, the Combined Test Force managers were not totally convinced that the situation was a CTF problem requiring a CTF solution. Regardless of the convictions of the Tiger Team, the views of Program leadership, or the acquiescence CTF leadership regarding a serious performance gap, he CTF Operational-level personnel largely questioned the need for innovative solution; essentially they perceived no performance gap.

Secondly, the Flight Sciences and Mission Avionics IPT leaders were willing to concede that CCPM made a lot of sense for some applications in the program (including Maintenance Mods and LT&E). However, they were convinced that the form of the CCPM solution described and offered to them was not suited to the extreme dynamics of the flight test operations environment; essentially they perceived no "match."

These views clearly indicate that the external change agents were not successful with relevant CTF leaders in two ways. First, even granting that there were myriad factors out of CTF control, the change agents were unable to clarify what part of the flight test performance gap perceived by others the CTF could address; if such an effort were initiated and successful, the need for a management innovation might have been created. Second, the change agents were not sufficiently sensitive to the managers' description of the dynamic variables at play to generate cooperatively "reinvent" the CCPM innovation so it could work in the flight test operations environment.

Thus, the CTF leaders concluded that even the "rolling wave" CCPM variant imposed too much effort for questionable benefits. Though the CTF commander had seemed willing to make a firm decision to use the CCPM innovation four months earlier (in May-June 2001), his subordinate CTF leaders were able to convince him that the long-range planning at the detailed level required for CCPM was a potentially wasteful use of resources. In support, they cited consistent evidence of changes for a host of mostly external reasons by the beginning of the second week of the two-week detailed schedule cycle mandated by the Air Force Flight Test Center at Edwards AFB.

At the bottom line then, the decision rejecting use of CCPM for flight test operations was the predictable combination of a failure to perceive either a performance gap as motivation, or a match between CCPM and the flight test operation to support a decision to adopt CCPM. Those observations notwithstanding, the fact should not be lost that the entire process started with an authority innovation decision (insisting on use of CCPM in flight test operations) that violated the IPT policy for working level go/no-go decisions on processes. The ultimately futile efforts to “make it work” might be characterized as the price paid for CTF (Program-level) leaderships’ failure to comply with the F/A-22 team’s fundamentally solid organizational policy. In an ironic way, final rejection of the CCPM innovation at the Operational level actually reinforced team policy.

Part A-4: Description of CCPM Use in Logistics Test and Evaluation

The CTF leader’s message terminating use of the CCPM innovation in flight operations simultaneously committed the CTF continued use in Maintenance Mods (as described in Part A-2) and in a new area, Logistics Test and Evaluation (LT&E). In fact, the LT&E CCPM innovation process involved both a distinct initiation stage independent of the Tiger Team pressure and an implementation stage. This section describes the emergence of a new multi-project application of CCPM that sharply departs from the “classic” implementation and that was quite effective for LT&E. The mini-analysis reveals the potential of this process to overcome problems encountered in Maintenance Mods as well, possibly, to overcome objections and resistance in flight test operations.

Initiation

The importance of LT&E testing was made clear in the F/A-22 specifications, was constantly reinforced by the logistics component of the F/A-22 SPO and was certainly a somewhat daunting challenge. The scope of the overall LT&E planning effort can be appreciated from the contrast between some 300 LT&E test points for the C-17 transport aircraft and over 20,000 test points for the F/A-22. Further complicating the scheduling challenge, the test points evolve from several separate requirements—Human Factors Engineering (HFE), Reliability & Maintainability (R&M), Bio-Environmental Engineering (BE), maintenance, Support Equipment (SE) equipment, and Tech Order Data (TOD) validations. Besides that, aircraft differences evolved because all the LT&E testing required a “production representative configuration” and not all F/A-22 test aircraft are the same—each becomes progressively closer to the production representative vehicle. As a result, not all LT&E activities can be conducted on all aircraft.

The job of developing a database that became the Logistics Test Management System (LTMS) to store and account for Ready-to-Test (RTT) points fell to the Chief LT&E Planner. He brought C-17 experience and substantial database development expertise to the job of gaining control of the mass of LT&E information. Essentially, the LTMS the planner developed related the thousands of test points and evaluation requirements to the physical description and function of the myriad systems and parts that together constituted the F/A-22.[124] The LTMS organized the interlinked database structure to group the vast majority of test points either by “panel” (Figure 40) or by “system” to facilitate testing functions or procedures related by proximity to a single panel (or group of panels) or by system (e.g., hydraulic or electrical power system). The

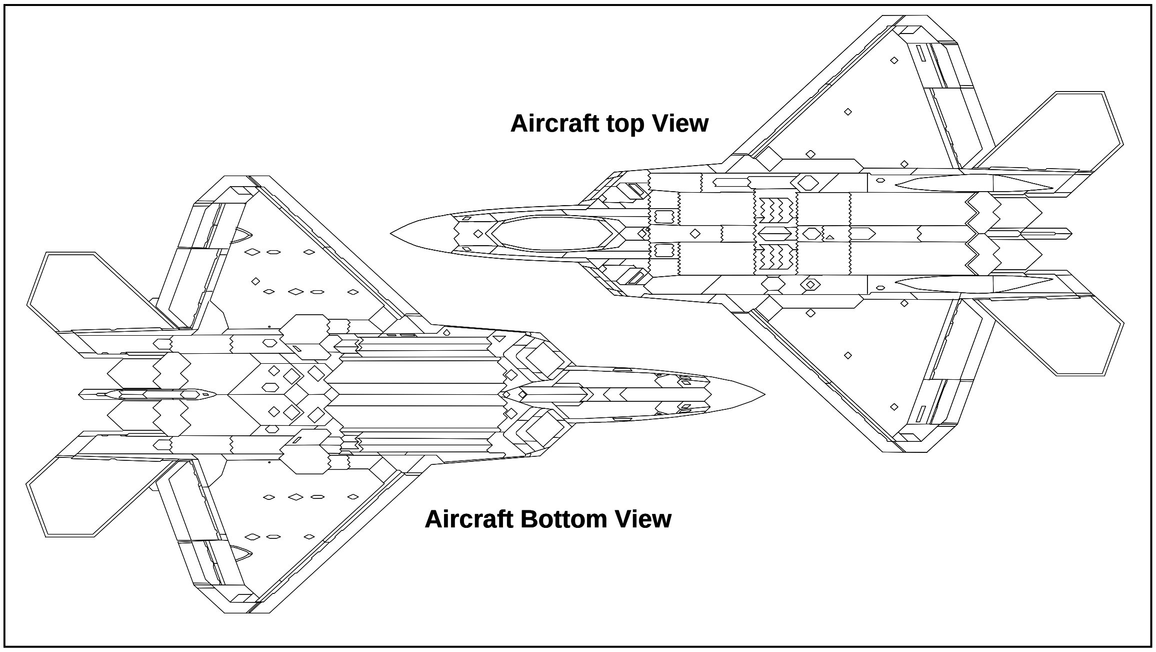

Figure 40. Planform view of F/A-22 aircraft showing panels.

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[124] Within LTMS, TOD tasks were also linked to aircraft effectivity (i.e., what equipment was on what aircraft) skill code for maintenance specialists, task time (Mean Elapsed Time, Mean Man Minutes and task roll-up times via links to LSA), and support equipment/consumable availability (via Supply links) to automatically calculate and determine test point Ready To Test (RTT) status.

comprehensive, integrated design of the LTMS assured that when any particular LT&E effort that might focus on a panel or system was initiated, the test points from all disciplines would be considered. To make it work the LT&E planner realized he needed a system to efficiently schedule and track LT&E tests to complete remaining test points.

In fact, prior to exposure to CCPM and its supporting software, he had already been searching for a solution. He had even rejected several software packages, including MS-Project™, and taken some initial steps towards creating a unique scheduling tool for LT&E use when he became interested in the possibility that Critical Chain and its enabling software could satisfy the need.

Innovation Decision

Once he became familiar and experimented with the software supporting the Critical Chain applications at the CTF, the LT&E planner immediately recognized the potentially ideal compatibility among the LT&E need, the Critical Chain concepts and the high-end Sciforma® PS8™ supporting software capability. He quickly decided to adopt the CCPM solution with authority that been delegated by the leaders of the LT&E group. In acting to merge the LTMS with Critical Chain, the Chief LT&E planner became the LT&E CCPM lead for implementation of the Critical Chain innovation in the LT&E.

Implementation

As soon as he decided to implement a CCPM solution, the LT&E planner/CCPM lead developed a vision that had as its objective the automatic generation of Critical Chain schedules based on operator selections. Over the period of the several months, while simultaneously maintaining the LTMS databases, he became immersed in the CCPM software to achieve his vision. He even penetrated the structure of the PS8™ software algorithms and data fields to assure that he could link the correct information from the LTMS databases to the appropriate data fields in the Sciforma® PS8™ tool. This effort led to progressively more sophisticated and capable versions of a totally integrated LTMS database and CCPM scheduling system which even included estimated task duration and resource requirements from sources within the LTMS. The chief LT&E planner then completed the total system design by automating the exercise of the Critical Chain methodology into a function called the Project Builder. Once the LT&E managers identified the likely test aircraft and the priority of the system or panel grouping targeted for test, the LTMS/CCPM system would provide a list (by system or panel) of suggested projects with the number of test points that could be achieved. After the test managers made their choices within the list, the Project Builder would generate a Critical Chain schedule automatically, literally with the push of a button.

Unfortunately, despite much successful use when short notice maintenance down time presented the opportunity, it became apparent that this kind of availability would not support LT&E goals alone, even with occasional employment of test aircraft totally dedicated to LT&E.

Cooperative use of CCPM for Mods and LT&E

Against this backdrop of increasing constraints, the Maintenance Mod and LT&E CCPM planners structured a cooperative venture on aircraft 4006 in the spring of 2002. As noted earlier (in the Part A-2 of this chapter), the objective was to either evaluate Tech Order Data verification that was required as part of an already planned 4006 modification or "job," or to accomplish LT&E testing on a non-interference basis, i.e., on a part of 4006 well away from the aircraft area on which the mod team was working. Because of uncertainty about how this arrangement might work, a very limited number of 46 LT&E test points were included in the plan approved by the CTF leadership. Getting to a final, joint plan was, however, quite difficult. As noted above, due the myriad databases and interrelated test points in LTMS, the LT&E information was far more detailed in terms of both task description and resource assignments than the Maintenance Mod information. Over time these differences were worked out and a joint plan was produced and approved by the CTF management.

Besides successful execution of the LT&E plan during the mod period, weaknesses of the approach taken to planning and execution by the Maintenance Mod team emerged in lengthy meetings to prepare weekly status reports on the joint mod/LT&E activities on 4006:

- The lack of detail in the definition of maintenance mod tasks prevented visibility into what specific task was causing problems.
- Resource unavailability (specialists and parts) for execution of the maintenance mod jobs caused extensive replanning and necessarily reinforced dependence on use of engineering judgment to “estimate” buffer penetration and project status.
- Because the major maintenance jobs were all connected in a single “mega-project,” there were often false interdependencies and precedent relationships that made changes forced by unexpected problems or new work difficult to incorporate.
- Infrequent (weekly) updates of task status forced two- to three-hour re-planning meetings.

The most significant of insight was that the software could accommodate the” mega-project” approach in the software, but was very difficult to deal with during execution. As a result, the LT&E planner decided to fully exercise the multi-project mode of the CCPM innovation that could be accommodated by the software.

Tailoring and Executing the CCPM Plan for an LT&E-dedicated aircraft

The opportunity to exercise all these 4006 lessons occurred in a span of approximately nine weeks during the April-June 2002 period. Rather than at Edwards

AFB, however, the dedicated aircraft, 4009, was made available to the LT&E team for nine weeks at Marietta, Georgia, before its transfer to Edwards AFB. A quick-look exercise of the LT&E Project Builder methodology by the LT&E planner suggested that, conservatively, some 1000 TOD test points could be accomplished during the period. However, since most of the team would have to travel to Georgia[125] to accomplish the work, geography generated a personnel constraint that had not been anticipated.

As a result the LT&E Planner modified the Project Builder to permit the managers to group all the open test points by specialty and then construct projects that focused the work in one or several weeks during the planned nine-week span. He then used the new capabilities to produce a synchronized, multi-project schedule incorporating eight, detailed, sequential one-week schedules, each focused on the test points generally associated with one or two main specialties. (The ninth week was left open to permit some allowance for repeat tests). Based on six-day, two-shift operations, some 1200 test points and other training objectives appeared achievable.

The plan was to have daily updates using electronic transfer between specialized remote databases the LT&E planner developed along with automatic information routing paths that updated the Critical Chain (i.e., Sciforma® PS8™) and other databases (LTMS, TOD, etc.). Access by LT&E managers at the F/A-22 SPO offices at Wright-Patterson AFB, Ohio, was automatic, and it was well recognized that there would be intense interest in the progress of the LT&E dedicated on-aircraft testing.

The LT&E team expected to execute the plan as scheduled, i.e., basically eight, sequential projects “by week” with variations to accommodate changes prompted by the expected TOD release. However, the actual execution followed a different path that

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[125] Approximately 50 percent of the personnel were from Edwards AFB, with additional contractors coming from LM Aero (Ft Worth) and the remaining Air Force personnel coming from the primary operational user of the F/A-22, Air Combat Command (ACC) at Langley AFB, VA, and the Field Training Detachment (FTD) at Nellis AFB, NV, a part of the Air Education and Training Command (AETC), the Air Force organization tasked to train pilots and maintenance personnel assigned to the F/A-22.

resulted in the overall period being broken up into three clearly identified periods, each dominated by a different approach for planning and execution to achieve project goals.

The very first week of the initial period produced turbulence that quickly led to dissatisfaction with the CCPM “by-week” plans. Parts availability required resequencing so that the Week-3 project was first. Even then, instead of rigorously following the plan, managers decided to extract tasks from other “by-week” plans to complete them early. Jobs associated with seven of the eight sequential projects were begun during the first week. Tasks from both Week 2 and 3 projects were begun simultaneously with an unplanned aircraft modification task, and all of them were conducted in the “fuel barn”.[126]

Mechanically, the “by-week” structure was easier to update in the software than if all the tasks had been incorporated in a single “mega-project,” but by the end of the third week, LT&E on-site managers became very frustrated and abandoned the CCPM plan in the belief that traditional “daily planning” approaches offered more flexibility.

During the second period traditional “daily planning” practices were used, with the on-site managers essentially evaluating ”yesterdays” progress and then identifying the tasks for “today” and the next few days. Unfortunately, one- to two-hour meetings were required each day to decide on tasks and priorities. Besides inefficiencies and low productivity measured in LT&E test points accomplished per day, it was very difficult to determine to what extent the overall project 1000-test point objective was at risk.

Meanwhile, while the on-site team was managing by “daily planning,” the LT&E planner began work to develop a new CCPM plan to eliminate problems with the initial “by week” CCPM plan. At the same time, Casey provided training on CCPM concepts to the workforce. This training was intended to lay the groundwork for another attempt to win LT&E managers support for implementing the new/revised CCPM plan when it

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[126] “Fuel barn” is the colloquial reference to a hangar facility specially equipped to deal with potentially dangerous fuel system maintenance or modification tasks on an aircraft.

became available. Many who participated in this training had no knowledge of basic Critical Chain concepts because they had missed training at Edwards AFB or had come from other bases.   This training helped defuse some of the misunderstandings in the workers and especially the supervisors who became somewhat more willing to reconsider a CCPM approach.

Toward the end of the "daily planning" middle period of the nine-week span dedicated to LT&E, the LT&E planner joined the LT&E team in Marietta to familiarize them with the new approach dubbed "multi-project/dynamic execution" which incorporated 84 projects, each capturing work in a given panel area, with all 84 projects synchronized into a multi-project portfolio. Using the Critical Chain software, the LT&E planner was able to show the managers that it was possible to "fit" the remaining 50 percent of total work into the remaining one-third of the overall dedicated aircraft period ***if*** the group followed some additional ground rules built around the "relay runner" part of the Critical Chain approach. This new "dynamic execution" permitted active tracking in the software only when the individual panel projects were actually started, rather than requiring all projects to be simultaneously activated at the beginning the effort.[127]

To facilitate the entire process, the LT&E planner printed out spreadsheet versions of all the panel projects and posted them in the work area. Each panel project listed the tasks that needed to be accomplished, clearly indicating the precedence order of each project and the total work to be done.

The "by-panel" plan was implemented to begin the last period and the supervisor of each shift used a "highlighter" to indicate on the posted project listing what was accomplished on each project on each shift. Within minutes of completing the software update based on this information, the LT&E planner could provide feedback to the

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[127] Essentially, this dynamic execution approach realized the goal of the "rolling wave" approach considered at one point in Part A-3. It included detailed planning for each of the projects, but permitted the LT&E supervisors to choose which projects to activate based on the situation at hand.

managers and exercise some "what-ifs" to see if there was flexibility to initiate other projects instead of the ones initially designated. In fact, very little was changed during execution because the portfolio of projects generated more flexibility during execution—virtually all "by panel" projects were delivered on or under the planned CCPM span.

Overall, the dynamic execution process worked very well, and the managers very quickly became convinced that the new process was exactly what they needed. In fact, the most strident and vocal opponents of CCPM during the first period of the 4009's dedicated span became outspoken *pro*ponents of the methodology before the project was completed in the third period.

Evaluation of the CCPM innovation on Dedicated LT&E Aircraft

The *evaluation* phase of the organizational innovation process for LT&E is greatly facilitated by the almost serendipitous breakdown of the project during execution into the three periods described. Without such a breakdown, the evaluation of the CCPM innovation would have had no baseline to measure against. With the breakdown, the "way this kind of work has always been done" is represented by Period 2's "daily planning" approach, essentially the baseline against which any other approach could be assessed. Given this baseline, the analysis can compare the relative results of two tailored forms of the CCPM innovation generated during the initial "by-week" period, and the final "by-panel" period (Figure 41).

Results of the overall project are divided into the three periods as shown in Figure 41, with daily (solid line) and cumulative (dashed line) test points completed over the entire span. A separate analysis was done to assess the difficulty of the work accomplished during the three periods, to assure a relatively unbiased comparison of results from the three periods. This analysis showed that on average, more of the longer duration and more intrusive work were done during the third period than during the first, so if anything, any bias would favor the “by-week” and “daily planning” plans dedicated to LT&E activities.

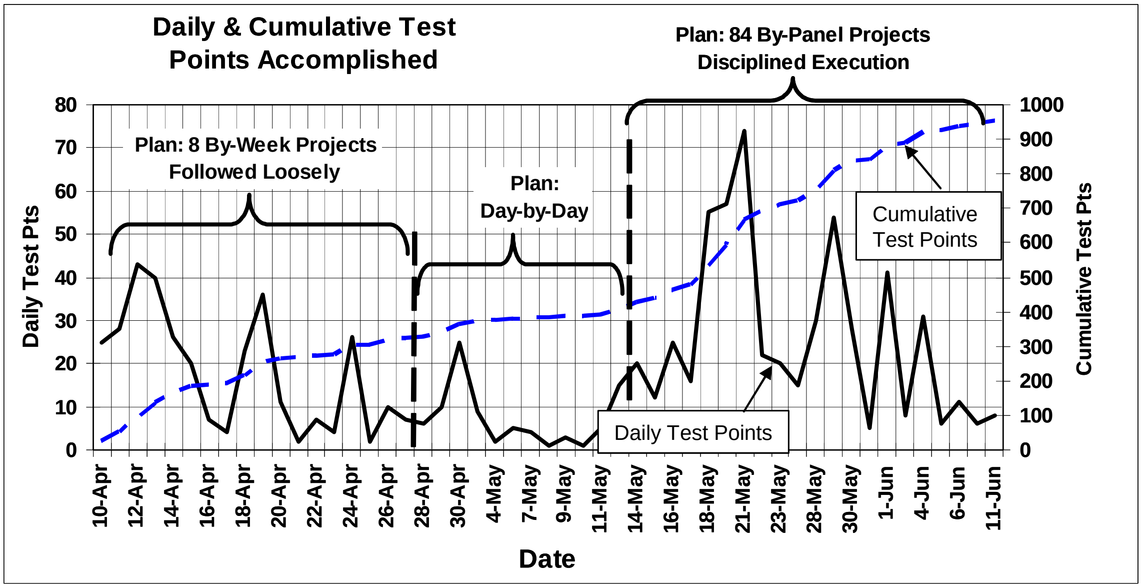

Figure 41, Results of LT&E evaluations on dedicated aircraft 4009.

These preliminary considerations are quite pertinent to the very important construct validity consideration that attempts to assess evidence that any difference in results can be attributed to CCPM alone or, at least, mainly to CCPM. Here it is quite clear. Once results are normalized for numbers of days and workers in the periods, and the reasonable assumption made that workers are equally qualified for assigned work, the *only difference* was the scheduling method.

In Figure 41, the comparative effectiveness of the plans for the three periods can be judged by the slope of the cumulative test point line. The generally positive slope during the first period shows that the “by-week” CCPM plan, even though followed loosely, started out quite well, despite its unpopularity with the work force supervisors. During the ”day-by-day” or “daily planning” phase, the cumulative curve almost flattened out, indicating the relatively poor performance noted earlier. Finally, the pace of test point accomplishment picked up again in the third CCPM “by-panel” phase with the steeper slope being maintained through completion of the project.

Figure 42, below, directly compares the percent of the total span versus the percent of total test points accomplished. This contrast clearly shows that the last period was more efficient in generating test points, accomplishing one-third more of the test points than expected from its share of the total dedicated aircraft span. Essentially, the effectiveness of the “by panel” plan combined with the dynamic execution approach made up for the lack of productivity during the “daily planning” period.

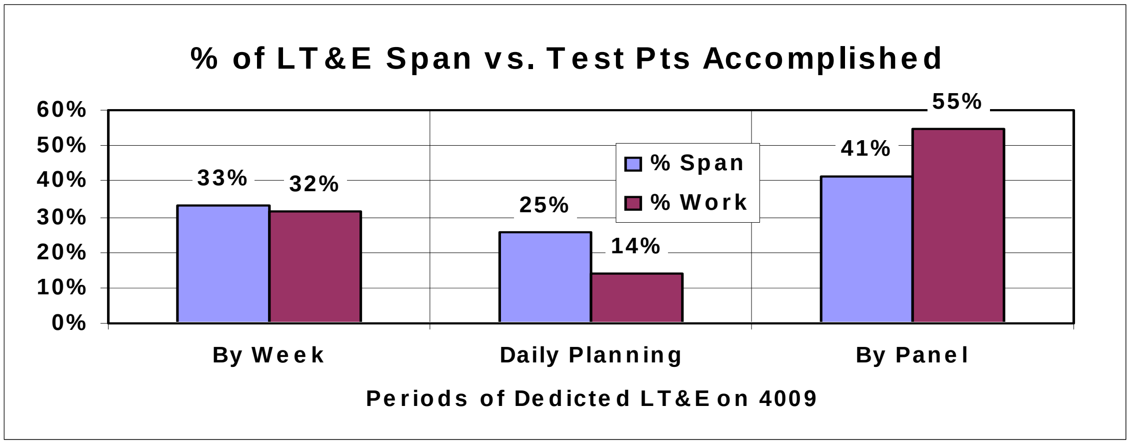

Figure 42. Percent of total span vs. percent of total test points accomplished.

Measuring effectiveness or workforce productivity in terms of test-points-per-day, the “by panel” approach becomes even more attractive when one considers workforce availability for the three periods. As reflected in Figure 43, specialist availability varied, becoming progressively reduced across the spans. This comparison shows that the middle, traditional “daily planning” approach fared the worst. The “by week” plan, even though followed only loosely, was more than twice as productive as the “daily planning” approach. But clearly, the “by panel” plan with dynamic, disciplined execution was by far the most effective. Compared to the next best ”by-week” plan, the “by panel” approach had 40 percent fewer specialists, but accomplished 72 percent more work.

For the record, the final tally of LT&E results achieved during the 10 April to 11 June 2003 span during which 4009 was almost completely dedicated to LT&E activities. The original goal of 1000 LT&E test points was accomplished. It should also be noted

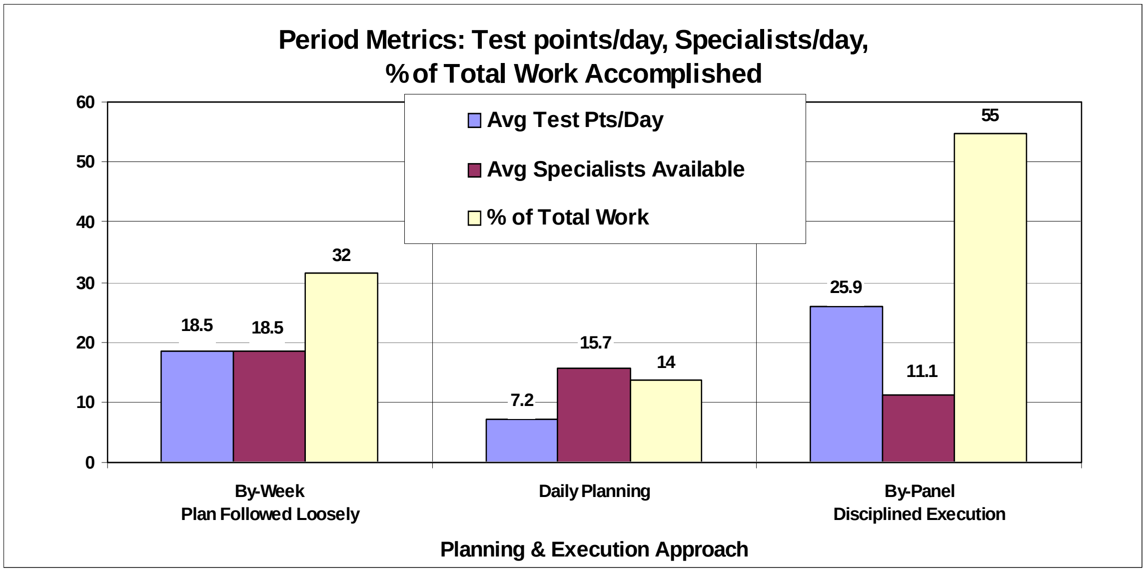

Figure 43. Metrics for three approaches to LT&E planning and execution.

that some of the originally planned points could not be completed due to aircraft configuration or inoperative systems. In their place, other available test points were added to the effort during the third period. The fact that these alternate points were packaged into projects and added to the overall effort through the synchronization process with minimum effort bears further testimony to the flexibility of the process and LTMS/CCPM tools.

Finalizing the Implementation Stage in the LT&E CCPM Innovation

In one sense the CCPM innovation as implemented in multi-project, dynamic execution form required no further “tweaks” to the process. Essentially the approach, practices, and procedures used for 4009 could be duplicated in the same form for any other dedicated aircraft. Actually, the pressures to sustain the F/A-22 test aircraft in flight test operation precluded periods of aircraft dedicated to LT&E. As a result, the LT&E process completion depended on use of the ADHOC approach described earlier. Still, the validation of the multi-project/dynamic execution approach provides a solid base for use to support F/A-22 or any other weapon system LT&E requirements.

Mini-Analysis of the CCPM innovation in the LT&E Area

Overall, the use of the CCPM innovation to support CTF's LT&E project using aircraft 4009 can be characterized as a solid success. What limited evidence is available supports the validity of the construct that use of CCPM would be better than other approaches tried. If either of the other methods tried during the period when 4009 was dedicated to the LT&E effort had been pursued throughout the nine-week period it is extremely unlikely that project goals would have been achieved.

With regard to the first few weeks of the project, despite the fact that the early multi-project form of CCPM scheduling was technically on track at the end of the first period, had the CCPM demonstration project ended at that point when the initial CCPM schedule was abandoned, it is likely that CCPM would never have been used again. Essentially, a good methodology applied in the context of a bad plan will likely produce less than optimum results. During the second period, traditional planning and execution practices more familiar than CCPM were in play, but time wasted on intuition-based planning and daily results showed the project progressively falling further behind. If continued, this approach would have produced results far short of the goal.

The Period 3 use of the multi-project, synchronized CCPM approach with dynamic execution to make up for poor performance in Period 2 supports the contention that CCPM support for LT&E was successfully demonstrated. The fact that managers and workers became completely converted to enthusiastic support for CCPM adds further proof that CCPM in LT&E was totally successful.

Two other measures suggest the benefits of the CCPM innovation in its final form. One is the potential reduction in the cycle time/duration of the dedicated period. If the daily rate of test point accomplishment in the third period had been available from the beginning, the cycle time required to produce the total number of points eventually achieved could have been reduced by 25 percent. Another measure is the potential for more productivity in the same span. If the duration for which 4009 was dedicated to LT&E had been fixed, 37.5 percent more test points could have been achieved had the Period 3 productivity had been available for the entire period.

The expectations of the CHIP model were largely fulfilled in the LT&E implementation that was quite unique among all case studies. The LT&E application of CCPM was a “one-man show” driven by the LT&E planner who was responsible for all stages and phases of the innovation process from initiation through decision through implementation. Regarding *structural levels and actors,* virtually everything happened at the Operational level, and the LT&E planner not only acted as CCPM lead, champion and change agent, he engendered the most disciplined execution of any CTF CCPM plan despite an LT&E team made up of individuals from several sources. Even after the CCPM failure encountered using during the first period of the 4009 dedicated aircraft project, the group was willing to commit to the LT&E planner’s very unconventional experimental plan for the third period, despite great risk of failure.

Part B: Analysis of the CCPM Innovation at the CTF

Assessment of CCPM-driven Changes

As made clear by preceding mini-analysis, conduct of a top-level summary analysis is problematic regarding the construct validity of expectations that the CCPM innovation was partly or completely responsible for demonstrated on-time achievement of CCPM schedules, improved ability to anticipate and mitigate difficulties in schedule execution, and improvement in schedule performance compared to the past. Flight Operations provides no evidence since it did not get beyond the planning stage. Evidence from Maintenance Mods is negative, marginal or at best mixed, but inconclusive because of contamination by the failure to employ so many of the basic precepts of the innovation in any form, e.g., disciplined adherence to CCPM precedence, daily updates, proactive buffer management, incorporation and "rebaselining" when added work is unavoidable. Only the LT&E innovation provides support for the construct validity, but even there, though very dramatic and positive results from a creatively tailored form of the innovation in direct comparison with alternative, the sample is so small that the best analytic conclusion is that more evidence is needed.

Analysis from the Perspective of CHIP Model

Consistent with the pattern of the previous case study chapters, core initiation and implementation stages and the innovation decision that separates these stages are definitely of interest as well as the motivation for adopting an innovation.

Motivation for Innovation

The theory and much accumulated evidence suggest that problems ranging from a perceived performance gap to a crisis are typically the catalyst for initiation of an innovation by an individual or the organization as a whole. However, to employ a well-worn metaphor, internal description of CTF's situation was akin to blind men describing the elephant. The most influential personnel, the commander, the LM Aero director and the Flight Sciences and Mission Avionics Managers, perceived a problem, but external to their control. They were convinced that any schedule management problems could be solved with sufficient and timely resources. Operational-level IPT leaders did perceive a performance gap (Maintenance Mod planner) or, at least, a need (LT&E planner). However, all were overridden by high level external forces. When the Pentagon convenes a Tiger Team manned with general officers and highly qualified, well recognized experts to attack a problem on *any* turf, there is little doubt there *is* a major problem that requires response, even if the organization affected does not perceive the same "gap" or impending crisis.

Initiation Stage

The Flight Test Tiger Team concerns about schedule management virtually compelled the CTF leadership to initiate some innovation to deal with schedule problems, even though the CTF leadership did not believe the problems originated within the CTF. Given that the problem had been the subject of extensive internal reviews and that the problem still existed after corrective action failed (e.g., the Flight Test Working Group discussed in Chapter 5), it is unlikely that innovative solutions would come from internal sources. Assignment of action for a study comparison of CCPM and CTF scheduling processes to the LM Aero Program Integrator and change agents of the only external option that was considered, along with tepid involvement of CTF personnel in the study, the recommendation of CCPM as the preferred option was analytically defendable, but almost a foregone conclusion. The availability of funding from the SAF/AQ organization left little opportunity for the CTF leadership to use scarce budgets as a constraint (or as a reason) to reject CCPM.

While the CTF leadership and flight test operations managers participated (through agreement to conduct the trade study), the initiation activity for them was largely the result of external pressure, since they did not see a need for the CCPM innovation or, seemingly, any other innovation until problems beyond CTF leadership control were addressed. In contrast, there was an “internal pull” from the Maintenance Mods organization, particularly the lead planner who became the internal champion for the innovation. (The LT&E interest and equally strong internal “pull” developed later and totally independent of any Tiger Team pressure).

Innovation Decision

Under the intense visibility of the Tiger Team expectations (if not pressure) the initial, top-down decision to direct implementation of the innovation occurred quickly, largely based on a conceptual analytic comparison of CTF and CCPM approaches, rather than a rigorous, detail evaluation of the potential of CCPM to “work” for the specific challenges facing the CFT. Though the decision had the trappings of an “authority” decision at the implementing IPT level, it was really one level up, and even at that CTF leadership level (actually part of the Program level in the *structural levels construct)*, the decision seemed made with misgivings and perceptively under duress. Bearing testimony to this conclusion is that with the accumulation of time, the CTF leadership was able to make its opposition to CCPM, at least in the Flight Sciences and Mission Avionics areas, clear and effective enough to overcome F/A-22 program-level leadership’s hope and desire that CCPM could work in the flight operations area.

One other observation from the author’s now 40 years of experience in military and large hierarchical private industry perspective. Both the CTF commander and the Mission Avionics IPT Manager had substantial background in the military, and the CTF director and Flight Sciences Manager had dealt in the military-industrial bureaucracy for years. Typically in those environments, a legal order from above usually results in prompt execution by subordinates, regardless of whether the subordinates agree. That the subordinate successfully reversed the order in this case reflects either a change in the traditional effect or meaning of civilian or military organizational top-down orders, adds credence to the IPT policy regarding decision authority and responsibility balance, or simply suggests that the IPT leaders were able to convince others that CCPM would not work as proposed. From the observer posture, conditioned by the insight gained as participant, some of all three perspectives were involved in the eventual rejection of the CCPM innovation in the flight operations area. As noted earlier, from the perspective of F/A-22 team policy on Operational IPT-level decisions, the reversal of the Program decision based on opposition from the IPT leaders was right and proper, even though it conflicted with the more traditional response to top-down organizational direction.

Implementation Stage

Description of the implementations and attendant evaluations need little recounting here. It might be observed that they ran the gamut of totally started but resisted and finally aborted (Flight Operations areas), to marginally assessable and barely successful despite several badly flawed iterations (Maintenance Mods), to almost quite successful after adjustments, conditioned on only limited evidence (LT&E).

In one sense, the applications in Maintenance Mods and Flight Operations employed the same classic version of the CCPM innovation. Both struggled with that version, i.e., the detailed planning of the scope of work within one, or a series of single projects. In the flight test operations area, the struggle was associated with the size and duration of a single huge project to cover the entire flight testing span, when time-honored, traditional flight operations planning had dealt with only the next two weeks in detail and everything else on a parametric basis. In Maintenance Mods, the classic, single project approach was slightly more workable, because the span for any given mod was usually much less than six months. However, it was still difficult to revise the plan during execution to reflect the changes forced by reality because of the absence of effective ways to do so. Here, the lesson seems to be that the first imperative is to complete in-depth analysis of what is the best approach to tailoring or reinventing promising innovations to meet the needs of a very difficult environment.

Of course, the well documented LT&E reinvention demonstrated the potential for transformation into a major alternative to the classic CCPM innovation approach for application to problems faced in Maintenance Mods and Flight Operations.

Analysis from the Perspective of the Structural Levels and Actors Construct

This implementation was largely consistent with the *structural levels* expectation of “top-down” construct for initiation and support from the Program level and the only one where the Program level (represented by the CTF leadership) expected compliance with unusual authority decision directing implementation of the innovation by the IPTs at the Operational level. In support of that decision, however, the top Program level (above the CTF) supported each of the implementations with external change agents, funding and encouragement, even though the CFT part of the Program *structural level* remained skeptical about the need, applicability and utility of the innovation.

Regarding organizational innovation *actors*, the influence and importance of groups and individuals varied by level of activity. At the CTF leadership level, decisions were largely driven by the inputs from external groups, the Tiger Team which included membership and close involvement of key F/A-22 leadership groups—the SPO and the F/A-22 LM Aero Program Office. Besides the Program champions (the LM Aero Program Integrator and SPO Technical Director), there was one quasi-champion at the CTF leadership level, the Deputy Directory for the CTF. However, his was more an assigned responsibility than one voluntarily and independently sought. At the same time in the CTF employment of the CCPM innovation, there were many change agents.

Like Finishes, this CTF case involved an external actor, the TSC expert/change agent, who was confidently trusted to have the knowledge sufficient to assure that the new idea would be applied in an appropriate way. In retrospect, a better appreciation for the impact of the dynamic environment faced by the CTF might have produced an application other than the “classic” CCPM approach. The potential for other CCPM approaches became especially clear in the success of the multi-project approach demonstrated in the LT&E application.

Otherwise, as reflected in earlier implementations, once the CCPM innovation decision was made, the organizational actors at the individual level essentially controlled the implementation of the CCPM innovation. The Mission Avionics manager appeared to be something of an anti-champion, but hindsight suggests that his position was justified because the form of the innovation offered was a mismatch with his needs. In contrast, the Maintenance Mod planner and the LT&E planner persevered because both believed so strongly in CCPM.

In the Maintenance Mods area, the Maintenance Mod Planner/CCPM lead was unquestionably the driver who persevered in the use and continuing refinement of the innovation. At the same time though, the general skepticism of the group affected—the maintenance mechanics that did the modification work—was translated into actions that limited success. The inclination to follow the CCPM schedule as a broad guide, instead of a roadmap to be followed with discipline compromised the process, led to difficulty in updates, and invalidated the buffer reports.

One final somewhat subtle organizational observation is the distinctive nature of each of the organizations involved in a CCPM implementation. There was some cross talk and interactive communication between or among the groups wrestling with the effort to implement a new idea from outside the larger CTF organization to which they all belonged. However, the majority of discussions focused on functions and capabilities of the Sciforma® software. The flight operations group, the maintenance mods group, and the LT&E group operated largely independently. (The one time there was active cooperation between the LT&E and Maintenance Mod teams, there were distinct differences of opinion over the level of detail, setup of some of the formats, etc.). The relative independence of the three groups suggests very intense identification with the immediate organization, (e.g., Flight Test Operations, Maintenance, LT&E) that can be observed elsewhere (Pell and Adler, 1994). Even though each organization was committed to the larger organizational goals and coordinated activities to achieve impressive results in a very dynamic environment, each organization had its internal process for planning and executing activities. The expertise and specialties in the three areas were sufficiently different to reflect different ways of thinking about problems.

Summary

Overall, the application of the CCPM innovation in the flight test environment was painful in many ways provided somewhat limited benefits to the CTF, though substantial payoff regarding the CCPM innovation itself. Part A-1 described an environment somewhat hostile to initiation of any innovation and an innovation decision contrary to IPT policy. Remaining Part A sections described and analyzed a range of difficulties and experiences gained from employing CCPM in an extremely dynamic environment. Though the difficulties were significant, the innovation did enjoy some success, despite one very flawed approach and, possibly, the failure to tailor the innovation in the best way to meet the needs of the organization. Part B, Analysis from the organizational theory perspective showed how organizational actors, both groups and individuals, can drive or reverse decisions and affect success. Table 12 draws the elements of the mini- and summary analyses together in a form similar to that used in previous chapters.

Construct validity: expected changes found?					Structural Levels: Program and Operational
Organization	Change	1	2	3	USAF Tiger Team affects CTF Program level initiation & decision; Many differences at Operational level
	short description	meets CCPM schedule	better ability to foresee & deal w/ difficulties	better than past	
Maint. Mods	→	mixed	unassessable	uncertain	Organizational Actors
Flt Test Ops	→	rejected - leaders convinced CCPM unusable			Top team & Quasi-CTF Program champions; anti-champion in Flt Ops; ext chg agents across all; internal chg agents in Mods & LT&E
LT&E	→	yes	yes	yes	
	supporting evidence	limited data, but solid support for validity based on direct contrast with other options in same setting			

Casey Hybrid Innovation Process (CHIP) Model					
Organization	Element of Interest	Motivation	Initiation Stage	Innovation Decision(s)	Implementation Stage
CTF Leadership	short description of application	external pressure	external ID of CCPM	CTF authority decisions to begin (& reject in Flt Ops)	N/A
Maintenance Mods	short description of application	performance gap; internal "pull"	external identification of CCPM	quick initial-authority/optional (no further decision)	iterative, flawed implementation; continued despite mixed success
Flight Test Operations	short description of application	external pressure; IPT views problem as external	external ID of CCPM; internal perception of mismatch	resisted authority decision to start; finally rejected	rejected after planning only
LT&E	short description of application	performance "need"; internal "pull"	external identification of CCPM	quick initial-optional (no further decision)	iterative process; proved multi-project version of innovation

Table 12. Analysis Summary: CCPM case studies in Test Operations areas.

Chapter 8: CCPM INNOVATION IN SUPPLIER DEVELOPMENT

Overview

In this case study, the specific application of the CCPM innovation addressed supports the development by the Avionics IPT of a new generation of the module used in the Raptor's computer known as the Common Integrated Processor or CIP.[128] The new module was called CIP-2000, which was quickly shortened to CIP-2K.

Interest in the potential application of the CCPM innovation for avionics system development area emerged during, and to a certain extent because of, on-going applications of the CCPM innovation in the Finishes IPT at Marietta, GA, and the Combined Test Force at Edwards AFB, CA. The LM Aero Vice President and F/A-22 General Manager (VP/GM) for the F/A-22 program had recognized the broad potential of the CCPM innovation and had specifically suggested exploration of opportunities in the avionics area when he was briefed on the status of the CCPM project in the Finishes area in the spring of 2001. By that time, Casey had already provided an overview of the CCPM concepts to the Avionics IPT leader for possible initiation of a pilot in the avionics area. Later, the urgency of the problems encountered in the CIP-2K development using traditional management processes quickly led to a preliminary decision to adopt the CCPM innovation for use by the primary developer of the new module, Raytheon Systems Company,[129] and, shortly, to the other primary suppliers involved.

Because well over 50 percent of the F/A-22 aircraft parts and components are made by suppliers under contract to LM Aero or Boeing, an evaluation of the CCPM innovation during supplier development of a product, and even more so, a *multi*-supplier

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[128] In contrast with the common personal computer, the CIP (of which there are two on the F/A-22) can best be pictured as a rack that has two shelves, each of which can accommodate up to 33 of the modules of concern here (as many as 66 modules for each full rack). Each module is a single board computer, and all are connected together by a back cover or "back-plane" that permits electronic integration and cooling of the modules. Together the two CIPs serve the computational and data storage/manipulation needs of the F/A-22.

[129] The company is referred to hereafter as "Raytheon" or "RSC."

development of a product, has significant implications for single- or multiple-supplier developments on other programs, whether the result is positive or negative. Consequently, while the CCPM application to the CIP-2K product development described and analyzed in this chapter was suspended before completion of the project (for reasons unconnected to CCPM), the process up to the point of suspension provides important insight for the multi-case study research purposes of this paper.

Part A describes the substantial tailoring of the CCPM innovation process to meet the CIP-2K challenge and specifically avoid the lengthy start-up time experienced at Marietta and at Edwards AFB. Still more tailoring was required as other CIP-2K suppliers also became key members of the CCPM project. Part B uses the CHIP model and the *structural levels and actors* construct to assist analysis of the CCPM innovation.

Part A: Description

Initiation

At the outset of the F/A-22 EMD program in 1991, Raytheon had been given primary responsibility for development of the modules at the heart of the F/A-22 CIPs, each of which harnesses the computing power equivalent to a Cray Super-Computer. In the latter part of the 1990s, to deal with emerging obsolescence and affordability concerns,[130] Raytheon was given responsibility for developing a new version of the module, named CIP-2000, or CIP-2K. By early 2001, however, F/A-22 program leadership recognized that CIP-2K was not staying on track to support availability of new CIP-2K modules when needed. Delays were caused by a number of factors, such as

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[130] There were actually three interrelated phenomena. One was accumulating obsolescence. Parts that were state of the art (or practice) when designed into the F/A-22 in the mid-1990s, for example, a family of eleven key computer chips had to be redesigned to overcome obsolete technology. Another problem was known as “Diminishing Manufacturing Resources” or DMS. Here, suppliers were becoming reluctant to continue producing parts for the F/A-22 program because reductions in funding and total F/A-22 numbers weakened the business case for continued supplier involvement. The third problem prompting the CIP-2K program was the continuing challenge of F/A-22 affordability. Under constant pressure from DOD and Congress to avoid cost growth, CIP-2K was one of many F/A-22 components affected by DMS that had cost reduction as a key design consideration to help meet program affordability goals.

continuing stretch-outs because of basic design delays and the threat of "unknown-unknown"[131] risks associated with each "new" projected delivery date of module.[132] Though module design was approaching "design freeze" for fabrication of engineering versions, the next step—integration and use of the module across the team—was fraught with additional risk and uncertainty, as the integration with the original CIP module had proven earlier.[133]

Given these factors, there was clearly a sense of urgency on the part of both LM Aero and Raytheon to find a way to develop a schedule that accounted for the integration risks and that was truly achievable. Solid and relatively unchanging plans and schedules were badly needed for the many suppliers and development groups of the program that depended on CIP-2K. At the working level, because he recognized that CCPM had the potential to solve CIP-2K schedule performance problems, the Avionics IPT leader asked Casey, Colby and Pennington to present an orientation briefing on CCPM at a LM Aero-Raytheon Technical Interchange Meeting (TIM) at Raytheon's CIP -2K facility in El Segundo, CA, on June 2001. The briefing conveyed the basic concepts of the Critical Chain innovation. Noteworthy success in commercial electronic areas akin to Raytheon's CIP-2K project and even in other parts of the Raytheon Corporation[134] were included.

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[131] "Unknown-unknowns" or "unk-unks" is a term that has become common-place in the taxonomy of risk management over recent years. "Known-unknowns" are problems that may affect development, so that some reserve schedule and funds can be set aside to accommodate them. "Unk-unks" are problems that cannot be anticipated in terms of their nature or impact, so trying to accommodate for them presents planners with a great dilemma.

[132] As an example, in December 2000, the CIP-2K hardware was projected to be available at the LM Aero integration laboratory in August 2001. By June 2001, just prior to and a catalyst for the CCPM briefing, the delivery date was slipped to December 2001, but that projection was accompanied by a moderate risk that the delivery would actually take place six months after that, in late June 2002. (Information extracted from unpublished LM Aero 22 August 2001 CIP-2K Program Management Review (PMR) briefing "Lot 1 Discussion: Background/Action Items," presented at RSC, El Segundo, CA).

[133] The same briefing noted that "based on EMD Integration experience [with the original CIP module] (24 months) and more recent… integration experience [with another, original CIP component] (13 months), the planned 7 month span for CIP 2000 integration is underestimated by 4-6 months"

[134] By chance, the Casey, Pennington and Colby were in Los Angeles, CA, to present an overview of CCPM use on the F/A-22 program at the "2001 TOC World Conference." While there, discussions were held with attendees from Raytheon Electronic Systems Company regarding growing support for CCPM within

Innovation Decision

Though somewhat time-constrained, the briefing and discussion led to a consensus among both LM Aero and Raytheon participants that the innovative CCPM process could work towards more successful schedule planning and execution support so badly needed. The option of internal training and support for initiation and implementation from Casey and Colby limited non-recurring costs to an investment of software. On-going or recurring costs were not considered an issue, because all agreed that some type of scheduling process was required and conversion to CCPM would eliminate previous processes (rather than running old and new processes in parallel). Therefore, given no funding issues, Casey and Colby were tasked to work with the F/A-22 Core IPT (responsible within the Avionics IPT for overseeing CIP-2K development) to develop an approach and time-table to support immediate implementation.

Implementation

During July 2001, Casey and Colby worked with the Avionics IPT leaders, RSC CIP-2K managers, CIP-2K integration project leader (designated as CCPM lead for the CIP-2K group at Raytheon), contacts at Raytheon headquarters in Tucson, Arizona, the TSC involved in the Finishes and CTF efforts, the Sciforma® representatives and contracting personnel at all sites.[135] To get the CIP-2K CCPM implementation effort under way as quickly as possible, the foremost concern was to develop a technical approach capable of getting to a plan that could be baselined much quicker than had been the case in the F/A-22 Finishes CCPM pilot application at Marietta. Discussions with Raytheon users of the CCPM methodology headquartered in Tucson, AZ, led to the conclusion that a tailored version of what they called the "Blitz Week" approach to

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Raytheon's efforts to encourage/enable continuous improvement across the corporation.

[135] Details of this section are based on the author's Memorandum for Record: Summary of CCPM Jump-Start Week at Raytheon Company, 23-27 July, 31 July 2001 and Memorandum for Record: Follow-on Support to Raytheon after Initial Blitz-Week for CIP-2K, 13-15 Aug, 20 August 2001

implementing CCPM should work in the CIP-2K program.[136] The approach was especially appealing because experience had proven it was possible to conduct an intense initial week of effort leading to a schedule that workers and management could commit and begin tracking to in just a few weeks.

With the help of the Raytheon and TSC personnel, the Blitz Week approach was transformed into what was called the "F/A-22 Jump-Start" game plan (Table 13) and approved by LM Aero and RSC IPT leaders.

"Jump-Start" Plan

Jump-Start begins with a week-long activity on location with right attendees

Monday (Training):

- Critical Chain training for larger group, followed by development of project Objectives, Deliverables & Success Criteria

Tuesday – Thursday (Develop 60-80% solution):

- Smaller group develops initial project network including dependencies tasks, durations and resources using Scitor PS8 software
- Subject matter experts (SMEs) augment small group to do safety checks, help "fix the logic", finalize & buy-in to durations, task dependencies, etc.

Friday Morning (Jump-Start week wrap-up):

- Review progress, develop plan to go forward

Follow-up (Finalize & Implement Plan)

- Local team expands plan as needed to refine & validate (2-3 weeks)
- "Coaches"/Facilitators return after 3-4 weeks to help finalize plan & present to management who agree plan is a "go"
- Implement schedule
- Update frequently, track and report progress on a weekly basis
- Institute Buffer Management

Table 13. Summary of CCPM Jump-Start plan.

The plan was carried out as designed, with 13 personnel participating in the initial Critical Chain training presented by Casey and Colby who acted as coaches/facilitators for the execution of the plan. The objective at the time was to deliver the initial module for which Raytheon was responsible to the Raptor Integrated Avionics Lab (RAIL) in Marietta, GA, by June 2002. With the drive of the Raytheon CIP-2K Integrator/CCPM

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[136] At Appendix F are the full details of the development and initial implementation of the approach called "Jump Week" that evolved.

lead and the help of subject matter experts during the rest of the week, the first week went very well. The initial result was expanded over the next few weeks and finalized in a working meeting at El Segundo. The result was presented to Raytheon and Core IPT team managers on 15 August by the Raytheon CIP-2K Integration/CCPM lead. The plan was well received by the managers, even though the projected completion date was December 2002, approximately six months later than the previously established goal of June 2002. In addition, there was concern about the veracity of assumptions made about the supplier interfaces, deliveries and pace of activities that were key to the success of the overall CIP-2K project. At the request of the managers, further "what-if" cases were run and details added the following week.

The product of the effort was used as the centerpiece for a Program Management Review, chaired by the LM Aero VP/GM. Though the delay in the Raytheon delivery date was disappointing, the LM Aero VP/GM regarded the detailed planning that supported the new estimate as quite compelling. At the same time, he was concerned about the absence of explicit supplier tasks in the plan and expressed his conviction that the only way to fully understand and confidently project total system delivery was to expand the coverage of the Critical Chain effort. As a result, he directed that the Critical Chain focus be expanded beyond Raytheon's effort to include the supplier efforts and interfaces required to get their products to the RAIL along with Raytheon. This direction considerably expanded both technical and geographic scope and the time span of the project to be incorporated by the CCPM plan. The primary additions involved the suppliers, known collectively as the "Group 1/3 Suppliers" as shown in Figure 44. In addition, the new scope expanded the requirement for LM Aero Core IPT oversight of CCPM use at the suppliers, as well as substantially increased the involvement of the Program-level laboratories in Marietta and Seattle, responsible for the integration and testing of the components generated with the help of CCPM innovation.

Since the basic options included the development of separate Critical Chain networks and schedules at all locations, it was clear that the Jump-Start approach should be the basis for moving forward. As in the case of Raytheon, use of F/A-22 program-level LM Aero change agents for planned training and implementation effectively defused funding issues by limiting non-recurring costs to small software investments in Sciforma® PS8™. Tasked with leading the planning effort, Casey and Colby developed a plan and made preliminary arrangements with Group 1/3 supplier representatives. Results were briefed to the LM Aero Core IPT and Avionics IPT managers who approved the plan and directed immediate implementation.[137]

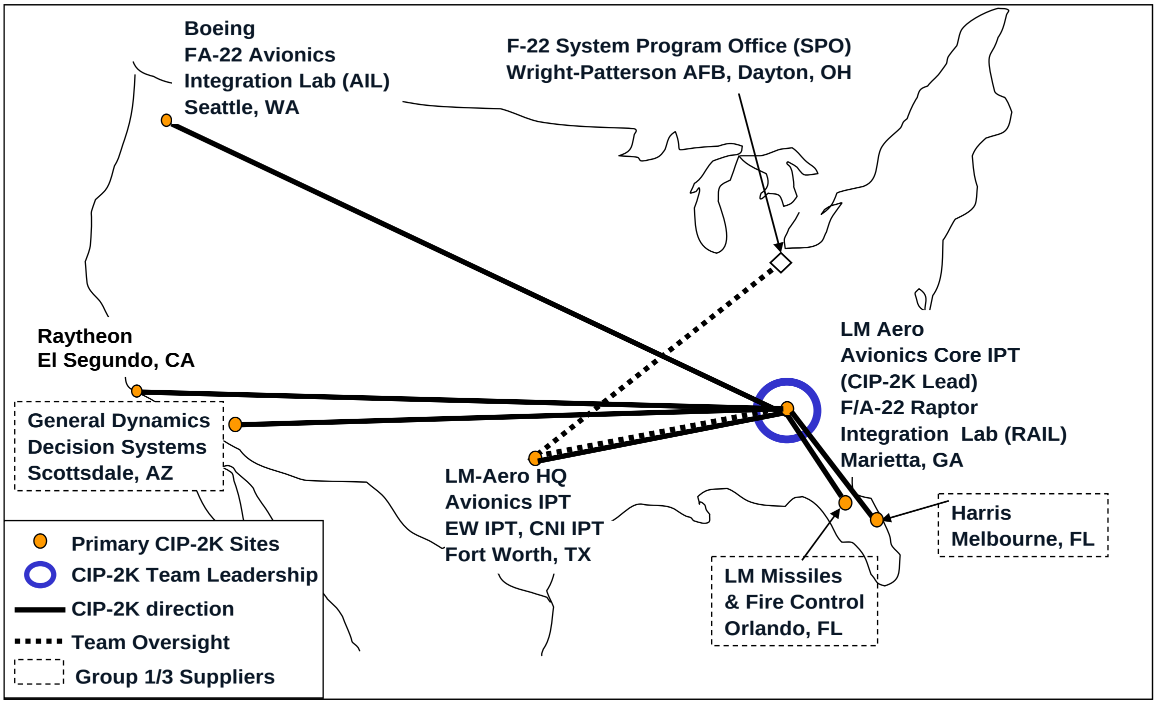

Figure 44. Location of key players in expanded CIP-2K Critical Chain effort.

Over the next three months, the CCPM leads worked with the Group 1/3 suppliers to develop components of a plan that could be implemented starting in January 2002 (Figure 45). The order of supplier CCPM Jump-Starts and the detailed development of their separate schedules generally followed the priority order from

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[137] Unpublished briefing, Ken Seeling, “CIP-2K Lot 1 Critical Chain Implementation Plan,” 7 September 2001

Raytheon's original schedule. GDDS was first, largely because both the Raytheon CCPM plan and experience to date with GDDS' development of computer security modules indicated that the iterative series of product hand-offs would be key to achieving project goals. LMM&FC was a close second in priority and timing, because the electronic warfare modules for which the LMM&FC team was responsible were complex and the hand-offs were also quite frequent. The Harris Corporation module development schedule was less complex than the others, so CCPM planning was later

Given the products of the Group 1/3 supplier Jump-Start efforts and those from the integration labs and Harris, Colby developed a single project schedule which merged the separate plans and incorporated all tasks. After an iterative learning process across the entire CIP-2K team, an integration meeting was held in November 2001 to finalize a plan for CIP-2K development with feasible delivery dates and enough detail to permit active management throughout the period of execution. A significant benefit of the entire process was the much improved visibility gained by each of the participants into the specific tasks and activity flows of their teammates. Even so, to reach consensus, extensive discussion was required to (1) clarify and detail all the hand-offs of progressively better engineering versions of the modules between and among the

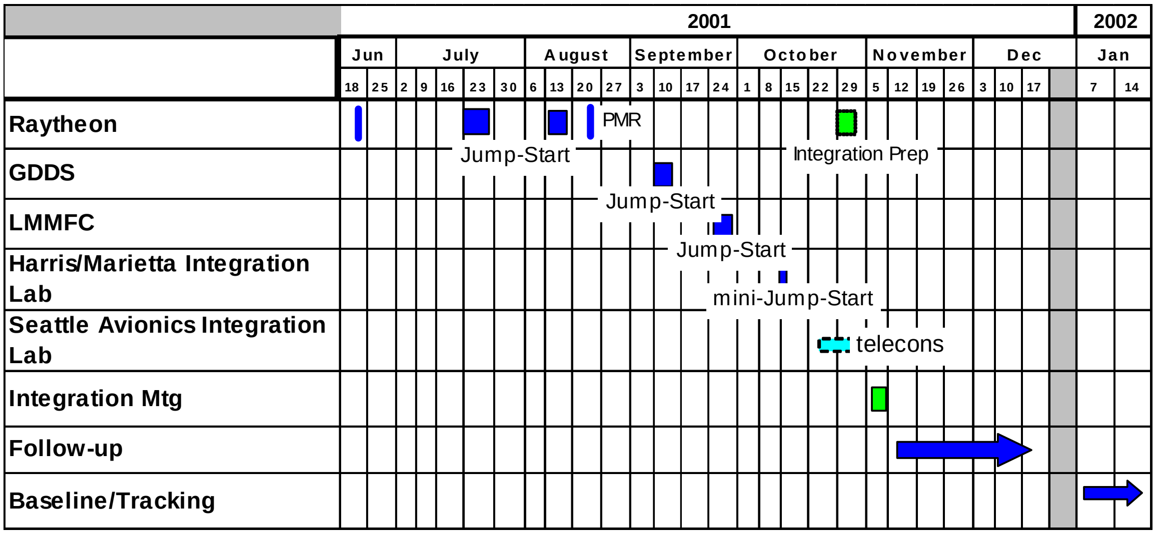

Figure 45. Chronology of activities to develop integrated CCPM CIP-2K plan.

suppliers,[138] (2) reduce duplication and misunderstandings, and (3) brainstorm for ways to cooperatively reduce spans. The major benefit of the integration meeting was a fairly strong agreement across the entire CIP-2K team that the plan developed represented a feasible development plan. It was clear to all concerned that close cooperation and frequent updates focused on the plan would be required to achieve project goals.

All these activities produced a total CIP-2K project span of some 28 months based on a planned start in January 2002. After the Avionics Core IPT leader directed that the schedule be implemented, weekly tracking meetings commenced during early January 2002. He also approved the plan proposed by the LM Aero CCPM leads to conduct a workshop at Marietta, Georgia, 14-18 January, with external technical support on Critical Chain single- and multi-project concepts.[139]

Implementation in January 2002 employed the weekly teleconference form for communications and coordination common to the F/A-22 IPT development program. However, meeting substance was significantly improved by information from the CCPM update process and the actions that it prompted compared to other multi-supplier groups. In non-CCPM based meeting structures, the status reports were at a higher level and, because each participant maintained their own separate schedule to which other players were not privy, there was neither a common understanding of the "big picture" nor of the impact of delays and stretch-outs on overall project completion. In contrast, the detail of the CCPM schedule information for the CIP-2K meetings significantly improved the extent of mutual knowledge and the CCPM process generated both highly

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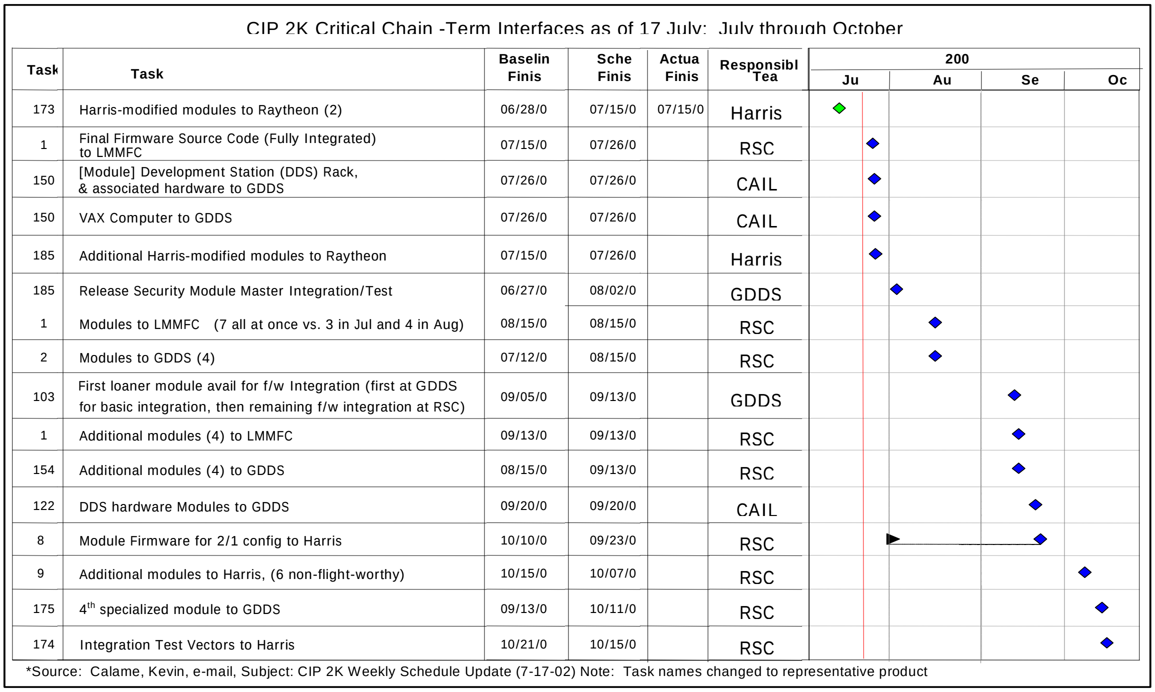
[138] "Engineering versions" are the initial or iterative products of either hardware or software items that have many or even all of the functions of the final design but which are not completely finished or completely tested. These engineering versions are often used by other customers who need or interface with the product until the "final version" is available, thereby permitting parallel (vs. serial development and helping to compress the total span. Use of engineering versions was very helpful in reducing the total CIP-2K development span.

[139] Training on concepts was provided by an acknowledged expert and author, Gerald Kendall of TOC, International, from whom some graphics for this dissertation were drawn. Training on the PS8™ software was provided by Sciforma® Corporation representatives.

visible accountability and proactive efforts to stay ahead of problems of to preserve "buffer" so the project goals could be achieved.

The solid foundation for the weekly update telecons was a disciplined process of sending electronic updates to Colby (in his master scheduler role). He produced an aggregate, updated schedule that was sent out for review prior to the telecon. Then, given a clear, current picture of project and buffer status, the team focused on the handoff of products from one company to another. The practice of using the projected hand-offs or deliveries during 30-, 60-, and 90-day "look-ahead" period (illustrated in Figure 46) as the framework for these proactive discussions forced candid discussion, off-line meetings and timely efforts to keep the project on track. Besides permitting all players insight into the progress and problems being experienced by other CIP-2K principals, the communication permitted cooperation on other technical issues that might have otherwise been worked in isolation.[140]


CIP 2K Critical Chain -Term Interfaces as of 17 July: July through October

Task	Task	Baselin Finis	Sche Finis	Actua Finis	Responsibl Tea
173	Harris-modified modules to Raytheon (2)	06/28/0	07/15/0	07/15/0	Harris
1	Final Firmware Source Code (Fully Integrated) to LMMFC	07/15/0	07/26/0		RSC
150	[Module] Development Station (DDS) Rack, & associated hardware to GDDS	07/26/0	07/26/0		CAIL
150	VAX Computer to GDDS	07/26/0	07/26/0		CAIL
185	Additional Harris-modified modules to Raytheon	07/15/0	07/26/0		Harris
185	Release Security Module Master Integration/Test	06/27/0	08/02/0		GDDS
1	Modules to LMMFC (7 all at once vs. 3 in Jul and 4 in Aug)	08/15/0	08/15/0		RSC
2	Modules to GDDS (4)	07/12/0	08/15/0		RSC
103	First loaner module avail for f/w Integration (first at GDDS for basic integration, then remaining f/w integration at RSC)	09/05/0	09/13/0		GDDS
1	Additional modules (4) to LMMFC	09/13/0	09/13/0		RSC
154	Additional modules (4) to GDDS	08/15/0	09/13/0		RSC
122	DDS hardware Modules to GDDS	09/20/0	09/20/0		CAIL
8	Module Firmware for 2/1 config to Harris	10/10/0	09/23/0		RSC
9	Additional modules to Harris, (6 non-flight-worthy)	10/15/0	10/07/0		RSC
175	4th specialized module to GDDS	09/13/0	10/11/0		RSC
174	Integration Test Vectors to Harris	10/21/0	10/15/0		RSC

*Source: Calame, Kevin, e-mail, Subject: CIP 2K Weekly Schedule Update (7-17-02) Note: Task names changed to representative product

Figure 46. Typical team handoff schedule for the next 30-60-90 days.

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[140] An example was the emergence of a bonding problem at GDDS that threatened delays in the completion of the CIP-2K security modules. A series of action items generated a reallocation of modules to free up

The benefit of this approach was demonstrated several times during the execution period. For example, the program was able to absorb the remanufacture of a key computer chip needed for one of the modules being produced by Raytheon. In one major surprise, demand on the use of the Avionics Integration Lab (AIL) at Seattle forced the program to delay CIP-2K access to the lab and instantly consumed nearly 60 percent of the 155 day Project Buffer intended to absorb variability over the entire 28-month project. Rather than start a major re-plan, the team jointly agreed to live with a sharply reduced project buffer for the remainder of the project with little chance that additional buffer could be developed. This made handoff commitments even more critical and also meant that any action items assigned to address issues had to be worked very aggressively.

Despite these efforts to respond quickly to problems, buffer consumption continued to edge up over the summer months of 2002, peaking at 66 percent in June-July, prompted by both the AIL availability problem and by technical difficulties with the engineering modules. However, by extra efforts to take advantage of accelerated testing and an early LM Aero avionics software delivery, Raytheon delivered its initial set of products fully seven weeks early in October 2002. Not only was this crucial to keeping the overall project on track, it reflected progress thought impossible when the Critical Chain schedule was initially developed and baselined some 10 months earlier.

Though the performance to the CCPM schedule was better than any other any component of the avionics system development, a dramatic change took place in the avionics program. To assure readiness for the beginning of Initial Operational Test and Evaluation (IOT&E) by AFOTEC, top priority was suddenly and urgently placed on software and overall avionics system stability. This generated another major delay in

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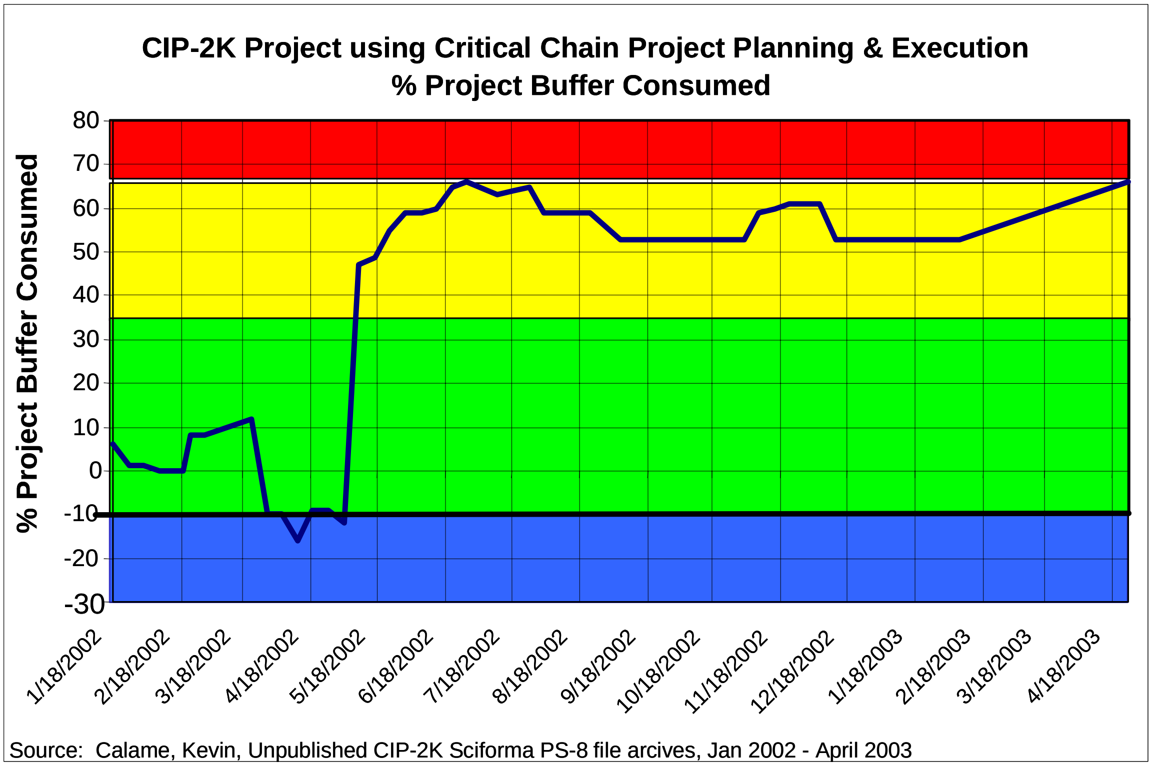
modules for testing and experimentation by Raytheon at manufacturing facilities in California and Texas. Also, a visit by GDDS technical leads to the LMM&FC facility in Orlando, Florida was arranged and TIMs were conducted to successfully resolve the problem and keep the project on track.

access of the CIP-2K system to the integrated labs and necessarily caused a replanning effort for the CIP-2K program that ended the original Critical Chain schedule successfully followed for 16 months.

- Work executed with the support of the CCPM process up to the point of suspension accounted for 92 percent (256) of the total 278 product deliveries of hardware, software and firmware and documents involved in 69 intra-team handoffs. The CIP-2K development process was transitioning from the hardware development to the integration phase of the project. Essentially, for purposes of assessing the utility of the Critical Chain process in a multi-company project, the information and evidence available up to the point of rescheduling is sufficient for purposes of the dissertation. Overall, up to end-April 2003, the use of CCPM to support the development of the CIP-2K product was quite successful, even though the buffer status chart over time (Figure 47) remained in the high-yellow range most of the time (for reasons discussed earlier).


CIP-2K Project using Critical Chain Project Planning & Execution
% Project Buffer Consumed

Source: Calame, Kevin, Unpublished CIP-2K Sciforma PS-8 file arcives, Jan 2002 - April 2003

Figure 47. Status of CIP-2K Critical Chain Project Buffer over time.

- After a fairly smooth initial Jump-Start at Raytheon and developing and integrating the separate supplier plans, the stability, successes and perseverance over the 16 months that the Critical Chain process was followed during execution of the schedule were all quite positive.[141] Several facts support this observation:

- The Jump-Start successfully overcame the problem of the extremely long start-up process encountered in the initial LM Aero demonstration of CCPM in the finishes area. From a technical perspective, far less training was required, and the combination of experience and perseverance of the LM Aero change agents and the Raytheon CIP-2K/CCPM lead generated a product with a meaningful level of detail that later turned out to be quite suitable for tracking, updating and reporting.

- The mega-project approach, originated using an unfamiliar "merge" function in the CCPM software, proved quite suitable for support of the multi-supplier project that stretched across the country. More than that, the use of the single project structure turned out to be something of an organizational communications bonanza. Essentially, every week, everybody knew what—and how—everybody else was doing. This contrasted with the situation often engendered by separate, company-maintained schedules where details were "beyond the veil" of scrutiny by team-members.[142] The single-project that incorporated every player's important tasks forced all participants to focus on the "team" plan that by its nature prevented masking of emerging problems and forced prompt action to mitigate them.

- Early focus on "handoffs" of myriad intra/inter-supplier products during the planning phase and maintenance of high-visibility attention to timeliness of hand-offs during the weekly team telecons was extremely valuable. The "one-plan" CCPM schedule and

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[141] While the status at the point of suspension potentially supported the May 2004 delivery date, the demands of the stability initiative on the RAIL facility actually delayed delivery until the fall of 2004.

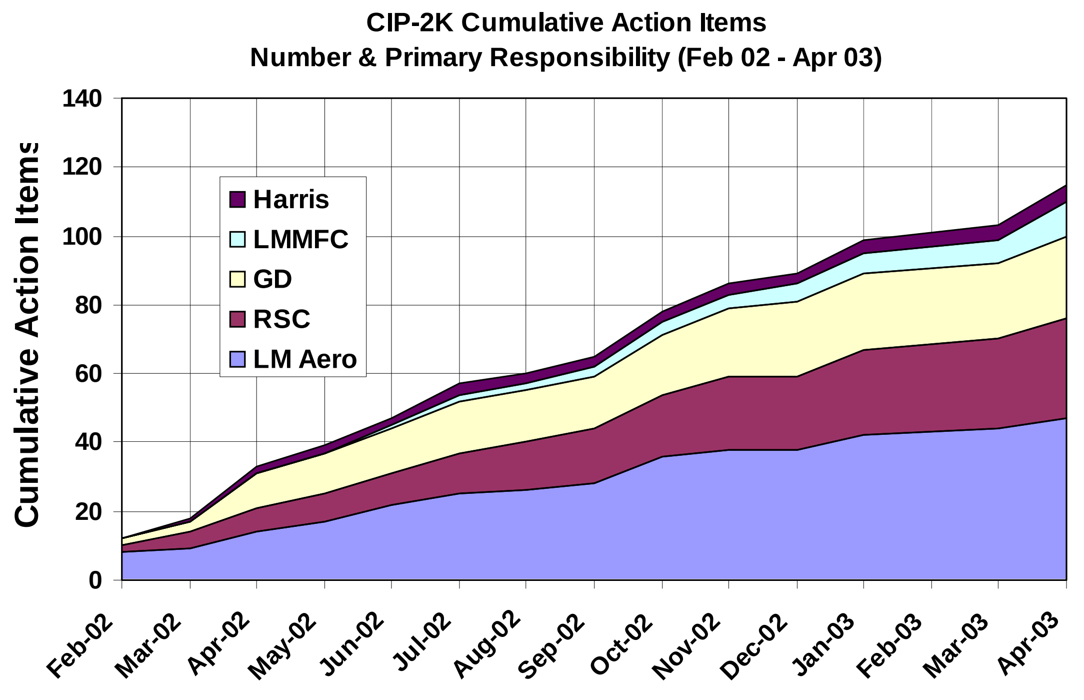
[142] It is true that all of the suppliers maintained more detailed schedules. However, all used those more detailed schedules to permit accurate updates of the team Critical Chain schedule and all agreed that the team Critical Chain schedule was the centerline for the CIP-2K development.

focus on hand-offs were perhaps the most powerful technical and organizational elements of the application. Because of the simplicity of the CCPM update process, all players learned very quickly to be completely candid, especially when difficulties were encountered. In the case of difficulties or potential slips by one supplier, the “team” often helped by providing new perspectives and expertise that helped resolve difficulties or at least permitted the team to deal with the impacts of the difficulties well before the “problem” became a crisis. In that way, accountability was reinforced again and again.

- What seemed somewhat infrequent weekly schedule updates (compared with the CCPM methodology preference for updates more often) worked well. Though greater frequency was prevented by multi-supplier commitments to other tasks and meetings, success with the weekly updates suggests that the level of detail was “about right” as long as bolstered by sustaining high visibility of the product handoffs.
- Regarding level of detail, the experience proved that when a project extends over a lengthy period as CIP-2K did, limited detail in even important tasks towards the end of the project is acceptable. In the project, a few “place-holder” tasks of reasonable duration were sufficient to represent integration tasks in the Marietta and Seattle integration laboratories until the schedule could be enhanced with essential details several months later. From practical and technical perspectives, this increased efficiency by avoiding wasted energy trying to detail tasks that were quite uncertain until progression of other project tasks is clear.
- Multi-supplier buffer management worked extremely effectively. With the foundation of a highly transparent single plan and high-visibility for handoffs, the impact on buffer consumption of missed or delayed hand-offs(which were often critical chain tasks) was immediately apparent so that action to mitigate impacts or even to “recover buffer” by finishing other tasks earlier than aggressive spans was perfectly aligned with the buffer management concept.

From the perspective of the prime contractor, LM Aero, and ultimate customer, the F/A-22 SPO, the mutual accountability engendered by the CCPM CIP-2K process and schedule was especially beneficial. Instead of constantly being in the role of the "customer" and demanding task-master, LM Aero and SPO representatives were much more facilitators and coordinators of actions and off-line meetings. The other suppliers/ stakeholders, as both providers and recipients of products, recognized the expectations of others embedded in the scheduled hand-offhand worked hard to live up them.

The sharing of responsibility for project success in terms of the myriad action items that had to be worked along the way by the team is reflected in Figure 48. It depicts the cumulative share of tracked action items for each of the suppliers over the period of CIP-2K project execution under the original CIP-2K schedule.[143] Instead of having almost all or a substantial majority of the action items, LM Aero was responsible



Source: Calame, Kevin, Unpublished CIP-2K Weekly Meeting Minutes (archives), Jan 2002 - April 2003

Figure 48. Distribution of CIP-2K project action items.

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[143] The figure should be considered representative in numbers and responsibility, since it was compiled by the author from available archive data covering approximately 90 percent of the weekly meetings.

for fewer than half of the action items, with Raytheon and GDDS taking on 29 and 24 percent of the action items, respectively. Several of the action items required leadership efforts to resolve or work-around problems evolving from a scheduled task. These efforts often generated separate action items which were not tracked by the central CIP-2K team process, and mutual accountability, frequent tracking/updates and constant communication helped to assure timely closure of the action items.

Beyond these extensive evaluation comments, prompted because of the unique nature of the application and the multi-supplier situation, the fact that the project was effectively terminated because of the broader avionics stability concerns mentioned earlier, this case study did not witness an institutionalization of the CCPM innovation in the Avionics IPT. There were follow-on applications of the CCPM innovation, but they followed the same form and process as describe here, thought the details are beyond the scope of this study.

Part B: Analysis

The purpose of this section of the chapter is to assess whether or not—and why--the types of anticipated changes did occur and to assess the CCPM innovation in the multi-supplier development of the CIP-2K module from the organizational perspective. In addition, the CHIP model and the *structural level and actors* construct facilitate analysis on the application of the CCPM innovation.

Assessment of CCPM-driven Changes in the CIP-2K Project

A top-level review suggests that CCPM “delivered” in the implementation in the CIP-2K application regarding two of the changes noted in the methodology discussion of construct validity, namely: Change 1 “on-time achievement of the CCPM” and Change 3 “Improvement in schedule performance compared to the past.”

Regarding Change 1, as reflected in the Figure 47 adaptation of the “fever chart”, the status of the project up to suspension was on track towards the projected delivery date, so the project was performing to the CCPM schedule. Even with the high level of buffer consumption the team had proven to be quite resilient and responsive to problems during the first 16 months of execution. Confidently predicting that the goal would have been achieved is somewhat problematic, because of the challenges of absorbing highly volatile variability in the impending integration phase of CIP-2K.

As for expected Change 3, improvement relative to the past, there are two bases for comparison. The first is the planning process used for CIP-2K prior to implementation of Critical Chain. As noted in the description of the initiation stage, just prior to the initiation of CCPM, the CIP-2K plan that had been in force for six months was on the verge of slipping product delivery by as few as four and as many as 10 months. Both the minimum slip and the magnitude of the uncertainty (six months) would be considered serious if not alarming concerns. By comparison, delivery of the initial module to the RAIL originally projected by the CCPM schedule for late December 2003, 12 months into the schedule, actually occurred 2 months early. Being on track for 16 months with the same CCPM schedule was itself quite an accomplishment.

The other contrast highlighting CCPM planning process utility in execution of the CIP-2K schedule plan is the picture of what was happening in the execution of the overall Avionics program plan. During the same period that the CIP-2K team followed and tracked to essentially the same CIP-2K Critical Chain schedule,[144] there were two major Avionics Master Schedule changes and 12 other fairly significant changes (though they did not result in formal recognition).[145] The impact of these changes was that the

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[144] As noted earlier, tasks were added when appropriate and expanded (as planned) to detail the RAIL/AIL integration process; there were no massive changes and the project target delivery date remained stable.

[145] Trine, P. J. e-mail, Subject: Avionics schedule change recap, 25 March 2003.

overall program slipped an average of eight months while the CIP-2K project continued to track to the same schedule goal.

Regarding Change 2, “Improved ability to anticipate and mitigate difficulties in schedule execution”, there was no quantitative measure of the impact of CCPM decision support for management in the face of adversity. There was much anecdotal evidence that qualitatively supported the contention that CCPM schedule and process highlighted emerging problems and prompted actions as reflected in the previous section.

There were some who challenged claims by Avionics IPT managers and some CIP-2K Team members that the CCPM approach was a central element in the sustained success of the CIP-2K process.[146] They suggested that “any” scheduling system would have worked given the process and attention established for planning and executing the CCPM CIP-2K schedule. In fact, that suggestion failed to acknowledge that the CIP-2K process prior to the use of CCPM was judged a failure despite the application of intense attention, manpower and multi-player, multi-management-level efforts. The same can be said of the overall Avionics program which involved even more intense planning and management efforts.

In any case, to respond to claims of “essentially no value added by CCPM” a survey was developed to generate additional information and insight on the potential value of the use of CCPM compared to previous planning/scheduling and execution processes. The survey was also conceived as a way to simultaneously find out “how well CCPM worked” and capture a cross-section of views for dissemination to others contemplating the use of CCPM (as well as provide additional research insight). To achieve these purposes a small “selective survey” was conducted of a cross section of those key players most closely involved and familiar with the CCPM concepts and

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[146] Though the challenge was unrelated to this paper, responding to the challenge effectively addresses the construct validity of this paper.

application to the CIP-2K process.[147] Their company and role in the CIP-2K process is reflected in Table 14, below. Even more important than knowledge of CCPM, the survey participants were tasked with substantial responsibility for their company's performance in the CIP-2K process. Personnel were selected in the three roles important to the employment of CCPM. Schedulers[148] were required to sustain the update process and the first to identify progress (or lack of progress) to the local team. Technical leaders were the individuals at the working level responsible for completing tasks and deliveries and for taking or directing actions deemed necessary by the team during the weekly CCPM/CIP-2K telecons. Managers for whom the technical leads and schedulers worked were important because they provided oversight of the process, supported team actions when higher level authority was required, and reported progress to higher management.

The right column of the table reflects that in aggregate, among the 20 CCPM/ CIP-2K project participants surveyed, 10 people or 50 percent responded, A slightly higher percent for the prime contractor, LM Aero (56 percent) responded than for the supplier group (45 percent), but the 10 that did respond were evenly divided between LM Aero and the supplier group. As to the roles represented, the top rows of Table 14 show that for the categories of interest, the percent of respondents in each

Selective Survey on CCPM use in CIP-2K development (R=response; NR=non-response)										
		Managers		**Technical Leads**		**Schedulers**		**Total**		
	#/% of polled-->	**5/25%**		**12/60%**		**3/15%**		**20/100%**		
	#/% of respondents	**2/20%**		**6/60%**		**2/20%**		**10/100%**		
Organization	**Prime**	**R**	**NR**	**R**	**NR**	**R**	**NR**	**R**	**R+NR**	**% R**
	LM Aero	1	2	4	2			5	9	56%
	Supplier									
	Raytheon		1		2	1		1	4	
	GDDS	1			1		1	1	3	
	LMMFC				1	1		1	2	
	Harris			1				1	1	
	Boeing			1				1	1	
	Supplier Totals	1	1	2	4	2	1	5	11	45%

Table 14. Role and home company of CIP-2K survey group.

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[147] The description here focuses on the construct validity and is extracted from Appendix G, which includes a more detailed discussion of the survey on these and other questions of interest to the F/A-22 team.

[148] As a CCPM change agent with a strongly biased view of CCPM, Colby was not asked to complete a survey, even though he was the individual responsible for transforming inputs into the aggregate schedule.

category was quite close to the percent of participants in the total polled. The fact that both respondents and total surveyed were dominated by the technical leads was intentional, in that a primary interest in the survey was the utility of the information to the decision maker on scene at each site. Other than that, by both source (prime/supplier) and role, the respondents fairly represent the select group asked for a response. Respondents had a wide range of experience, from 1 - 9 years on the F/A-22 program, and from 2 – 15+ years and in the aerospace industry. All respondents indicated familiarity with either Microsoft Project™ or the Critical Path Method as the basis for comparison with scheduling aspects of CCPM.

The form of the survey itself is provided in Appendix B. The two main parts of the survey solicited respondents' opinion from home company and cross-team perspectives on a number of statements. The statements related the team's ability to make decisions and manage the project, the most important characteristic of any scheduling system according to F/A-22 Team and Avionics IPTs leadership. Relative impact could be indicated as *reduced, the same, or improved* and the basis for comparison was the respondents own experience with other projects and scheduling management systems, whether on the F/A-22 program or any similar project.

In the first part of the survey, the respondents were asked to rate the impact of CCPM relative to approaches before CCPM was implemented on a series of statements that were later grouped into three areas. The first is characterized as "situation awareness" roughly defined as sufficient knowledge of what is going on to recognize the need to make decisions or take action, e.g., ability to identify problems before they become crises, understanding of current status relative to the project goal. The second group is called "management and decision making" to capture the decisions to take action and meet goals, e.g., ability to set priorities based on data instead of intuition, understanding the priority order for working problems/issues. The third area is "resource management", included because of the emphasis on resources in the CCPM process compared to only limited emphasis in the CPM approach.

At a top level, across all statements focusing on CCPM impact within the respondents' company, there were no "reduced", 89 "same" and 71 "improved" responses. There was nearly unanimous agreement that the impact in the resource area was very small, with 23 "same", and only 7 "improved." Otherwise, results of the questions in the first area were most interesting when the responses were separated into two groups, prime contractor (i.e., LM Aero) and suppliers, and focused on the answers that indicate the factor of interest "improved" with the impact of CCPM (Figure 49).

Other than Resource Management, it is clear that the prime respondents were much more positive about the impact of CCPM, and the suppliers much more muted in their view of the impact of CCPM. Regarding Situation Awareness, 80 percent of the responses from the prime respondents indicated that CCPM had improved the LM Aero capability. In contrast, fewer than half of the supplier answers (44 percent) indicated "improved" situation awareness. The likely answer here is that integration of the supplier

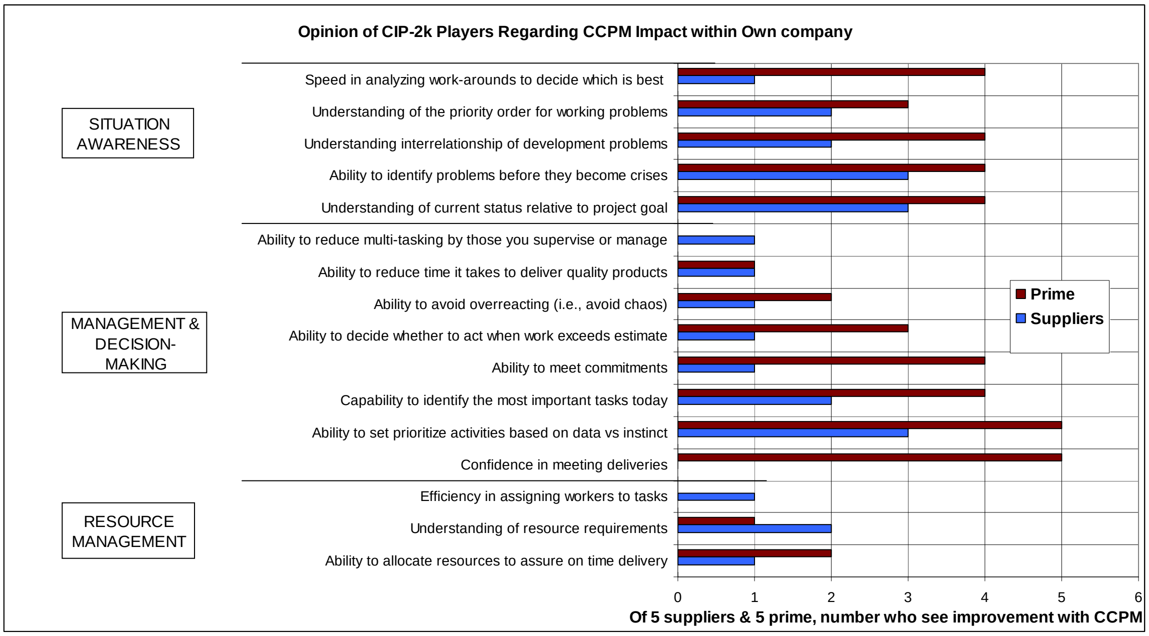

Figure 49. CIP-2K survey: Impact of CCPM on own company capability.

schedules in the CCPM schedule provided the LM Aero with a much better sense for the situation. Previous information from the suppliers was aggregated at a higher level so problems at lower task levels were, literally, invisible.

As for Management and Decision Making, 60 percent of the LM Aero “prime” responses indicated improvement in this area, as opposed to only 25 percent of supplier responses. The major areas of perceived improvement for the prime respondents had to do with ability and confidence in meeting commitments, and knowing what was most important and how to set priorities based on data. Improvements in these areas are extremely valuable for those tasked with managing a complex process like the CIP-2K development. Perhaps the most striking contrast between prime and supplier respondents is “confidence in meeting deliveries” where every supplier respondent indicated their confidence was “same” as before CCPM, but every prime respondent said their confidence in meeting deliveries was “improved.” This dichotomy might be explained by the fact that the prime respondents were totally convinced of the value of CCPM and therefore inclined to be more positive. However, although the belief in the utility of CCPM did grow through the project, the LM Aero personnel were far more pragmatic. They were mainly concerned with, and under pressure from upper management for, the delivery of the entire CIP-2K product for which LM Aero was ultimately responsible. From that perspective, the fact that the project was substantially on track at the time of the survey (March 2003) might explain prime responses that assessed the situation as “improved” by CCPM. On the other hand, suppliers were more focused on the shorter term and consistently on-time deliveries were problematic.

As noted earlier, the other area of interest in the survey was the impact of CCPM on activities across the multi-company/player team. Here, the interest focused in two areas, Situation Awareness and Teamwork. Situation Awareness was similar to the internal company issue, but statements focused on the team perspective and the impact of CCPM on knowledge about changes across the team, e.g., knowing the status of all team activities, etc. Teamwork statements were formulated to help assess whether the CCPM schedule and process contributed to aspects of team operation, with statements focusing on mutual accountability, coordination with other CIP-2K suppliers, etc.

Figure 50, below, presents the results of the survey on the issues of Situation Awareness and Teamwork for the CIP-2K team as a whole. The results at the team level are quite dramatic in that over 80 percent of all responses indicate that CCPM "improved" capabilities across the board, 85 percent indicating improved Situation Awareness and just under that indicating improved Teamwork. The improvement in Situation Awareness over prior systems is especially impressive given the scope and complexity of the CIP-2K project. In the Teamwork area, it is equally impressive that 8, 9, or 10 respondents felt that CCPM "improved" CIP-2K team capabilities in 4 of the 6 areas assessed.

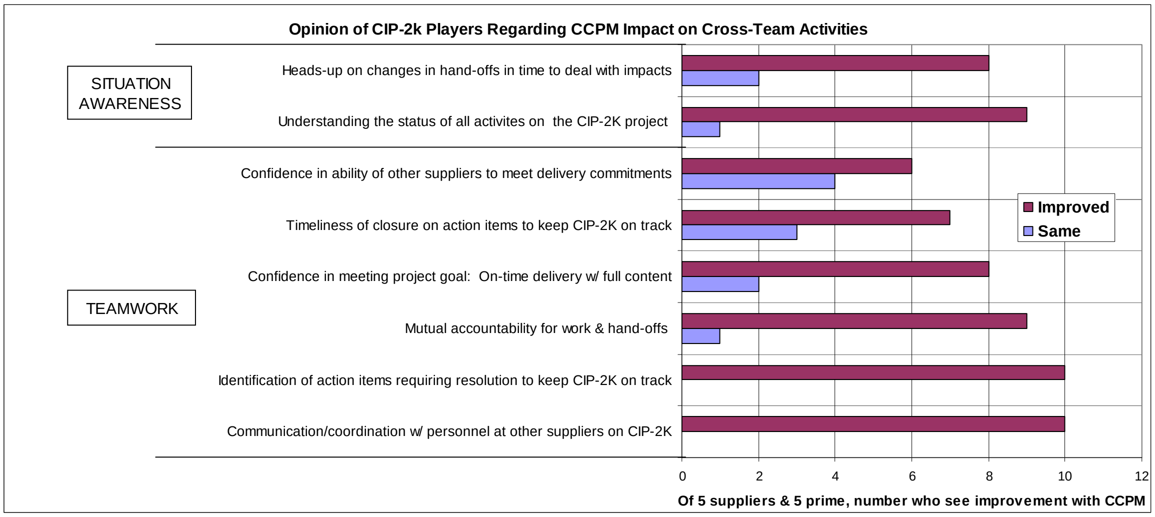

Figure 50. CIP-2K survey: Views of CCPM impact on team activities.

As a final point, though they did not participate in the survey, the government representatives closely involved with the project strongly supported the use and *value* of Critical Chain in managing and developing the CIP-2K system. The F/A-22 SPO counterpart to the Core IPT leader who spearheaded the effort said he "…appreciated the efforts to keep the CIP 2K program on track, the best we have done on the F/A-22". At the next higher level in the government management structure at the SPO, the Chief of the Avionics Systems Development IPT said of the CCPM process: "I consider the CCPM planning and execution management process one of our biggest successes in the CIP 2K development effort."[149]

Overall, given the small number of respondents, the information doesn't *prove* construct validity for the expectation that the CCPM innovation deserves credit for changes in meeting schedules, for improving over previous systems for schedule planning and execution and for better anticipation/mitigation of difficulties in schedule execution. However, the quantitative "on-track" data and the survey information do provide support for the contention. The alternate explanations, that "any scheduling system could have succeeded given the attention and focus of the CCPM effort", seem refuted not only by the performance and survey data, but by the evidence that other elements of the avionics development program supported by traditional systems were not doing as well as the CIP-2K program.

Analysis from the Perspective of the CHIP Model

As in the previous case study chapters, the primary elements of the CHIP model that are of interest are the motivation for innovation, the initiation and implementation stages and the innovation decision that separates these stages.

Motivation, Initiation Stage and Initiation Decision

The CIP-2K application of the CCPM innovation was one of the organizationally most complex and challenging projects addressed in this dissertation. The technical risk in the CIP-2K project was itself a source of fairly intense organizational strife because of

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[149] Peet, Bruce, E-mail message, 25 February 2003, Subject: Comment on Value of CCPM to CIP-2K Project.

seemingly constant change with wide margins for error in projected dates prior to the initiation of the CCPM innovation. With this backdrop, the initial areas of analytic interest within the innovation framework, motivation, initiation and innovation decision, are combined in this one section. That is because they all, for the most part, happened nearly simultaneously in a very concentrated time period, though there were components that stretched out on the front and back ends of the initiation/initiation decision elements of the innovation process.

On the front end, there was an accumulating motivation for change that intensified with every disappointing slip in the early CIP-2K project and the accompanying replan. By the time CCPM became an available option, the clear gap between what was needed and what was happening had transformed the motivation to unequivocal urgency for a different approach, not just to scheduling, but to management of the CIP-2K problem. Other approaches had been tried and not worked for years, and all parties were ready for a new idea. CCPM arrived at a propitious time in a ready-made setting so that acceptance by the LM Aero and Raytheon CIP-2K managers of CCPM's potential of to fill the need was almost a foregone conclusion. There was a virtually immediate decision to initiate the application of CCPM to the CIP-2K problem, based on only an overview of the concepts and process.

The "back end" of the innovation decision is stretched out and made interesting by the VP/GM's follow-on decision to sharply expand the implementation across the team of CIP-2K suppliers and labs. The CHIP model would anticipate that a typical implementation in demonstration form would be complete through results before a follow-on decision can be made for expansion to a larger implementation.   Here, based purely on results of planning for Raytheon's portion of the CIP-2K project, the decision was made to expand the innovation to the entire project including other suppliers and the integration phases at the prime contractor's laboratories.   In a sense, the lightning speed decision not only seems a variation on expectations based on the CHIP model, but also bears on the radical theory of innovation. The latter is affected because the decision essentially transformed what was planned as an *incremental* form of the organizational innovation on the CIP-2K project to its alternate form called *radical* innovation. The expanded application could be labeled “radical” by inclusion of a much larger technical and geographic scope and a different management approach than what existed before (Gopalakrishnan and Bierly, 2001). It is also true that the avionics IPT managers, the VP/GM and the organizational situation embodied a favorable managerial attitude toward change, a concentration of technical specialists and substantial depth of the organization’s knowledge resources, all of which facilitate radical innovation (Damanpour and Gopalakrishnan, 1998, based on Dutton and Dewar, 1986).

Implementation Stage

In the case of the application of the CCPM innovation to the CIP-2K project, the reinvention and restructuring descriptors of the CHIP model seem more appropriate than the metaphorically gentler “tailoring” term generally used in this dissertation. That is because of the very extensive modification of the CCPM innovation and process from the Jump-Start, to the merging of multiple networks, to the tracking and update process.

The implementation stage also demonstrated that a great deal of skepticism can be overcome by perseverance in the application and appropriate adaptation of the innovation To some extent, there was a kind of continuous reinvention of the innovation into a form that proved sufficiently flexible to meet individual supplier needs. At the outset of the CIP-2K project, there was considerable technical doubt about the feasibility of several aspects of the CCPM innovation in the hectic development environment with multiple suppliers. These doubts included concerns about the Jump-Start process which was completely new and untried in the F/A-22 environment, the prudence of merging the files into one mega-file, the workability of the weekly update process, the initiation of the 30-, 60-, 90-day “look-ahead” for hand-offs, and the requirement for complete cooperation among multiple suppliers to gain the benefits of buffer management across the entire project. However, all of the technical issues were resolved at the outset or early in the process. The result was that the CCPM innovation demonstrated an unanticipated capability to support and enhance an extremely complex process that was, literally “on the rocks” and at substantial risk before the application of CCPM.

The last phases of the CHIP model implementation stage—clarifying and routinizing—did not occur in a formal sense. In fact, a follow-on phase of the CIP-2K process (not documented here) used the same process as describe here, clarifying and routinizing phases occurred in the process of executing the original CIP-2K, even though not identified as separate identifiable phases.

Analysis from the Perspective of the Structural Levels and Actors Construct

The CCPM implementation in the CIP-2K project operated as expected based on the *structural levels and actors construct.* Prior to the beginning of CCPM use on CIP-2K, the potential for employment of the CCPM innovation was recognized by Program-level leadership in the person of the VP/GM. He mentioned the general potential for utility of CCPM in the avionics area in the spring of 2001. At a lower Program-level organization, closer but still above the Operational level, the Avionics IPT leader became familiar with the CCPM innovation because of an information briefing from the Program-level change agents. When the problems of constant schedule slips and revised plans fraught with risk intensified in the CIP-2K development, it was the Avionics IPT leader who took the first step toward initiation by scheduling a briefing on CCPM at an important CIP-2K Technical Interchange Meeting. Though the Core IPT which was directly responsible for the CIP-2K development and other IPTs at the Operational level were concerned about the schedule development and execution problems, none would have known about the CCPM innovation without Program actions to make it available.

Consistent with F/A-22 organizational policy, the formal decision to adopt the CCPM innovation was made at the Operational level by the Core IPT leader, but the decision was almost a foregone conclusion because of the projects' very difficult and highly negative visibility situation. Later, the Program level directed and supported expansion of CCPM use to the rest of the CIP-2K development program with contractual direction to make it happen. Throughout the implementation, from development of the specific Jump-Start process, to the coordination and execution of the planning process and integration TIM, to active tracking and reporting, the Program level was very heavily involved in an active and on-going leadership role.

Overall, the expectation from the *structural levels* construct that innovations like CCPM will be "top-down" driven from the Program level for initiation and support was proven quite valid for this application of the CCPM innovation.

Regarding the *actors,* while individuals dominated, there was a legitimate draw or "pull" for the use of CCPM by groups of very bright engineers and managers who knew there had to be some way to get the CIP-2K project under control. In a sense, the perceived success of predecessor F/A-22 IPT CCPM "users" can be considered group actors here because the "pull" and the perceived success of the CCPM implementations made for a very receptive CIP-2K environment for the CCPM innovation.

Within that environment, individual organizational actors were central to the use of CCPM as an organizational innovation. The LM Aero VP/GM clearly played the role of champion in directing the expansion of the innovation across the team. The LM Aero change agents performed effectively during the initiation of the innovation at all the sites and throughout the planning portion of the implementation stage. Colby, in his role as master scheduler was essential to the maintenance of discipline for updates and timely action during the execution of the schedule that evolved. Beyond these program players, the Core IPT managers and the Raytheon Integration Manager/CCPM lead were particularly well qualified and creatively flexible regarding the CCPM innovation and its use. The Raytheon lead, internal change agent for the Raytheon and overall CIP-2K teams, was crucial to establishing and sustaining application of the CIP-2K innovation. Overall, these observations reinforce the CHIP and *structural models* regarding the importance of change agents and champions to organizational innovation success.

Summary

This case study of the application of the CCPM innovation to the CIP-2K development arena was an unexpected and very beneficial element of this multi-case study of the CCPM innovation and the overall organizational innovation process. Part A described the completion of the initiation stage and innovation decision in a very short period of time, as well as the evolution of one of the most complex “reinvention” phases and the longest implementation stage of all the case studies. The initial and continuous refinement of the Jump-Start process was ideally suited to the multi-site implementation challenge. The very useful weekly update meetings established and sustained a highly disciplined and aggressive buffer management process that kept the program on track through mutual accountability despite some very significant challenges. The Part B analysis supported the construct validity of the dominant changes expected from the CCPM innovation. The analysis also reinforced several elements of the CHIP model, including the importance of a flexibly iterative reinvention process as well as the disciplined compliance with the central elements of the innovation, particularly aggressive buffer management. Finally, viewed through the lens of the *structural levels and actors* construct, it is clear that this particular adoption of the CCPM innovation was totally consistent with the concept “top-down” initiation and support, and several groups, champions and change agent actors operated in and across Program and Operational levels of the organization to execute a successful application of the CCPM process.

Table 15 summarizes the analysis of the CCPM - CIP-2K application.

Construct validity: expected changes found?			
Change	1	2	3
short description	meets CCPM schedule	better ability to foresee & deal w/ difficulties	better than past
overall answer	yes	yes	yes
supporting evidence	substantial data showing far better performance to schedule compared to past & current programs; limited, but strongly supportive survey data		

Structural Levels: Program and Operational
Top-down process w/ Program level initiation & support; comprehensive, sustained Operational-level implementation
Organizational Actors
groups played minor role; external champion; both int. & external change agents

Casey Hybrid Innovation Process (CHIP) Model				
Element of Interest	Motivation	Initiation Stage	Innovation Decision(s)	Implementation Stage
short description of application	performance gap; external pressure; internal "pull"	external identification of CCPM	quick initial optional; expanded by authority decision	iterative process developed "jump-start" approach & multi-site application

Table 15. Analysis Summary: CCPM case study in supplier development.

Chapter 9 - ANALYSIS & FINDINGS

Overview

The purpose of this chapter is to elevate the information provided thus far to support a cross-cutting analysis of the implementations using the same three analytic perspectives as used in the case studies, namely construct validity (changes produced/driven by CCPM), the CHIP model and the *structural levels and actors* constructs of innovation. This broader analysis will support the multiple-case research objectives of first, examining Critical Chain Project Management (CCPM) as an innovation with potential to address the gap between major weapon system development schedule planning objectives and execution performance, and second, contributing to the literature on the organizational innovation process.

Accordingly, each of the sections will identify the analytic perspective and then be divided into two subsections focusing on analysis of the case studies leading to (1) *practical* insights that might improve the CCPM innovations potential to the closing of the acquisition schedule objectives-versus-performance gap, and (2) *academic* insights that contribute to the organizational innovation process literature. In general, aided by extracts from end-chapter summaries, the analysis first addresses commonalities, then differences, with insights and conclusions strengthened by multi-case external validity.[150]

Assessment of Construct Validity

The Practical Perspective – Insights Related to the Construct Validity

The Chapter 3 methodology discussion on construct validity posed the following specific types of changes expected from employment of the CCPM process that were to be studied and measured:

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[150] This claim on external validity is based on the belief that there was a sufficient degree of methodological replication across the cases.

- *Change 1:* Demonstrated on-time achievement of CCPM schedules. *Measure:* Difference between planned and actual schedule commitment to specific objectives.
- *Change 2:* Improved ability to anticipate and mitigate difficulties in schedule execution. *Measure:* Variable (direct contextual comparison; when possible, discussion/survey responses to specific questions on the issue).
- *Change 3:* Improvement in schedule performance compared to the past. *Measure:* Direct comparison (where comparable data for similar project executed prior to CCPM exists).

The composite of the case study results at the implementing IPT level are shown in Table 16. Essentially, the table shows that in the majority of the implementations (rows) there is support for the validity of the construct that expected changes (columns) did happen and can be largely credited to the impact of the CCPM innovation. The table also shows two very significant exceptions concerning the Combined Test Force.

Home organization & location	**Construct validity: expected changes found?**				
	Implementing IPT	Change 1	Change 2	Change 3	Supporting Evidence
		meets CCPM schedule	better ability to anticipate & deal w/ difficulties	improvement over past	
Boeing Seattle WA	Assembly Operations	yes	yes	yes	Some data clouded by technology cluster; other data unequivocally postive; limited survey support
LM Aero Marietta, GA	Finishes Operations	yes	yes	yes	Some data clouded by technology cluster; other data unequivocally positive; limited, strongly supportive data from discussions with key participants
Combined Test Force Edwards AFB, CA	Maintenance Modifications	mixed	flawed (unassessable)	uncertain	Implementation flawed by: failure to add new work and revise estimates; failure to follow wrok precedence; infrequent updates; buffer status manually estimated and unreliable
	Flight Operations	rejected - leaders convinced CCPM unusable			N/A
	Logistics Test & Eval	yes	yes	yes	Limited data, but solid support for validity based on direct contrast with other options in same setting
LM Aero Suppliers Multiple Locations	CIP-2K module development	yes	yes	yes	Substantial data showing far better performance to schedule than past and current programs; limited, but strongly supportive survey data

Table 16. Summary of case study analysis of construct validity.

The “yes” entries indicating a common, positive assessment of construct validity for four of the six applications require the caveat that the evidence is supportive, but not unassailable.[151] In every case, the quantitative data related to expected Change 1 is quite strong. Regarding improvement over the past (Change 3), despite research limitations on evidence before/without CCPM and after/with CCPM, case study evidence supports the contention that CCPM schedule planning and execution processes caused documented performance improvement. In the dynamic business of sophisticated system development, however, it must also be acknowledged that especially in manufacturing assembly (Boeing) and processes (Finishes IPT), claims for CCPM as the cause of both absolute and relative types of change are weakened somewhat by the “technology cluster” problem (Rogers, 2003), which cites the difficulty of isolating the effects of one factor while others are also changing.

As for Change 2—the provision by CCPM of a better method of anticipating and dealing with difficulties—the on-time completion of CCPM schedules when previous schedules were overrun provides prima facie evidence that the expected change was valid.[152] The other data that helps triangulate support for the construct validity of all three changes was obtained from focused discussions in the finishes implementation and surveys, some from Boeing and more from the CIP-2K implementation. Though the information was derived from a small group of participants in all cases, very careful selection assured that the respondents were most qualified to assess the value of CCPM, and they were nearly unanimous and strong in their support for CCPM. There is the possibility that the participants were unique and others would not reach the same conclusions. However, their comments are consistent with extensive reviews of Theory of Constraints and CCPM implementations (e.g., Detmer, 1997; Mabin and Balderstone,

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[151] The implication that the strength of evidence for construct validity of expected changes could have been better relates to a methodological issue addressed in Chapter 10.

[152] The only assumption required is “ceteris paribus”, and in the development environment it is reasonable to assume that execution of schedules before and after use of CCPM encountered the same kind of problems.

2000; Kendall, 2003). In addition, as noted in the methodology discussion on participant-observer bias, one of the most significant and reliable controls on the exercise of that bias is the fiercely independent, pragmatically candid engineers at the heart of the implementing IPTs from which the discussion information and survey data was drawn.

Regarding the exceptions to support for construct validity in Table 16, results suggest that the CCPM innovation “just didn’t work” in Maintenance Mods and Flight Test Operations. However, a more careful assessment is that the flaws in these applications do not undermine otherwise positive conclusions on CCPM’s potential to generate desired changes. The Maintenance Mods case makes it clear that several of the fundamental precepts of the CCPM innovation were violated as captured in the “supporting evidence” column of Table 16. Even the “mixed” support for Change 1—meeting CCPM-generated schedules—is generous because the last projects achieved the planned schedules only when buffers were manually inflated. The “uncertain” assessment that Change 3—improvement over the past—reflects the fact that only limited evidence from the past was available. These critiques not withstanding, it may be true that continued use of the CCPM methodology in spite of difficulties and “mixed” results means it was better than whatever approach had been used in the past.

Regarding the failure in Flight Operations, this participant-observer can admit to a bad case at the time of what has been called “pro-innovation bias” (Rogers, p. 106, 2003), a single-minded belief in the universal applicability of the CCPM innovation. That bias was so strong that it drowned out totally legitimate Flight Test Operations managers’ claims that if CCPM required a detailed plan for well over a year, it could not support the schedule planning and execution needs of the flight operations areas. Unfortunately, all other change agents were similarly afflicted with the pro-innovation bias so no suitable reinvention was attempted, except for the weak promise (at the time) of a “rolling wave” approach.[153]

The Academic Perspective – Insights Related to Construct Validity

Methodologically, analytic review of all the cases suggests that in a dynamic environment and complex organizational setting, construct validity is difficult to establish if the study limitations on the differences in projects are not offset by the research design. The best design would aggressively search out and maximize data mining and discussions/surveys of a larger group prior to their exposure to the innovation concepts or processes, then another after the implementation in the area affected. While this is little more than reinforcement of well established research design protocols, the case study evidence suggests that compliance is difficult given the organizational context and type of innovation investigated. In essence, as a researcher going in “you don’t know what you don’t know” and “by the time you do know, it’s too late”. The dynamics of a huge development project and the urgency of improvements sought by adopting the innovation may force a pace that limits access to pre-innovation data. The urgency may also unavoidably contaminate participants by exposure to the details of the innovation so that pre- and post-innovation discussions and interviews are problematic.

Regarding the strength of limited discussion or survey data in a situation like the F/A-22, conclusions might be altered if more people familiar with the project are involved, but it is uncertain whether expansion would change the conclusions. For example, more managers to whom CCPM-supported project data was reported or more workers whose efforts were prioritized by CCPM schedules might have been interviewed. Even with these enhancements, however, the substantial body of evidence supporting the positive impacts of CCPM in other (i.e., non-F/A-22) environments

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[153] Only when the LT&E planner/CCPM lead demonstrated the multi-project/dynamic execution approach for applying CCPM in dynamic environments did the veracity of the flight operations managers’ claims and the likelihood that the LT&E methodology could work for flight operations become clear to the change agents.

suggests that the conclusions would have been enriched, but not fundamentally changed.

The claim of external validity based on a “sufficient degree of study methodological replication across the cases” deserves some discussion in academic light. A narrow view of replication might undercut the external validity because the detailed case study descriptions revealed many differences in the application of the CCPM innovation. However, the organizational innovation literature makes it clear that across different instantiations, variations in specific elements of the innovation process should be expected. In the case of innovation decisions, the literature review (Chapter 2) described several kinds of decisions and, indeed, the case study evidence shows that different kinds of innovation decisions occurred. Similarly, the different reinvented forms of the CCPM innovation might suggest a compromise of the replication criteria, but the literature of recent decades [Rogers, 2003; West and Farr (eds.), 1990] makes it clear that reinvention will likely occur, will likely better match the innovation to the context of the implementation, and likely will strengthen the adoption of the innovation. Given that these variations in decisions and implementations are part of the process, the external validity is considered to have been preserved.

As a last point, the positive assessment of construct validity must be defended as legitimate, even in view of the author’s role as participant-observer-change agent-champion (POCAC). The main issue of concern is not necessarily whether there was improvement; the unbiased quantitative data supports that. Rather it is the issue of whether the primary importance of CCPM was the result of a biased, subjective judgment. On that issue, the argument that POCAC bias was not a factor depends on the strength of the discussions in the case studies. In each case, though multiple factors were involved, CCPM emerged as the most important factor based on the face-value strength of evidence. For example: The third implementation at Boeing succeeded when *only* CCPM provided the crucial information leading to on-time delivery. In other instances, the LT&E and CIP-2K project successes for example, the *major* factor that changed was the CCPM schedule and execution process.

Analysis from the Perspective of the CHIP Model

The Chapter 2 discussion noted that in its most encompassing form, organizational theory encompasses the well-established two-stage—initiation and implementation—model of the innovation process, treated in depth by Zaltman et al (1973) Rogers (2003), and also called *ambidextrous theory* (Duncan, 1976). However, for the reasons outlined, the CHIP model based on Rogers' work was developed for purposes of this research.

The Practical Perspective – Insights Related to the CCPM Innovation

Data from the analysis summaries at the end of the case study chapters is presented in Table 17. The interest here is to analyze the elements of Table 17 that reflect observations about each application (columns) across the key elements of the theory of organizational innovation captured in the CHIP model (rows). In Table 17, the heavy borders encompass areas of difference between or among the applications and make it clear that none of the applications were identical. The discussion which follows first analyzes the areas of commonality, followed by the areas of difference or exception. Analysis leads to practical findings about the using CCPM within the F/A-22 environment.

Regarding similarities in the *motivation for innovation* area, the case studies validate the CHIP model expectation that either a performance gap or impending crisis will be the source of interest in employing the CCPM innovation. There was no case in which the problem was not perceived as fairly serious at the F/A-22 Program leadership level or higher (the Pentagon, in the case of the CTF schedule problems). What all cases reinforce is that that perception *must* exist at the implementing IPT level.

Clearly, the CTF Flight Operations area stands out as an exception to the foregoing observation. Analytic hindsight suggests that the failure of CTF leadership and flight test managers to perceive the problem as theirs, and the failure of the F/A-22 Program leadership or CCPM change agents to gain agreement on the existence of a problem was the seed that eventually and finally withered into rejection. Elsewhere, both recognition of the problem and desire for a solution merged into a solid foundation on which the innovation process could build initiation and implementation stages.

Responsible Organization		Boeing	LM Aero	Combined Test Force			LM Aero+ Suppliers
Location		Seattle WA	Marietta, GA	Edwards AFB			Multiple
Casey Hybrid Innovation Process Model (CHIP)	Implementing IPT	Assembly Operations	Finishes Operations	Maintenance Modifications	Flight Operations	Logistics Test & Eval	Supplier CIP-2K development
	Motivation	performance gap; external pressure	performance gap; internal "pull"	performance gap; internal "pull"	external pressure; IPT views problem as external	performance "need"; internal "pull"	performance gap; external pressure; internal "pull"
	Initiation Stage	external identification of CCPM	external identification of CCPM	external identification of CCPM	external ID of CCPM; internal percption of mismatch	external identification of CCPM	external identification of CCPM
	Innovation Decision(s)	initial-optional; intermediate-contingent; final-authority	quick initial optional decision to adopt; final authority decision to terminate	quick initial-authority/optional (no further decision)	resisted authority decision to start; finally rejected	quick initial-optional (no further decision)	quick initial optional; expanded by authority decision
		Decision types: optional; collective; authority; contingent					
	Implementation Stage	iterative process & decisions; CCPM impact initially unclear	iterative process; lengthy start & near failure; tactical success strategic failure	iterative, flawed implementation; continued eval despite mixed success	rejected after planning only	iterative process; proved multi-project version of innovation	iterative process developed "jump start" approach & multi-site application

Table 17. Extracts of case-study summaries for CCPM CHIP model analysis.

<u>FINDING</u>: INTERNAL PERCEPTION OF A PROBLEM AT IMPLEMENTING IPT-LEVEL MUST BE PRESENT BEFORE PROCEEDING WITH A CCPM IMPLEMENTATION.

Concerning the *initiation stage* of the innovation process, Table 17 shows the common characteristic across all applications that the CCPM process was identified as the potential solution to the problem from outside the implementing IPT. This was due to the nature of the tasking from the SPO Technical Director and LM Aero Integrator to the change agents to find suitable venues and funding to demonstrate CCPM. The organizations that showed interest, were aware of their problem, but, being conservative by nature (Robbins, 1998), had generally not been actively looking for solutions. However, once the CCPM innovation was offered via a persuasive “buy-in” presentation from the external change agents *and* accompanied by valuable, active technical and funding support from the F/A-22 Program leadership level, all Operational-level implementing IPTs were almost immediately convinced CCPM could work.

The exception in this area was, again, the CTF Flight Operations managers. Despite agreeing with (or at least not rejecting) trade study results that CCPM *could* work, they remained skeptical that it *would* work in the flight operations area.

Whether agreeing or disagreeing with the applicability of CCPM, case study evidence shows that IPT views were not based on the kind of in-depth discussions called *matching*—the examination of the CCPM innovation in light of the problem at hand. Even for those that willingly proceeded beyond initiation based on the conceptual strength of the innovation, discussions could have converged on existing or new forms of the CCPM innovation that would have provided a more solid foundation on which to base the implementation stage. It is even conceivable that discussions could have defused the Flight Operations managers’ doubts about the applicability of CCPM.

FINDING: BEYOND NECESSARY LEADERSHIP-LEVEL SCREENING AND FUNDING SUPPORT OF CCPM DEMONSTRATION PROJECTS, INITIATION AT THE IMPLEMENTING IPT LEVEL MUST INCLUDE IN-DEPTH “MATCHING” DISCUSSIONS WITH IPTs TO SUPPORT INNOVATION DECISIONS AND LATER REINVENTION OF CCPM FOR THE SPECIFIC APPLICATION.

Regarding the *innovation decision*, as the dark border around all entries in Table 17 implies, all the case studies were different, suggesting that there were no commonalities. In fact, analysis across all the case studies makes it clear that despite differences, there were also primary and secondary common threads. Primary was that in the F/A-22 IPT organizational structure there were a number of decisions on use of CCPM rather than just one or two involving implementation. Also, after a ”go” innovation made by the Operational-level IPT leader, an authority decision from the Program level can still halt the use of CCPM, as happened in the manufacturing finishes process area at Marietta.[154] The secondary common thread was that several of the initial innovation decisions were “quick”, perhaps even premature, since they were not based on an in-depth examination of the appropriate form of the innovation. The only ones who could have (but did not) slow the pace of decision were the external change agents.

FINDING: THE INNOVATION DECISION ON USE OF CCPM IN THE IPT ENVIRONMENT MUST BE AN OPTIONAL ONE BY THE OPERATONAL-LEVEL IPT LEADER, AND BASED ON A GOOD APPRECIATION OF REQUIRED REINVENTION.

FINDING: MULTIPLE INNOVATION DECISIONS WILL OCCUR. CONSTANT REVIEW OF CCPM CONCEPTS AND PROGRESS IN AND OUT OF THE IMPLEMENTNG IPT WILL ASSURE THE BEST INFORMATION IS AVAILABLE FOR DECISION-MAKERS.

The *implementation stage* of each CCPM application, as the longest and most variable stage across the case studies, gives rise to the numerous findings. In Table 17, because the case studies were all different, they are all highlighted by the bold border. Certainly on one level, the point that the CCPM innovation cannot be applied with a “cookie cutter”, “one-size-fits-all” approach is important and must be recognized by acquisition programs interested in using the CCPM innovation in different parts of its

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[154] Unfortunately, no effort was mounted to continually reinforce the CCPM concepts and Finishes IPT success in other manufacturing operations areas at Marietta. It is possible that had that been done, the CCPM innovation would have seen expanded use instead of termination.

program. Beyond that main point, there are several generically common elements of the implementations, with specifics that varied as a function the operational context.

With the exception of the LT&E and CIP-2K cases, the first common element resulting from the compressed initiation stage and quick decision is that all implementations started and developed the CCPM project networks and frameworks as a classic, single-project. From that common beginning, all followed a sometimes rocky, iterative process to converge on a “reinvented” form of the innovation, especially the first four implementations (the first four columns in Table 17). The least “rocky” was the assembly process implementation at Boeing, and only because of the inability to “prove” CCPM’s value did the form almost naturally evolve and improve to final success and institutionalization. Change agents facilitating the Finishes IPT innovation fell prey to the lure of proving CCPM on a large project without making sure that the CCPM form and level of detail was right; failure was averted only when iteration led to an executable form of the CCPM solution. The Maintenance Mods implementation was more repetitive than iterative, and its problems need no reemphasis here. Even the Flight Operations applications followed an iterative path, from huge “mega-project” for the entire program to a still-too-large second version which was promising, but not enough to forestall termination. In all cases, though not shown on Table 17, there was wide variation in the timing and depth of the software training, but case study evidence showed early training was best. These common characteristics lead to several findings:

FINDING: “COOKIE-CUTTER”/ONE-SIZE-FITS-ALL INITIATION MUST BE AVOIDED WITH CAREFUL TAILORING/REINVENTING OF CCPM FOR THE ENVIRONMENT.

FINDING: STARTING WITH SMALLER PROJECTS WILL GREATLY ASSIST IN ESTABLISHMENT OF USEFUL TEMPLATES, THE PROPER LEVEL OF DETAIL, AND GENERATION OF QUICK SUCCESS.

<u>FINDING</u>: EARLY CCPM SOFTWARE TRAINING WILL ACCELERATE SCHEDULE DEVELOPMENT AND INDEPENDENCE OF IMPLEMENTING TEAM FROM EXTERNAL HELP.

The most striking exception to the general practice of starting and iterating the classic single-project approach to CCPM implementation into a more useable form was the development of the multi-project/dynamic execution approach created to meet the specific needs of the LT&E application. In fact, the development of this approach actually occurred last in the flow of the implementations and complied with every one of the findings outlined above. Besides proof of its effectiveness in direct comparison to another version of CCPM and traditional methods, this reinvented form of CCPM appeared to have the potential to handle the extreme variability affecting the other CTF areas. Knowledge and application of the “multi-project/dynamic execution” form of CCPM might have overcome objections of the Flight Test Managers because it encompasses elements of the “rolling wave” approach that the CTF commander indicated a willingness to implement at one point. By the same token, the multi-project/dynamic execution form of CCPM seemed like an approach for overcoming a number of the major problems encountered and never resolved in the Maintenance Mod area: inability to deal with unexpected changes in the sequence of planned work; the addition of unexpected, unavoidable new work; updates that assured accurate buffer status as a basis for buffer management actions; etc.

Fortunately, though the opportunity to evaluate this approach in flight operations never emerged, the opportunity to test the analytic speculation that the multi-project/dynamic execution methodology would work for modifications did occur when an F/A-22 Modification Center, quickly nicknamed “Speedline” was established in the spring of 2004. The Speedline’s objective was to add modifications (identified by flight testing results as needed) to the airplanes as soon as full aircraft assembly was complete and before addition of full aircraft finishes.[155] At that time, with the concurrence of the Speedline senior manager and the floor manager, the author, the Critical Chain-trained and experienced master scheduler reassigned from the finishes IPT and the LT&E planner/CCPM lead who originated the methodology became a mini-implementation team that developed an approach that was reviewed and approved by the floor manager for implementation in the Speedline area. Though a ponderous recapitulation of the adaptation of the multi-project/dynamic execution process is not appropriate, a thumbnail description of the implementation and results is useful.

Essentially, depending on the aircraft serial number, each F/A-22 entering modifications had an identified series of required modifications, from 10 to 25 per aircraft. The CCPM mini-implementation team used the installation procedures from engineering to develop a detailed single "project" for each of the modifications, including estimated durations and resources. Then the modification projects were combined into a "portfolio" for each aircraft and synchronized with other standardized pre- and post-mod projects. With the help of the floor manager, the projects were prioritized, resources and durations refined and the portfolio re-synchronized and finalized. The necessary mod span for each aircraft plan was the result of this process and provided to the Speedline senior manager for integration with other post-assembly processes.

The plan was implemented with discipline, and quickly smoothed to daily updates and reviews of only those projects in each portfolio on which work had started. The practice of treating each modification as a separate project within a portfolio completely eliminated the kind of contentious, two- to four-hour weekly update sessions experienced during the CTF Maintenance Mod team's use of "mega-projects." Projects

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[155] The necessary modifications could not be added during assembly because in many cases the need for the modification was identified after assembly began. Rigorous engineering design and some fabrication was required to develop installation procedural instructions and "kits" of parts. In many cases, the modifications were originally planned for installation after delivery of aircraft to the field, but the F/A-22 leadership team concluded that by using the Speedline approach before final finishes were applied, one cycle of finishes removal and restoration could be avoided.

were occasionally resynchronized to assure that they would “fit” in the originally projected span, and actions were taken when required. Executions of multi-project portfolios for up to six aircraft at a time were able to absorb a number of sources of variability, whether parts, kits, or personnel. In fact, the Speedline group was often able to make up for occasional discrepancies and delays in delivery of the aircraft to be modified. The process proceeded so well that the daily telecons with the SPO were quickly reduced to one each week, usually punctuated at the end by a SPO comment that “you guys are really smokin’ on these mods” (personal communication, March, 2004). At the bottom line, the results verified the predicted potential (beyond LT&E) of the multi-project/dynamic execution methodology.

FINDING: VERIFICATION OF THE ABILITY TO ADAPT THE MULTI-PROJECT/ DYNAMIC-EXECUTION CCPM METHODOLOGY TO THE MODIFICATION ENVIRONMENT SUGGESTS POTENTIAL FOR EXTENTION TO OTHER AREAS.

The other substantial modification of the CCPM single-project methodology was the creation of the Jump-Start approach for the supplier CIP-2K module development, designed to avoid the frustration with excessive delays in the Finishes and CTF implementations between an innovation-decision and development of a schedule ready for execution. Though employment of the approach and the integration of results of the separate Jump-Starts at several supplier locations involved some months (because of geography and other program demands), the relative stability of the resulting plan during execution of the CIP-2K project speaks well for the approach.

An unexpected revelation that evolved from the CIP-2K project was value as a superb communications device during execution associated with the schedule generated by the Jump-Start process. Once the intra-supplier hand-offs became the focus of the CCPM execution and update process, all players focused on the schedule and aggressively took short-term actions to protect the project end date.

All these benefits of the CIP-2K reinvention of the CCPM innovation prompted the search for opportunities to verify the analytic conclusion that, like the multi-project/dynamic application methodology, the Jump-Start process could applied to other environments. In the winter of 2002-2003, because of interest Pennington generated by promoting the success of CCPM use in the CIP-2K program, he was able to gain support from the Air Force Aeronautical Systems Center at Wright Patterson Air Force Base, Dayton, OH, for a small Industrial Base research project. The objective was to build on the single-project CIP-2K form by developing and demonstrating a multi-project version of the Jump-Start process that could be used across any acquisition program's supplier base. As with the follow-on multi-project/dynamic execution demonstration, only a thumbnail description of the implementation and results is needed for present purposes.

Essentially, the F/A-22 Controls and Displays (C&D) IPT within the Avionics IPT gained agreement from one of its suppliers to employ and evaluate a generic multi-project version of the Jump-Start. The specific development project to be supported was a Diminishing Manufacturing Sources problem with the development and integration of computer chips in a unit called the Data-transfer Mass-memory and Video Recorder (DMVR) used on the F/A-22.   To assist in the formalization of the process, the services of an external CCPM-knowledgeable and experienced technical support contractor (TSC) were procured. The TSC was given a specific outline of the Jump-Start process and tasked to provide the formal "Day-1" training and facilitate the rest of the process, including the addition of the multi-project component. The services of the Sciforma® Corporation were also procured for software training immediately following the Day-1 CCPM concept training.   The Jump-Start process was initiated in early 2003 and implementation proceeded as normal. Besides "working" by leading to a multi-project plan that was implemented and tracked as effectively as the single-project plan in the CIP-2K application of CCPM, there was another substantial, unexpected benefit.

The CCPM plan created proved that if the original plan developed by traditional methods[156] had been put under contract it would have almost certainly failed. By adopting the CCPM plan with a more feasible, but later, delivery date, the C&D IPT was able to buy sufficient chips to meet interim needs and avoid the significant costs that would have been incurred to restart the old manufacturing line when the original plan failed.[157] Once the Jump-Start plan was implemented, tracking and buffer management supported such excellent performance and clear communication of status by Smiths Industry that what had been daily telecons using traditional schedule management tools quickly became once/week telecons, and then, by the third month of the two-year project, only weekly e-mail updates.[158]

FINDING: PERFORMANCE OF THE SINGLE AND MULTI-PROJECT JUMP-START APPROACH DEMONSTRATES ITS UTILITY AS A GENERAL AND USEFUL APPROACH FOR IMPLEMENTING THE CCPM INNOVATION.

FINDING: MULTI-COMPANY SUPPLIER IMPLEMENTATIONS SUGGEST THAT A PROPERLY STRUCTURED ALL-PLAYER CCPM SCHEDULE UPDATE PROCESS ASSURES CLEAR COMMUNICATION THAT PROMPTS GOAL-SEEKING ACTIONS.

The other variable across the implementations was the degree of conformance to CCPM execution protocols, i.e., avoiding multi-tasking with the “relay-runner” approach, following the precedence work order, frequently updating, and using buffer management. Those that shared reasonably good compliance in common—Assembly and Finishes operations, LT&E and CIP-2K—performed well to the CCPM schedule; the one exception, Maintenance Mods, did very poorly. This too leads to an important finding:

FINDING: THE ESTABLISHMENT OF A DISCIPLINED EXECUTION EMPLOYING THE RELAY-RUNNER APPROACH, PRECEDENT WORK ORDER EFFORTS,

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[156] Microsoft Project software and its embedded Critical Path Method.

[157] The”old chip” manufacturing line shutdown had already been projected; re-start costs would have been incurred if inability to make the unrealistic goal occurred after shutdown. (Acquisition program experience showed the cost to re-start a manufacturing line for an old chip was in excess of $1 million.)

[158] The implementation was so successful that the supplier’s DMVR project engineer was asked to provide a presentation at an annual conference of Theory of Constraints practitioners.

FREQUENT UPDATES AND BUFFER MANAGEMENT IS IMPORTANT TO ESTABLISH AS SOON AS THE FIRST CCPM SCHEDULE BEGINS EXECUTION.

One global benefit of top-level analysis not reflected in Table 17 is recognition that the change team violated its own “preaching” of the CCPM caution to carefully stagger multiple projects to avoid overloading resources. As a member/leader of the change team, the author can assert that once given the “green light” from the initiation process at F/A-22 Team Leadership level, the change team never considered the multi-project perspective. Instead, the group shared almost missionary “pro-innovation bias” and zeal to apply CCPM wherever it might work as soon as any IPT would “sign up”. We simply pressed aggressively with the initiation of CCPM use in the first four very substantial, different, complex, and heavily overlapping implementations in Finishes, CTF/Maintenance Mods, CTF/Flight Sciences, and CTF/Mission Avionics, all in a concentrated three-month period in early 2001.

With Pennington pre-occupied with other SPO business as well as coordinating on-going contractual support for the CTF implementation, and Casey and Colby consumed with the work of finalizing the Finishes IPT CCPM processes and particularly the schedule for the first full aircraft, the change team was spread too thin to assist with the vitally important applications at the CTF.[159] Partially as a result, the Maintenance Mods implementation was initiated without ever establishing necessary execution discipline. Similarly, the critical, initial Flight Operations efforts depended wholly on external change agents for support; the LM Aero change agents were not available to either assist in the development of initial networks and plans or to ease the administrative burden on the CTF imposed by escorting of the external TSC facilitators.

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[159] To underscore the multi-tasking issue even further, both Casey and Colby had other responsibilities to the Program besides those of change agents/champions. Casey was lead for coordination of a process to establish the readiness of the first “avionics test aircraft” (4004) for its maiden flight, and Colby had broad and demanding master scheduling responsibilities in support of the Avionics IPT.

FINDING: CAREFULLY PLANNED STAGGERING OF CCPM IMPLEMENTATION PROJECTS WILL ASSURE THAT ADEQUATE CHANGE AGENT SUPPORT IS AVAILABLE AND PERMIT LESSONS LEARNED TO BENEFIT SUCCESSIVE IMPLEMENTATIONS.

The Academic Perspective – Insights Related to Organizational Innovation

In this section, analysis is focused on the potential contribution to process theories of organizational innovation literature that might be mined from the considerable evidence looking across the case studies using the CHIP model. To assist this effort, the Table 17 summary of more specific analytic evidence has been transformed into Table 18. The “location” and “implementing IPT” are not relevant because the analysis seeks to look across the case studies independent of these factors. Information in the primary elements of the CHIP model have been added for Program and CTF leadership levels because the units of analysis were heavily impacted by activities and decisions at that level. In addition, the units of analysis have been reordered slightly to allow highlighting of some of the analytic points regarding commonalities and differences.

<table>
<tr><th colspan="2">Unit of Analysis</th><th>Program Leadership</th><th>Assembly Operations</th><th>Manufacturing Process</th><th>Supplier computer development</th><th>Test Ops Leadership Level</th><th>Test Ops Maint. Mods</th><th>Flight Test Operations</th><th>Test Ops LT&E</th></tr>
<tr><td rowspan="7">Ambidextrous Theory Elements</td><td rowspan="3">Motivation (perceived performance gap/crisis)</td><td colspan="5">yes →</td><td colspan="3"></td></tr>
<tr><td rowspan="2"></td><td>yes</td><td>yes</td><td>yes</td><td colspan="3">conditional yes →</td><td>▨</td></tr>
<tr><td colspan="2"></td><td></td><td></td><td>yes</td><td>no</td><td>"yes"</td></tr>
<tr><td>Initiation Stage</td><td>distinct phases</td><td>compressed</td><td>compressed</td><td>compressed</td><td colspan="3">participated in external process</td><td>compressed</td></tr>
<tr><td>Innovation Decision(s)</td><td>N/A</td><td>multiple</td><td>multiple</td><td>multiple</td><td>multiple</td><td>single</td><td>multiple</td><td>single</td></tr>
<tr><td>Implementation Stage</td><td>N/A</td><td>iterative</td><td>iterative</td><td>iterative</td><td>iterative</td><td>iterative</td><td>iterative</td><td>iterative</td></tr>
<tr><td>Key Personnel</td><td>yes</td><td>yes</td><td>yes</td><td>yes</td><td>yes/no</td><td>yes</td><td>no</td><td>yes</td></tr>
</table>

Table 18. Extracts of case-study summaries for CHIP model analysis.

As to the *motivation for innovation,* the performance gap, shock, or crisis that organizational innovation theory consistently agrees are the nearly essential catalyst for innovation (Rogers, 2003; Van de Ven and Poole, 2000, 1989; Zaltman et al, 1973) were commonly observed in every one of the multiple-case studies. The literature goes on to discuss the possible sources of these kinds of catalysts (Zaltman et al, 1973;

Gopalakrishnan and Bierly, 2001; Rogers 2003) with the inference that recognition of the problems is typically black and white; it is either there to be dealt with or not. What the Table 18 highlights in this area is that agreement that a problem exists can vary vertically and horizontally across the units of a large, complex organization such as represented by the F/A-22 IPT structure. By definition, the "problem" had a different nature specific to the context and responsibilities of the unit of analysis. Finally, Table 18 shows that Program-level perceptions do not automatically generate agreement at Operational levels. Test Operations leaderships' "conditional yes" reflects recognition of the problem, though external to their making or responsibility to fix. Even there, the upper Program-level view did not necessarily drive agreement at the lower levels.

FINDING: IN THE IPT ENVIRONMENT, IMPLEMENTING IPT PERCEPTION OF A CATALYST FOR INNOVATION IS ESSENTIAL AND WILL NOT (NECESSARILY) BE CONGRUENT WITH OR DRIVEN BY PROGRAM-LEVEL PERCEPTIONS.

The *initiation stage* of the organizational innovation process encompassed by the CHIP model suggests a fairly substantial process of "agenda-setting" and "matching" leading to the innovation decision to implement the innovation. Analysis of evidence from the case studies concludes that in the multi-tiered IPT structure, the substantial process in terms of distinct phases may only take place at the Program level as documented in Chapter 5 (addressed further under the *structural levels* construct.) This can lead to a very compressed initiation phase for all units of analysis (e.g., a briefing and limited discussions)[160] and potentially ill-informed innovation decisions. The finding in the preceding section, regarding the need for a substantial "matching" phase for the CCPM innovation at the Operational IPT level appears to have general application.

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[160] Chronologically, the Boeing application preceded and was not affected by the Program-level initiation process. Boeing's compressed initiation process was prompted by the prior experience and authority of the Lean Improvement Team leader. "Participated in external process" for Test Ops Leaderhip Level to acknowledge that a trade study was accomplished as part of a matching phase. However, the trade study's failure to support then-current Test Ops practices or reveal a "poison pill" to support rejection of CCPM was nearly more important than the evidence of the strengths of the CCPM innovation.

FINDING: WITHOUT A SPECIFIC MATCHING PROCESS, THE INITIATION PROCESS BECOMES COMPRESSED AND MAY LEAD TO A PRE-MATURE DECISION ON ADOPTION OF AN INNOVATION.

The case study evidence reinforces the importance of the *innovation decision* element of the CHIP model as a line of demarcation between the initiation and implementation stages. Results across the cases consistently show that of the decision types described by Rogers and included by reference in the CHIP model, only the "optional" decision to implement by the individual responsible for the unit of analysis can lead to a successful and/or sustained implementation. As it happened, the use of authority decisions external to the unit of analysis became counter-productive, whether forcing (Flight Operations) or terminating (Finishes) innovation implementations. Rogers' did not include a type of decision that was quite important for the F/A-22 implementation, the "gating' decision at the Program level that essentially screened the CCPM innovation before IPTs were allowed/encouraged to consider its use. (New/revised decision types are included in proposed revisions of the CHIP model at the end of this section.)

FINDING: IN AN IPT ORGANIZATIONAL STRUCTURE, OPTIONAL INNOVATION DECISIONS BY THE IMPLEMENTING IPT APPEAR ESSENTIAL TO SUPPORT SUCCESSFUL, SUSTAINED IMPLEMENTATION OF INNOVATION.

While generating several findings regarding the CCPM innovation itself, analysis of the *implementation stage* across case studies from an organizational innovation prospective provides at least one very solid contribution to the CHIP model. Reinforcing existing literature establishing the central importance of reinvention to innovation success, the insight gained here relates to the nature and duration of reinvention. A point emphasized regarding the CCPM innovation is strong and consistent enough across the cases to suggest they apply generally to other innovations. What analysis of the empirical case study evidence suggests is that in a complex development program, reinvention will likely be an iterative process of extended duration. In the widely varying contexts of an acquisition program, this span can range from 5-20 months before the process is fully stable and institutionalized.

Other evidence from case studies reinforces the need to accomplish the reinvention in a way that preserves the central precepts of the innovation in order to maximize the benefits of the innovation in response to the original catalyst for innovation. Though logical enough on its face to require no emphasis, the Maintenance Mods reinvention of the CCPM process disregarded several of the "central precepts" and suffered marginal results (at best).

<u>FINDING</u>: THE REINVENTION PROCESS WILL BE REQUIRED TO ADAPT THE INNOVATION TO THE SPECIFIC IPT CONTEXT, MUST RETAIN CENTRAL PRECEPTS OF THE INNOVATION AND SHOULD BE EXPECTED TO BE ITERATIVE AND (POTENTIALLY) LENGTHY IN A COMPLEX ENVIRONMENT.

Based on the foregoing discussion, three modifications of the CHIP model for possible later use seem in order. The first two are visible in the revision of the model graphic in Figure 51. Most visible are the arrows intended to reflect the experience of

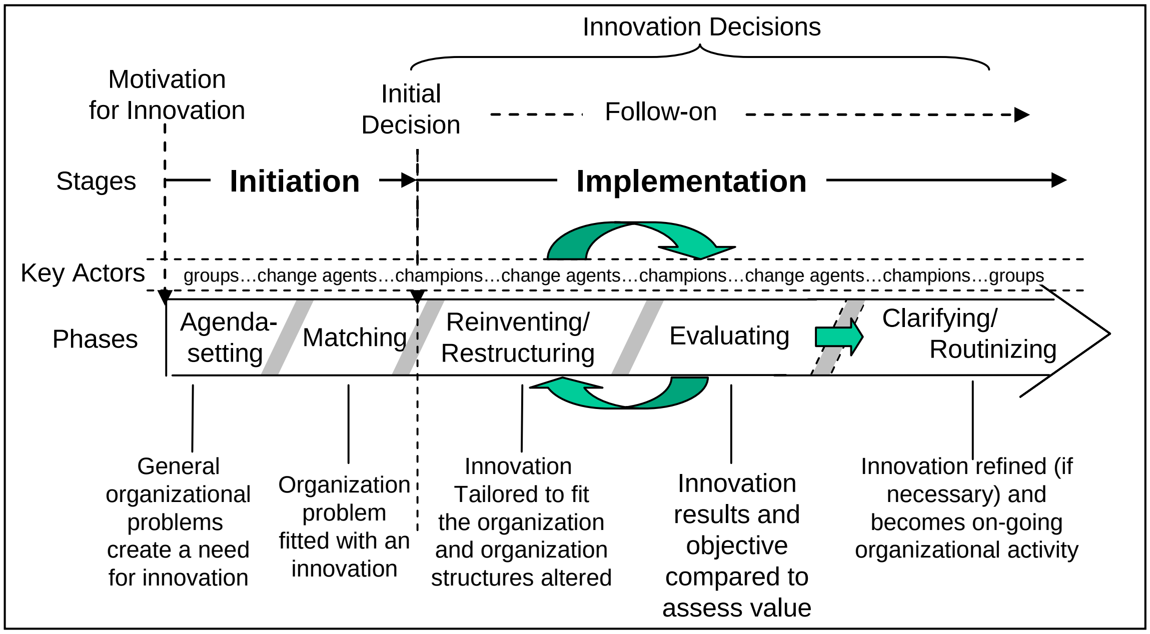

Figure 51. Revised Casey Hybrid Innovation Model (CHIP).

of this multiple-case study to underscore the expectation that in a complex, dynamic, multi-team, multi-company, multi-tiered organization, several iterations may be required to establish an innovation, as noted above in the general finding. The other change is made more tentatively, but included nevertheless. That is the combining of clarifying/routinizing as a single phase, much like reinventing/ restructuring. Though it is possible that the case studies here did not precipitate clear or clearly distinguishable clarifying and routinizing phases, the compression into one phase is based on the expectation that the iterations to generate an acceptable reinvented form of an innovation will make clarifying and routinizing transparent for the using team.

The other change in the CHIP model has to do with the types of decision. As noted in the discussion above, the decision types described by Rogers and included by reference in the CHIP model are not completely satisfactory and lead to the suggestion for refinements below. In the revised CHIP model, there are still three primary types, but their definitions differ as follows:

1. Operational innovation-decisions – choices to adopt or reject by the IPT leader at the Operational level responsible for the product, based on multiple inputs and his/her experience after assessing the potential of the innovation to meet the IPT's needs.
2. Authority innovation-decisions – choices to adopt or reject that are made by a relatively few individuals in a system who possess power, status or technical expertise. An authority-innovation decision is one with which the organization's employees must comply unless the Operational-level IPT leader can show cause to justify overriding the authority decision.
3. Gating innovation decision – Choices by individuals at the Program level (i.e., above the implementing IPT at the Operational level) to permit or to deny further consideration of implementation.

In the CHIP model, “Operational” replaces the similar “optional” term in the first decision type for three reasons: (1) it is consistent with the earlier description of the Program/Operational *structural levels* construct, (2) the IPT organizational policy vests the Operational-level IPT leader with the authority and responsibility to make the decision to implement the innovation, and (3) it is not “independent of other members” (as included in the “optional decision” definition by Rogers.). In the information-rich environment of an acquisition program, the Operational-level IPT leader will have many inputs from many sources that will affect his innovation decision.

The “authority” decision remains, but with the important caveat that compliance is not mandatory and subject to reclama if the directed IPT can show why the innovation should not be implemented in a particular Operational-level area.

Obviously new among this list of decision types is the “gating” decision, derived from the description and analysis of the Program-level initiation process. At that level extensive efforts lead not to a go/no-go innovation decision, but rather confirmation that the innovation has potential for utility in some areas of the acquisition program.

Clearly, these changes to the CHIP model are derived from the specialized arena of a DOD acquisition program. However, the increasing prevalence of distributed, multi-level, multi-organizational teams (O’Sullivan, 2003; Evaristo et al, 2004), suggests that the CHIP model expectations may apply elsewhere when policy allocates responsibility and authority for process decisions to the implementing team at the Operational level.

Analysis from the Perspective the Structural Level and Actors Construct

As noted in Chapter 2, based on the “dual-core” and other bimodal theories of organizational innovation, the *structural levels* construct postulated two organizational levels—Program and Operational—associated with the process-type innovation represented by CCPM. Such innovations are concerned with structure and management kinds of issues and are promulgated top-down in the organization with the intention of providing management support of the primary organizational work. Table 19 summarizes the case study analyses as the basis for insights from both practical and academic perspectives, with the cases ordered chronologically for ease of discussion.

The Practical Perspective – Insights Related to Structural Levels and Actors

Responsible Lead	Location	Implementing IPT Unit of Analysis	Case Study Observations on the Structural Levels Construct	Case Study Observations on Innovation Actors
Boeing	Seattle WA	Assembly Operations	Top-down Program-level initiation & support for Operational-level implementation	group actors @ initiation; external champions & change agents throughout
Program (Administrative Core) Level			Top-down initiation, encouragement and implementation support across all applications	many internal & external group actors; Program champions & change agents emerge
LM Aero	Marietta, GA	Finishes Ops	Top-Down Program-level initiation & support for Operational-level implementation	groups played minor role; internal champions; both internal & external change agents
Combined Test Force	Edwards AFB, CA	Test Operations	USAF Tiger Team affects CTF Program level initiation & decision; Many differences at Operational level	Top team & Quasi-CTF Program champions; anti-champion in Flt Ops; ext chg agents across all; internal chg agents in Mods & LT&E
LM Aero Suppliers	Multiple	CIP-2K module development	Top-down process w/ Program level initiation & support; comprehensive, sustained Operational-level implementation	groups played minor role; external champion; both int. & external change agents

Table 19. Case study summary extracts related to structural levels and actors.

When observations about the *structural level* construct are displayed together in Table 19, the consistency regarding the involvement of the Program in initiation is unlike any found in this research project. Arguably, all of the applications of CCPM were initiated and supported “top-down”,[161] consistent with the *structural* construct. For those initiatives after Boeing (which itself was top-down), there were many common elements demonstrating that the CCPM innovation was legitimately top-down, originating from the Program level. Perhaps the most important element was conduct of a complete initiation stage. This stage initially included: recognition of the schedule performance gap (or incipient crisis) in several program areas, identification and full screening of the CCPM innovation by Program-level personnel to support better schedule planning and

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[161] The “argument” might be that since the LM Aero prime or Boeing top management did not specify or CCPM as part of its pressure to improve performance to commitments, characterizing the initiative as “top-down” is inappropriate. However, the initiative leading to the use of CCPM certainly was a result of that pressure and the Lean Improvement Team leader who initiated and sustained use of CCPM was without question top management’s “man on the scene.”

execution, and assumption of responsibility for the innovation as Program-level champions. Essentially from then on, the CCPM innovation was a solution looking for a chance to demonstrate value in a specific problem, just as postulated by Rogers (p. 423, 2003). Given CCPM as an attractive solution, Program leadership established the change agents, directed or supported funding and contractual actions to relieve interested IPTs from that burden, supported the fact-finding trip to Seattle, and supported the search for demonstration venues. Per team IPT policy, the innovation was generally not directed or forced,[162] with the obvious exception of the CFT at Edwards AFB.[163] Once an Operational-level IPT made the decision to use CCPM, the Program re-engaged to fully support the implementation with funding, support from the technical and training services contractor and software training support from Sciforma®.

Given the introduction to the innovation by Program-level representatives, the Operational IPTs took over and were responsible for the implementation stage, including involvement in any reinvention/restructuring, execution of the CCPM plan, provision of data for evaluation and any clarifying or routinizing that the situation required. All of these activities are totally consistent with the *structural level* construct.

FINDING: THE F/A-22 INTEGRATED TEAM APPLICATION OF THE CCPM INNOVATION WAS CONSISTENT WITH THE PROGRAM AND OPERATIONAL COMPONENTS OF THE STRUCTURAL LEVELS CONSTRUCT FOR INNOVATION.

Moving from *implementation* to *key personnel,* Table 19 reflects the importance of the individuals largely responsible for the occurrence and extent of the success of the CCPM implementation. The constant in all of the applications was an internal change agent and/or champion within the implementing IPT. Certainly there were change

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[162] As POCAC, the author can verify that the F/A-22 Team Leadership did not “force” the CTF leadership to adopt CCPM; in fact, top Program-level leaders later supported the CTF’s later decision to reject CCPM.

[163] The other exception might be the CIP-2K application. However, in the context of the research interest in the incremental innovation, the Operational-level Core IPT did make the innovation decision to implement. The VP/GM authority decision from the Program level to expand application is somewhat unique to the prime supplier relationship. In fact, the suppliers could legally have demurred, but all agreed to use CCPM.

agents external to the implementing IPT, in the persons of the CCPM TSC external change agent and/or the LM Aero change agents. However, analogous to the F/A-22 team leadership role in the IPT structure of being able to encourage but not dictate use of CCPM, the external change agents could only help and facilitate the CCPM implementation. The implementing IPT had to take responsibility for “making it happen." In fact, personal observation suggests Schon’s 1963 adage (quoted in Rogers, p. 414, 2003) “The new idea either finds a champion or dies” should be modified to “The CCPM innovation either finds an internal change agent or dies.” Mere charisma (a primary attribute of a champion, according to Rogers), is insufficient. To assure the success of CCPM, case study evidence shows that someone who can grasp the concepts ***and*** the mechanistic levers of the methodology is required to use the software to develop, transform and track the project(s) and provide useful information for decisions to the IPT and technical leaders.

In that light, the CCPM experience would argue against the internal change agent role being necessarily singular or tied to a leadership position. Although the internal change agents emerged almost naturally—the scheduler in the Finishes IPT, the Maintenance Mod and LT&E planners at the CTF, the CIP-2K Integration/CCPM lead at Raytheon—it is important to find, encourage and mentor these change agents to enhance chances for CCPM success.

Emphasizing the importance of the change agent should not be taken to eliminate the importance of innovation champions, because they were vitally important across all F/A-22 program areas throughout the period encompassed by this research. Of particular importance at the Program level were the F/A-22 SPO Technical Director, and the LM Aero VP/GM and Program Integrator. Champions at the implementing IPT level, e.g., the Finishes IPT leaders and the CIP-2K Core IPT leader, are important because they can accelerate CCPM adoption and push for disciplined execution within the IPT. They also have a positive influence on their peers considering the use of CCPM (as happened during the visit by Marietta personnel to Boeing).

The exception to the foregoing common aspects of the case study key personnel analysis involved the CTF Flight Operations and LT&E implementations of the CCPM innovation. Interestingly, the outcome had the common characteristic of being driven by single individuals, each of whom had distinctly different objectives. The "anti-champion" CTF Mission Avionics manager was correctly convinced that the CCPM innovation (in the form offered) was a mismatch with his experience and the dynamics of flight operations environment. Since his and others' misgivings were not paid attention to, his view prevailed and the CCPM implementation—appropriately—died. With exactly the opposite outcome, the LT&E planner/CCPM lead single-handedly drove the entire innovation process to a very successful demonstration of CCPM's capability.

FINDING: WITH SUPPORT OF CCPM CHAMPIONS, IDENTIFICATION, EMPOWERMENT, ENCOURAGEMENT AND MENTORING OF AN INTERNAL CHANGE AGENT FOR CCPM IS CENTRAL TO SUCCESSFUL IMPLEMENTATION; ATTENTION MUST BE PAID TO ANTI-CHAMPIONS.

The Academic Perspective – Insights Related to Structural Levels and Actors

From the academic perspective, the multi-case study empirical evidence does contribute to the two-component structural theories of organizational innovation, here characterized as the *structural levels* construct.   The cross-case analysis in the preceding section is unequivocal regarding the consistency between the theory and the reality of Program-level initiation and support for the CCPM innovation.   However, as pointed out in the formulation of the *structural levels* construct, the F/A-22 organization (and likely any other acquisition development program) definitely does *not* conform to the "mechanistic organizational structure" expected in other, similar theories (the "dual-core" theory in particular). The necessity to change myriad aircraft parts within the F/A-

22 as dictated by testing, and to change or even invent innovative technologies qualifies the F/A-22 organization as organic in nature. Since the program has demonstrated exemplary success in instituting such changes, it appears that despite being a huge, complex, multi-organizational, multi-corporate and geographically dispersed organization, the F/A-22 program's IPT organization has the agility to use its organic structure to the kind of process innovations that CCPM represents.

<u>FINDING</u>: THE ORGANIC, ACQUISITION DEVELOPMENT PROGRAM IPT ORGANIZATIONAL STRUCTURE IS FULLY CAPABLE OF FACILITATING ADMINISTRATIVE INNOVATIONS FROM THE TOP-DOWN.

Case study evidence regarding *key personnel* reinforces the emphasis on *structural actors* in the research, including groups, champions and change agents. From the broader organizational innovation perspective, the contribution of the evidence adds the further caveat regarding “adopted’ innovations from outside the organization, [(i.e., not “generated” from inside (Damanpour and Gopalakrishnan, 1998)]. The analysis of the different applications of nominally the “same” innovation across different contexts of the “same” huge, complex development program organization make it clear that change agents external or internal to that organizations must be available as both facilitators and “innovation cops”. In the facilitator role, they help the implementing unit reinvent the innovation, they facilitate initial use, and they assist in the further reinvention likely required. However, to succeed in the complex dynamics of a huge organization it is important that they also act as “innovation cops” in all phases to insist that the innovation is not compromised to the point that it delivers less than promised. Change agents should also initiate a program to sustain the innovation at the unit level through accelerated mentoring of internal change agents, continuation training and frequent, informative status reports to higher management, including higher level champions. Such a sustainment program to preserve the innovation in what might be an exception to other “team standard practices” should also be the joint responsibility of the Program-level change agents and champions until the innovation becomes institutionalized.

FINDING: CHANGE AGENTS IN A LARGE IPT ORGANIZATION MUST (1) ASSUME THAT REINVENTION OF THE INNOVATION WILL DIFFER SIGNIFICANTLY ACROSS IMPLEMENTATIONS, AND (2) ASSURE THAT INTERNAL CHANGE AGENTS’ TRAINING AND REPORTING SUPPORT SUSTAINMENT OF THE INNOVATION.

Another conclusion regarding *structural levels* construct of organizational innovation is generalized from the finding that new applications of the innovations must be staggered. Though this finding was directly related to a violation of the specific scheduling innovation examined, this is clearly a lesson that applies generally. From the analytic perspective of a POCAC, it is clear that staggering is required to accommodate the certain need for more extended initiation-stage matching discussions as well as for appropriate reinvention and evaluation phases of any innovation’s implementation stage. Without such staggering, the lessons learned will either not be passed on or even be missed with resultant relearning, rejection or less than full benefits of the innovation. Establishment of the required staggering is clearly the responsibility of the Program level that sponsors the innovation process, not the Operational level.

Summary

This chapter integrated the key elements of the case studies to support a multi-case analysis from a top-level, global perspective centered on the construct validity of expected changes resulting from the CCPM innovation, as well as the examination of case study evidence from the theoretical perspectives of the CHIP model and the *structural levels and actors* construct of organizational innovation. The results of this broader analysis are the basis for the several sections of the next, concluding chapter.

Chapter 10 - DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Overview

This final chapter is organized into four sections. First, is a concise statement summarizing findings.   Answers to the research questions posed at the outset of the dissertation are provided in the second section. Given that the final research question asked "what can we learn from this study?" this second section translates key insights from the analysis in Chapter 9 into practical implementation guidelines and academic contributions to the organizational innovation literature. The third section discusses findings in relation to other studies, drawing on evidence from organizational literature supporting or contradicting the multi-case research findings and positioning findings vis-à-vis the broader literature. After brief comment on Study Limitations and the POCAC role, the final section presents conclusions and recommendations relating to substantive and scholarly implications of the research.

Summary Statement of Findings

Regarding the substantive objective of addressing the important gap between major weapon system development schedule planning objectives and execution performance, the research demonstrates that in key areas of the F/A-22 program, proper application of the innovative Critical Chain Project Management process can generate and achieve development schedules and do so better than traditional approaches. Results in manufacturing assembly and process areas represented substantial improvements over the past. Results in flight operations and maintenance mods demonstrated the penalties of improper reinvention or application of the CCPM innovation. Applications in Logistics Test and Evaluation and in a multi-supplier development project were not only successful, but generated new variants of the CCPM innovation in both form and substance.

Regarding the objective of contributing to the knowledge of organizational innovation, the research adds a substantial amount of empirical evidence on innovation in the somewhat unusual context of what was termed a VIM^{5}DO—virtual integrated multi-layer/ lateral/organizational/team/product development organization—in the DOD acquisition environment. In addition, the research was conducted from a unique variant of the participant-observer method, since the author was also change-agent and champion of the innovation and responsible for the breadth of cases. Research contributions to the knowledge of organizational innovation process in the Integrated Product Team context include development of the CHIP model, which includes many elements of Rogers' version of the "ambidextrous" theory of innovation, but incorporates expectations of a vitally important evaluation phase, potentially multiple iterations of an innovation and, likely, multiple decisions of newly-defined types better suited to the acquisition program context (and possibly, other VIM^{5}DO settings). Regarding the structural theories, the *structural levels—Program and Operational*—construct formulated to assist understanding and analysis seems especially well suited for the acquisition development environment. Results of the research directly support the *structural level* construct rejection of the commonly held expectation that a mechanistic structure is needed to facilitate an administrative innovation. In addition, the multi-case environment demonstrated the importance of, and the Program-level responsibility for, staggering innovation implementations.

Answers to Research Questions

Research Question Number One

How and where has CCPM permitted development and execution of more feasible or shorter schedules than traditional approaches for product/system development in general?

CCPM has proven to be a valuable source of more feasible and shorter schedules in many areas or product/system development. Mabin and Balderstone's review of nearly 10 years of published materials relating to the Theory of Constraints (of which CCPM is a subset), documented dramatic improvements in lead times, cycle times and due date performance over traditional approaches. A foremost educator and author, Larry Leach (2000), documented several commercial successes in industry such as reduction in a computer chip manufacturing plant construction time by a factor of 3, the reduction in aircraft maintenance cycle time by a factor of 6 and the reduction in project duration times by 25 percent. Information about CCPM applications in the DOD environment is limited, but impressive. A Marine Corp logistics center used CCPM to reduce repair times by 40-65% and costs by as much as 30%. (Srinivansan et al, 2004). In a DOD-sponsored development of an unmanned aerial vehicle urgently needed for combat operations in Afghanistan, CCPM supported system delivery in 55 percent of the time projected by traditional methods (Blair & McKenzie, 2004).

Reports typically attribute these and other successes to CCPM's explicit attention to resource and policy constraints and the need to deal with uncertainty and reduce negative behaviors in ways substantially different than traditional approaches (see Question 2). Reports also credit CCPM's greater success in achieving project goals than traditional approaches to the management approach that focuses on project goals with a unique approach to absorbing variability called buffer management.

Research Question Number Two

How is the CCPM approach to schedule planning and execution different than traditional approaches?

CCPM places overwhelming emphasis on achieving the *project goal* on time, expecting and accepting variability in task completion durations. The traditional CPM process emphasizes on-time task completion. Even though almost all tasks can be completed on time, many CPM projects still fail because of the few tasks not on time.

The CCPM emphasis on resources is reflected in the definition of the critical chain as the longest sequence of task and resource dependent activities. Because the primary traditional approach, CPM, defines the critical path as the longest sequence of task dependent events, accounting for constrained resources is difficult and the subject of extensive critiques and mitigation efforts (Moisuddin and Selim, 1997; Gemmill and Edwards, 1999; Bowers, 1995).

CCPM handles variability by recognizing that the difference between aggressive and highly probable estimates for task duration is safety. By developing the schedule based on the aggressive time, the schedule is stabilized and on-time completion of project goal is protected by using “safety” in feeder buffers and a project buffer to absorb variability and focus on the critical chain. In the traditional approaches, safety is embedded in each task and often wasted due to a variety of human behaviors inimical to project success (Leach, 2000; Kendall, 2003).

Critical chain execution process employs the “relay race” approach to task completion without multi-tasking, inhibits other negative behaviors by insisting on the discipline of following task precedent order, frequently updates the schedule and bases operational decisions on a concept of buffer management. Without the stability of the schedule provided by buffers and buffer metric, traditional approaches accept negative behaviors and must base decisions more on potentially misleading intuition than on data.

Research Question Number Three

Why was the CCPM innovation successful (or unsuccessful) in improving schedule planning or execution in the organizations of application on the F/A-22 program?

At a top level, the research concludes that the CCPM innovation was a success everywhere but CTF Flight Operations and Maintenance Mods, but the evidence is not unequivocal regarding the sources of success or failure.

As to the “whys” of success, they are likely not due to the long held idea that “a new technological idea enters a system from external sources and is then adopted with relatively little adaptation of the innovation” (Rogers, p. 181, 2003). Instead, case study analysis concludes that the common precursors of success at the implementing IPT level are recognition of a problem and perception that CCPM can work at the Operational level. Thereafter, success was a matter of discipline and perseverance/ ownership. Discipline was required to implement the concepts of the CCPM innovation outlined above in Research Question 2. Perseverance and progressive ownership of the process was required to pursue iteratively reinvented forms of the innovation.

Reinforcing this analysis of “why success?” are two generalizations from Rogers (2003), merged into one for our purposes here: “A higher degree of reinvention leads to faster adoption [and] a higher degree of sustainability of an innovation” (p. 183). Essentially, the more the implementing team reinvents the innovation, the more likely they are to take ownership of the process and responsibility for its success.

The “whys” of failure in Flight Operations and Maintenance Mods noted before can be characterized differently here. In the case of Flight Operations, in the absence of clear agreement on a problem, it is not unreasonable to characterize the source of failure as “lack of communication” or “too much communication” independent of the innovation itself. Both external change agents and potentially implementing managers were, in the vernacular of aviation, in the transmit mode with receivers turned off. The external change agents were promoting the universality of the single project form of CCPM, and the IPT managers were trying to convey the dynamic requirements that had to be addressed. Neither was listening to the other. The failure to listen and respond with appropriate CCPM reinvention on the part of the CCPM change agent/advocates left the “organization decision makers [convinced] that the innovation [was] mismatched with the problem [leading to] rejection…prior to the new idea’s implementation” (Rogers, p. 423, 2003). Even though training and planning proceeded to a semblance of implementation, the unavoidable analytic conclusion is that it was dead long before 9/11/2001 when the implementation in Flight Operations was finally terminated.

The “why” of the failure of the Maintenance Mod implementation was detailed in the implementation discussion of the previous section. In analytic retrospect, despite dogged perseverance and Herculean attempts, the failure to “make it work” *might* be attributed to the compromises of the methodology that were too severe to have a chance at success. In fact, the-story-behind-the-story is that failure was the result of insufficient oversight on the part of the external change agents to insist on correction of the flaws in the very first implementation, with the result that the absence of disciplined compliance with CCPM precepts was institutionalized and never corrected.

Research Question Number Four

As posed in Chapter One, research question number four was: **How can we learn from this study?** From the practical insights sections of Chapter 9, Table 20 displays these findings, including those related to key *actors* from the *structural levels and actors* construct, reformatted to directions or recommendations for future CCPM implementations. For the most part, the practical implementation guidelines derived from case study results reinforce well-accepted guidelines for the implementation of the CCPM innovation process. However, those in bold represent new insights derived from the research, specifically from the LT&E and the CIP-2K supplier development cases.

As to what we can learn about the organizational innovation process, or more specifically what this research contributes to knowledge in the stream of organizational literature, that also can be derived from the academic insights in Chapter 9.

Process element	Lessons learned for application
Motivation	• Ensure that Operational-level IPT decision-makers perceive a problem requiring solution before proceeding with a CCPM implementation.
Initiation Stage	• During initiation stage, include in-depth "matching" discussions with Operational-level IPT decision-makers to support the initial innovation decision and later reinvention of CCPM for the specific application.
Innovation Decision(s)	• The Operatonal-level IPT leader must make (and support) a well-informed, operational innovation decision for use of CCPM. • Expect/plan for multiple innovation decisions. • Constantly review (throughout implementation) CCPM concepts and progress in and out of the implementing IPT to assure decision-makers have the best information.
Implementation Stage	• Carefully work with Operational-level IPT members to tailor/reinvent CCPM innovation for the environment; "Cookie-cutter"/one-size-fits-all approach must be avoided. • Start with small projects to establish useful templates, proper level of detail, and generation of quick success. • Provide early CCPM software training to accelerate schedule development and IPT independence from external change agents. **• Adapt the multi-project / dynamic CCPM methodology for highly dynamic environments.** **• Employ the jump-start approach to expedite CCPM implementation.** **• Structure an all-player CCPM-update process to facilitate communications by focusing on key hand-offs and buffer management actions that emphasize on-time delivery.** • Establish/insist on disciplined execution process including the relay-runner approach, precedent work order efforts, frequent updates and buffer management. • Carefully stagger CCPM implementation projects to assure that adequate change agent support and permit lessons learned to benefit successive implementations.
Key Personnel	• CCPM champions must stay actively and visibly engaged in the process. • Identify, empower, encourage and mentor an internal CCPM change agent. • Listen to anti-champions.

Table 20. Practical Learning from the Study: Findings Translated to Actions.

In Table 21, the insights gained from the research that contributes to knowledge about the CHIP model are summarized and include observations regarding the *structural levels and actors* construct. For the most part, the findings extend the knowledge of innovation literature into the IPT organizations of the DOD acquisition development environment. They are written as if applicable to any weapons system acquisition program since the mandate to employ integrated product team structure remains in force; they may be applicable outside the DOD environment to government-industry teams or other teams that might be described by the VIM^{5}DO shorthand descriptor.

Elements of the CHIP Model	Lessons learned for application
Motivation	• In the IPT environment, implementing IPT perception of a catalyst for innovation is essential and will not (necessarily) be congruent with or driven by top team leadership perceptions
Initiation Stage	• Without a specific matching process, the initiation process becomes compressed and may lead to a pre-mature decision on adoption of an innovation.
Innovation Decision(s)	• In the weapons system or other multi-team development programs, a better set of decision types includes *Operational, Authority,* and *Gating* • In an IPT organizational structure, *Operational-level* innovation decisions by the implementing IPT appear essential to support successful, sustained implementation of innovation.
Implementation Stage	• The reinvention process will be required to adapt the innovation to the specific IPT context, must retain central precepts of the innovation, and should be expected to be iterative and (potentially) lengthy in a complex environment.

Elements of the Structural Levels and Actors Construct	Lessons learned for application
Structural Levels	• The structural names and characteristics associated with *Program* and *Operational levels* appears to be part of a very robust construct for examination and analysis of innovations in weapons system or other multi-team development programs
Structural Actors	• Program-level change agents in a large IPT organization must: (1) assume that reinvention of the innovation will differ significantly across implementations (2) assure that Operational-level change agents receive training, support and widely report on-going progress of the innovation.

Table 21. CHIP model and *structural levels and actors* construct contributions.

The other contributions to the knowledge in the stream of organizational innovation literature both extend and modify the CHIP model *structural levels and actors* construct as they relates to the IPT organizational structure mandated by DOD for use on weapon system acquisition development program. These findings are:

- In an IPT environment, the Program- and Operational-level construct establishes reasonable expectations for application of incremental, process-type innovations.
- The organic, acquisition development program IPT organizational structure is fully capable of facilitating process innovations from the top-down.

Overall Research Question

How and why does the Critical Chain Project Management process improve schedule planning and execution over traditional approaches in various areas of the F/A-22 program?

“How” the CCPM process was successful in improving schedule planning and execution where applied on the F/A-22 program can be answered from a methodological perspective. The key characteristics are not discussed here, since they have already been captured in the answer to Research Question 2, above. Essentially, the differences in the characteristics of the primary traditional approach, CPM, and those of CCPM lead to impacts that permit CCPM to generate improved performance. That’s “how”.

The “why” of the improvements documented in previous sections depend largely on the flexibility in implementation across all the applications. Though, as noted earlier, the “standard” or “classic” single- multi-project form of the CCPM innovation was always tried first, in every successful application, the form of the CCPM process had to be “reinvented” before success was possible. The contrasts between successful applications and both Maintenance Mod and Flight Operations require no further comment.

The other conclusion regarding “why” CCPM generated improved schedule planning and execution is the importance of the people involved, a fact that is consistent with the extensive discussion of change agents and champions in Rogers (2003).

As a last point, it should be noted that the original hope and expectation of the research project was that the implementation of CCPM would lead to reduced cycle time. However, the more practical and achievable objective that emerged when the overall research question was posed is that schedules be achievable. Essentially, the quantitative and qualitative evidence derived from the multiple cases demonstrates that when CCPM was properly reinvented, this measure of success was satisfied with IPT-level schedules that remained fairly stable and could be executed to completion on time. Said another way, the proven capability to reliably plan schedules and execute them such that the product or process delivery goals were met makes the CCPM innovation very attractive in comparison to methods previously used. In the context of the substantive vision of the research, to help reduce acquisition cycle time, results suggest that the vision can be served by first arresting schedule overruns at the IPT level.

Discussion of Organizational Innovation Findings in Relation to Other Studies

Research findings that contribute to knowledge of organizational innovations do so, primarily, by providing empirical evidence that even in the complex VIM^{5}DO of a DOD weapon system acquisition program, the structural theories of innovation, as refined for this research in the CHIP model and *structural levels and actors*, hold up well. Despite Stever's "glass wall" between the DOD and other civil administration, nothing in the research suggests that the "glass wall" hides organizational anomalies or unspoken policies that invalidate organizational theory. Even the policy and importance of "implementing IPT leaders *operational*[164] innovation decision" in the acquisition IPT organizational does not contradict the literature. That is because the literature, from Zaltman et al (1973) through the fifth edition of Rogers (2003), focuses on types of decisions and who might be involved, with little if any emphasis on the actual innovation decision maker. Similarly, the research conclusion regarding the expectation for, and iterative nature of, innovation reinvention refines and substantially reinforces current literature (Rogers, 2003; Damanpour and Gopalakrishnan, 1998; Gopalakrishnan and Bierly, 2001).

Regarding the *structural levels* construct, the findings indicate robust validity in the VIM^{5}DO nature of a large acquisition program. Clearly, the Program level needs carry out responsibilities for initiation and support to permit the Operational-level IPTs to focus on reinvention of the innovation and execution in the best way possible to gain the desired benefits. The potentially more substantial finding supported initially by the

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[164] Under the initial CHIP model definition this would be called the "optional" decision. Under the revised CHIP model described in Chapter 9, the new *operational decision* type is preferred here.

formulation of the *structural levels* construct and then by the research is that the obviously organic organizational structure of a large acquisition program IPT structure can support a process innovation like CCPM. This finding contradicts what seems the prevailing theoretical expectation that a mechanistic organizational structure will likely be needed (Daft, 1982; Damanpour and Gopalakrishnan, 1998). The implication of the conventionally expected "need" for a mechanistic structure is clearly not a characteristic of the IPT structure. Since the Program level was able to solidly support implementations in spite of its own policy of decentralized decisions, it appears that the type of structure is not the success driver or even a necessary administrative innovation characteristic implied by current literature.

Comments on Study Limitations and the POCAC Role

The study limitations and the author's role as participant-observer-change agent and champion (POCAC) addressed in Chapter 3 warrants closing comment regarding impact on study findings. The Study Limitations section highlighted the facts that: dynamic change is the nature of a development program, the high perishability of baseline or historical data complicates or precludes before and after comparisons, and the nature of the innovation initiation process almost necessarily contaminates potential discussion or survey participants with new information so that "before innovation x" and after innovation x" opinions are almost always retrospective. It is the author's belief that the impacts of these limitations were mitigated to the greatest extent possible by following the study methodology plan.   Even so, more follow-up on discussions and surveys could have been used more heavily to strengthen the qualitative assessment of the innovation where comparative quantitative data was weak or unavailable.

Regarding the potentially most serious limitation, bias because of the multiple roles encompassed in the POCAC acronym, the potential impact of that bias was substantially mitigated by primary dependence on what data and discussion/survey results were available as the foundation for conclusions. The most serious impact of the author's—and other change agents'—multiple roles on the implementations was not personal opinion bias with respect to findings and observations, the usual concern. Rather it was the negative impact on results likely caused by the very kind of multi-tasking that CCPM and the underlying Theory of Constraints concepts verify as the most serious cause of poor project performance.   The impact of that failure was likely exacerbated by giving short shrift to the matching phase of initiation in order to accelerate movement to the innovation stage. That said, the impact the multi-tasking is primarily limited to the CTF implementation, where LM Aero change agents were simply unable to support the critical early stages in Maintenance Mods and Flight Operations. Even there, the result would not have been impacted in any way by the author's role, unless it was delayed long enough to permit the personal epiphany generated by full understanding of the generic power of the multi-project/dynamic execution form of the innovation for application to environments beyond LT&E.

Conclusions and Recommendations

Substantive Conclusions and Recommendations

CONCLUSION #1: WHEN IMPLEMENTED PROPERLY, THE CCPM INNOVATION GENERATED BETTER SCHEDULE PLANNING AND EXECUTION PERFORMANCE THAN TRADITIONAL METHODS IN KEY AREAS OF THE F/A-22 PROGRAM.

The evidence from the several implementations that favors the CCPM innovation *in a form aligned to the Operational-level IPT needs and environment* over traditional methods includes better quantitative results and discussions/survey data. The ability to consistently establish and execute stable schedules to on-time completion supports the following policy recommendation:

RECOMMENDATION #1: THAT SAF/AQ AND DOD ESTABLISH A POLICY TO ENCOURAGE FURTHER USE OF THE CCPM INNOVATION FOR PLANNING, SCHEDULING, EXECUTION AND REPORTING PROJECTS AND PRODUCT DEVELOPMENT IN OTHER ACQUISITION PROGRAMS.

The other recommendations relate to further substantive research regarding the accelerated implementation process and the innovation form that has shown promise for application of CCPM in highly dynamic environments:

RECOMMENDATION FOR FUTURE RESEARCH #1: FURTHER DEVELOP SINGLE- AND MULTI-PROJECT FORMS OF THE "JUMP-START" APPROACH

RECOMMENDATION FOR FUTURE RESEARCH #2: FURTHER DEVELOP THE MULTI-PROJECT/DYNAMIC EXECUTION FORM OF THE CCPM INNOVATION THROUGH PILOT APPLICATIONS IN FLIGHT TEST OPERATIONS

Scholarly Conclusions and Recommendations

The primary implication of multiple case-study research of an innovation in the complex DOD acquisition environment and program organizational structure is the need to recognize the potential of expansion of the initiative. The incredibly rich, complex, structurally and geographically diverse organizational structure presents a bonanza of fertile territory for research related to all aspects of organizational knowledge, clearly not limited to the organizational innovation "corner" that was the focus of this research. Importantly, the research concluded a high degree of compatibility of the organizational innovation theories employed here with not just *a* DOD organizational environment, but one of the most complex organizational structures in the entire acquisition arena of DOD. There is an implication that other organizational theories originating or primarily validated on one side of Stever's "glass wall" should be evaluated through empirical research on the other, DOD, side of the wall to discover variations or verify similarities. With the DOD long emphasizing "best commercial practices", it is imperative to find and apply those organizational theories that can help husband the billions of dollars toward the most efficient use for our nation's defense.

CONCLUSION #2: THE EMPIRICAL EXAMINATION OF AN INNOVATION IN THE DOD WEAPON SYSTEM ACQUISITION IPT ORGANIZATIONAL STRUCTURE VERIFIES THE APPLICABILITY OF ORGANIZATIONAL INNOVATION THEORIES.

RECOMMENDATION #2: INITIATE FURTHER EMPIRICAL ORGANIZATIONAL INNOVATION RESEARCH TO VERIFY OTHER THEORIES IN THE CONTEXT OF THE ORGANIZATIONALLY RICH IPT ACQUISITION ENVIRONMENT.

RECOMMENDATION FOR FURTHER RESEARCH #3: INITIATE EMPIRICAL ORGANIZATIONAL RESEARCH ON OTHER GENERAL THEORIES IN THE ORGANIZATIONALLY RICH ACQUISITION ENVIRONMENT TO BREAK DOWN THE GLASS WALL BETWEEN CIVIL ADMINISTRATION AND THE DOD.

RECOMMENDATION FOR FURTHER RESEARCH #4: INITIATE EMPIRICAL ORGANIZATIONAL INNOVATION RESEARCH ON TO REFINE OR VALIDATE THE CHIP MODEL AND STRUCTURAL LEVELS CONSTRUCT IN THE DOD WEAPON SYSTEM ACQUISITION PROGRAM

On a personal level, the primary scholarly implication of the research is the importance of continuing to pursue research in the DOD environment on the issue of schedule planning and execution. The research embodied here was both uniquely strengthened (in breadth and depth of coverage) and potentially weakened by the author's role as POCAC. Even so, the fact that it was completed adds only one more still lonely voice to what needs to be a chorus of researchers looking at innovative ways to arrest or reverse the constantly expanding cycle time of DOD weapon system acquisition time.

RECOMMENDATION FOR FURTHER RESEARCH #5: INITIATE EMPIRICAL ORGANIZATIONAL RESEARCH TO FURTHER UNDERSTAND THE SCHEDULE PLANNING AND EXECUTION GAP AND TO DEVELOP AND EVALUATE WAYS TO ARREST AND REVERSE THE CRUCIALLY IMPORTANT WEAPON SYSTEM DEVELOPMENT CYCLE TIME

The research opportunities are immense; the stakes in the post-cold war, world-wide war against terrorism could not be higher, and lives are literally at stake. The field is wide open; we need a lot more players!

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APPENDIX A – Glossary[165]

Term	Meaning
"3-minute egg rule" (behavior)	Suggests that when criteria for completion of a task are not clear, the measure of task completion becomes the span of time the task (or similar tasks) has taken in the past. Essentially, even though the worker may complete an assignment or product in a time shorter than in the past, he/she will continue to refine the result/product until the estimated time is consumed, thereby using up embedded safety time.
A&I	Analysis and Integration — an organizational element of the F/A-22 IPT structure, normally comprising the systems engineering element of the several disciplines represented in an IPT.
ABP (time)	Aggressive-But-Possible — the estimate for task duration based on the assumption that all the required resources—parts, personnel, engineering drawings, etc.—are available when needed and the worker (or work group, if applicable) is allowed to focus entirely on this task. Roughly, a 50 percent probable time for the task.
ACAT 1	Acquisition Category 1 — A Major Defense Acquisition Program(MDAP) that is estimated to require an eventual total expenditure for research, development, test and evaluation of more than $365 million in fiscal year (FY) 2000 constant dollars or, for procurement, of more than $2.190 billion in FY 2000 constant dollars. (DODI 5001.2, "Operation of the Acquisition System", May 2003).
ACC	Air Combat Command — A major Air Force organization headed by a four-star general and headquartered at Langley AFB, Hampton, VA. The lead Air Force "user" of the product of the F/A-22 program and manager of the pilots and maintenance personnel responsible for employing and maintaining operational F/A-22 aircraft.
AETC	Air Education and Training Command — A major Air Force organization headed by a four-star general and headquartered at Randolph AFB, San Antonio, TX. Responsible for training pilots and maintenance personnel who become responsible for flying and maintaining the F/A-22 aircraft.
AFB	Air Force Base.
AFFTC	Air Force Flight Test Center located at Edwards AFB, CA, and commanded by a two-star general. Responsible for the majority of flight testing of Air Force weapon systems, including the F/A-22 and all other types of aircraft and many of the weapons and support systems associated with them.
AFMC	Air Force Materiel Command — A major Air Force organization headed by a four-star general and headquartered at Wright Patterson AFB, Dayton, OH. Parent organization to the F/A-22 System Program Office.
AFOTEC	Air Force Operational Test and Evaluation Center headed by an Air Force general officer and headquartered at Kirtland AFB, Albuquerque, NM. The organization responsible for conducting the IOT&E of weapon systems such as the F/A-22.

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[165] The terms and their meaning are intended to assist understanding in the context of their use in this research project.

Term	Meaning
Agenda-Setting Stage	One of two phases in the initiation stage of Rogers' formulation of the ambidextrous theory of innovation, used to analyze the use of CCPM on the F/A-22 program. This phase occurs when a general organizational problem that may create a perceived need for an innovation is defined (Rogers, 2003).
Aggregation of Safety	Mathematical concept that the amount of safety needed to protect the completion of a series of tasks in a project from variability is less than the sum of the safety needed to protect individual tasks in the project from variability. In simple terms, the impact of one task finishing later than planned can be mitigated by another task finishing earlier than planned. This concept is embedded in the calculation of CCPM buffer duration.
Aggressive (time)	See ABP.
AIL	Avionics Integration Laboratory — Located Boeing's Seattle, WA, plant and used for the development and test of software for which Boeing is responsible, and the integration of all F/A-22 software. The AIL is the only F/A-22 avionics lab with the capability and authorization to certify avionics OFPs as ready for installation on F/A-22 aircraft for ground and flight test.
AIM-120	Air Intercept Missile-120 — the official designation of the AMRAAM.
AIW	Accelerated Improvement Workshop — a term adopted by Boeing which encompasses improvement activities related to the production of products.
AMRAAM	Advanced Medium Range Air-to-Air Missile (see AIM-120). This is a radar guided missile that is carried in an internal weapons bay on the F/A-22.
Ambidextrous Theory of Innovation	A theory of innovation that uses a stages heuristic to postulate that the process of organizational innovation is broadly divided into initiation and implementation stages. The theory is expanded in the Rogers and CHIP models to include several phases
Anchor	In project planning, the event or date (e.g., start date or promised end date) entered into the project planning software to permit calculation and depiction of total project duration and interim task start/finish dates based on the task durations and dependencies entered into the software.
Authority innovation decision	An innovation decision in the CHIP model framework made at the Program-level to direct or terminate employment of an innovation by an Operational-level IPT. Compliance is normally mandatory unless the Operational-level IPT can justify non-compliance.
Bad Multi-tasking	The attempt to work on two or more tasks simultaneously, thereby incurring set-up and set-down penalties when moving between or among tasks. The negative impact of "bad multi-tasking" on a project is to expand individual task time with the cumulative effect that the project overruns its intended completion date.
Baseline (n) Baseline, baselining (v)	(n) A set of original project data that can be used as a basis of comparison with current and extrapolated status to determine the health of the project. (v) The process of selecting the plan or schedule that will be both the guide for determining the sequence of work as well as the basis for assessing progress towards the goal. In the CCPM software activating the "baseline" function causes a visual indication of the original position by a special colored line or bar close to, and of the same length, as tasks and buffers. The baseline indicator remains fixed during project execution as an indicator of the original position.

Term	Meaning
Baseline (symbology)	Physical depiction by a unique symbol (e.g., underline in Sciforma® PS8™ Critical Chain software) of the positions and durations of all tasks (as represented by bars in a Gantt chart) as of the beginning of project execution.
BE	Bio-Environmental Engineering.
Bead Game	A management exercise used (generally during CCPM concept training) to convey the negative impacts on project goal achievement of bad multi-tasking.
Blitz Week	A term used to describe the process used by the Raytheon Corporation to initiate a Critical Chain application with a new group. Concepts and processes used during Blitz Week were the foundation for the F/A-22 Jump-Start process.
Block or Blk	Reference to a particular configuration of hardware and/or software on the F/A-22 aircraft.
Build (process)	The series of activities required to assemble a particular hardware or software product
Build Team	The F/A-22 organizational entity responsible for planning, coordinating and executing the build process or processes.
Buffer	With the exception of “resource buffer,” buffers in the context of Critical Chain Project Management are a reserve of time equal to a portion of the variability expected in the execution of a series of tasks directly related to the buffer. Graphically, the buffer appears as a task node with no resources assigned and is located at the end of the series of tasks to which it is related. As the tasks are executed, the variability encountered beyond the “aggressive-but-possible” durations is absorbed by the buffer and the amount of the buffer then available to absorb variability encountered later is reduced. See Feeder Buffer, Project Buffer, Milestone Buffer, Capacity/Synchronization/ Strategic Resource/Critical Resource Buffer.
Buffer Consumption	See Buffer Penetration.
Buffer Management	Central concept of the Theory of Constraints and Critical Chain Project Management that monitors the extent and rate of buffer penetration in a project as a basis for taking (or not taking) action during a project when variability is encountered. Normally used primarily in conjunction with the Project Buffer, buffer management is the primary mechanism for assuring focus on achievement of the overall project goal instead of completion of individual tasks.
Buffer Penetration	The amount of buffer used when variability is encountered during the execution of tasks to which the buffer is related.
Buy-in	Conviction by decision-makers or members of the implementing team that the benefits of the proposed plan warrant commitment to implementation and support of plan execution.
CAIL	Cockpit Avionics Integration Laboratory — Located at LM Aero’s Marietta, GA, plant, this lab is used to support development and check-out of software associated with the CIP as well as development and check-out of cockpit displays and associated software. In 2003, capability was added and the name was chanced to RAIL.
CC	Critical Chain — the shortest sequence of task and resource dependent activities in a project. Sometimes a shorthand reference to the overall process (see CCPM).
CCA	Common Cluster Assembly — A particular set of parts representing a key subassembly in the CIP module developed by Raytheon.

Term	Meaning
CCPM	Critical Chain Project Management The application of Theory of Constraints to the management of projects.
CCPM Policeman	A term which using the metaphor of a policeman to describe a useful role played by someone during project execution to assure the discipline of the CCPM approach is followed (e.g., following the precedence of the task order, employing the “relay runner” mentality, using buffer management techniques, etc.).
CHIP	Casey Hybrid Innovation Process model – a model of the organizational innovation process based heavily on Roger’s formulation of the “ambidextrous theory of innovation.” The CHIP model specifically adds “evaluation as a new phase to the implementation stage, postulates there will be more and different kinds of decisions, and several iterations of the reinvention & evaluation phases.
Chain Gang	Informal reference to a group of Critical Chain enthusiasts within the Raytheon Corporation.
CIP	Common Integrated Processor — the generic name for the F/A-22 computer which is physically composed of two racks. Each rack has space for 66 modules which together perform memory and computational functions for the operation of F/A-22 avionics and aircraft systems.
CIP-2K	Shorthand reference to an improved capability F/A-22 computer, with “2K” evolving from the popular reference to the year 2000, when the CIP-2K development was contractually initiated.
Clarifying Phase	One of four phases in the implementation stage of the innovation framework used to analyze the use of CCPM on the F/A-22 program. Clarifying occurs as the innovation is put into more widespread use in an organization, so that the meaning of the new idea gradually becomes clearer to the organization’s members (Rogers, 2003).
Clear (flight test context)	Verification through a formal testing protocol that there are no restrictions on ground or aircraft operations up to a certain point described by specific parameters [e.g., up to and including 550 nautical miles per hour (knots), up to but not beyond 50,000 ft altitude].
CLIN	Contract Line Item Number
Core IPT	F/A-22 Integrated Product Team responsible for the design of the CIP and tasked with technical oversight responsibility for suppliers responsible for developing and producing the components of the CIP.
CPIF	Cost Plus Incentive Fee — Shorthand reference of a particular type of contract providing for the reimbursement of costs incurred to accomplish the requirements of a contract plus an incentive payment for better than required performance (e.g., early delivery of product, better than minimum product performance, etc.).
CPM	Critical Path Method — A scheduling approach that requires construction of a network that shows the relationship of tasks in a project, then defines the Critical Path through the network.
CR	Change Request — Paperwork (normally associated with a five-digit number, e.g., CR 515578) that captures information associated with a change to a part or function on the F/A-22.
Critical Path	As defined within the CPM approach to project management, the Critical Path is the longest path of task dependent activities.

Term	Meaning
CTF	Combined Test Force — Located at Edwards AFB and led jointly by an Air Force colonel and a senior LM Aero Test Director. The CTF is the F/A-22 program organization responsible for producing test data related to validation of aircraft flight envelope performance, avionics/weapon system performance and logistics characteristics and equipment procedures.
Cycle Time	For acquisition program, time for development from start of development to transfer of first production article to customer (ACC in the case of the F/A-22. For product or project within an acquisition program, time from initiation to delivery of product or completion of project.
DB	Drum Buffer — A mechanism, expressed as a period of time in the multi-project environment, to maximize effective use of the drum resource by assuring that when the drum resource becomes available to a project manager, the task that requires the resource is available to be worked. Physically, the drum buffer “pushes” the series of tasks to which it is linked back to a start point which permits completion by the drum resource when available even if variability is encountered.
Deferred work (maintenance context)	Activity that is required and planned as part of the current scope (e.g., during a particular modification span), but which is consciously dropped from the current scope (often to be scheduled later). Differs from “traveled work” in that “traveled work” remains part of the current scope but is actually done at a later time or another location than originally planned.
Deliverable	An interim or final product generated during or at the end a project. Deliverable products may consist of hardware, software, data, completion of a particular event (e.g., a live missile firing) or achievement of a particular condition (e.g., structural testing verifying a level of strength or durability). Deliverables are often detailed in contractual documents, which themselves may be characterized as deliverables.
Design Freeze	Action to approve a particular hardware or software design in its current state. The “frozen design” becomes the basis for action to produce the product described in the design.
DHM	Diagnostics Health Management.
DMVR	Digital Mass-memory/Video Recorder.
DMS	Diminished Manufacturing Sources — reference to an F/A-22 program established to provide uninterrupted supply of parts, components and subsystems despite the exit of the original supplier for any reason.
DoD or DOD	Department of Defense.
Drum Resource	A heavily used resource across multiple projects. Just as the drummer established the rowing pace on ancient galley ships or the marching pace in military maneuvers or parades, the drum resource of a project sets or constrains the pace of goal accomplishment across multiple projects in a program or enterprise.
DT&E	Development Test and Engineering — Testing on the F/A-22 program that occurs during the EMD phase of the program, the majority of which occurs prior to DIOT&E.

Term	Meaning
dynamic execution	An approach toward execution of a multi-project portfolio which baselines and begins to track the first few projects the team has agreed to begin at the outset of execution. Thereafter, other projects that are part of a multi-project portfolio are baselined and tracking initiated at the time the managers decide to activate them.
ECD	Estimated Completion Date.
EIR	Engineering Inspection Requirement — Documents specific type, location and frequency of an inspection of a part, system, or function on an aircraft.
ELT	Enterprise Lean Team — a government/contractor, top-level team that initiates, encourages, communicates, sponsors and reviews “lean” activities across the F/A-22 team. (See Lean.)
EMD	Engineering and Manufacturing Development - Until publication of DODI 5000.2, May 2003, “EMD” defined the acquisition phase during which weapon system development takes place. The term replaced Full Scale Development (FSD) in earlier acquisition program definitions to emphasize the need for production tools and processes to be developed during the same period as the weapon system to smooth the transition to production. The roughly equivalent term to EMD in the current DODI 5000.2 taxonomy is “System Development and Demonstration”.
Envelope or Flight Envelope	The area in which a system operates, normally bounded by upper and lower limits on speed, altitude, maneuver and other parameters.
EPS	Electrical Power System.
Evaluation Phase	One of three phases in the implementation stage of Rogers’ formulation and one of four phases of the CHIP model formulation of the ambidextrous theory of innovation.
EVMS	Earned Value Management System — A system of reporting requiring that contractors organize and report on the cost and scheduling status of ongoing effort using a work-breakdown system (hierarchical structure building from tasks to subsystems to the overall weapon system). As tasks are completed, value is earned against estimated costs.
FASA	Federal Acquisition Streamlining Act 1994
FB	Feeding or Feeder Buffer — In Critical Chain Project Management, a mechanism (expressed as a period of time) to protect the Critical Chain of tasks from delays in the execution of tasks that feed into the Critical Chain. The beginning of the FB is linked to the last of the series of tasks to which it is related. The end of the FB is linked to the beginning of the task on the critical chain which requires the result or product of the feeding chain. Physically, the drum buffer “pushes” the beginning of the feeding chain back to a start point which permits completion even if variability is encountered.
Feeding or Feeder Chain	A series of tasks that generate a result or product required by a succeeding task that is part of the Critical Chain.
FFP	Firm Fixed Price — Shorthand reference of a particular type of contract which requires achievement of contract objectives for a fixed cost.
Firmware	Electronic instructions or algorithms embedded within and directly controlling the functioning of an electronic component. Normally not adjustable by anyone other than specialists of the company that produced the component.

Term	Meaning
FRP	Full Rate Production (decision) — The decision to continue beyond low-rate to full-rate production shall require completion of IOT&E, submission of the Beyond LRIP Report to DOT&E Oversight Programs, and submission of the LFT&E Report (where applicable) to Congress, to the Secretary of Defense, and to the USD(AT&L). (DODI 5000.2, May 2003).
FTD	Field Training Detachment, an Air Force organizational unit.
FTE	Flight Test Engineer.
FTR	Flight Test Request — Documents a request/action to provide capability to measure or test some function on an aircraft; generally requires addition of test instrumentation sensors or wiring.
FTWG	Flight Test Working Group — An F/A-22 working group consisting of contractor and government personnel tasked to evaluate extended delays in the beginning of IOT&E and to establish minimum necessary testing required prior to the beginning of IOT&E.
Gantt chart	A popular format for depicting a variety of information including durations, interrelationships (or links), dates, etc., about the tasks in a project. The chart is vertically divided into two main parts, with most information about the tasks depicted in spreadsheet form on the left side of the chart and bars representing task length (and, often, interdependency linking lines) arrayed in relative chronological relationship on the right side of the chart.
Gating decision	An innovation decision in the CHIP model framework that is the province of a Program-level decision makers to permit or preclude the use of an innovation by Operational-level IPTs
GDDS	General Dynamics Decision Systems Company located in Scottsdale, AZ. An F/A-22 supplier responsible for development and production of a CIP component associated with protection of classified information.
Go-forward plan	Description of a series of steps planned from a given point in project execution to some future decision point or to project completion. The “given point” is usually either the current condition or a clear, near-term condition that makes it apparent that the original plan requires adjustments embodied in the “go-forward plan”.
Good Multi-tasking	Use of resources to complete a task (usually on another project) without causing any delay in the beginning or completion of tasks in the current project. Essentially, the practice takes advantage of the availability of a resource that would otherwise be idle in the current project.
Green Zone	Descriptor for the first portion (generally the first 1/3) of the Project Buffer; also referred to as the “OK” zone. If variability encountered in the execution of the Critical Chain schedule has caused penetration no further than the “green zone” the project is considered on track and no management action has to be taken
Group 1/3 or Group 1/3 suppliers	Shorthand reference to key F/A-22 suppliers associated with development of the various types of CIP modules. The “1” refers to RSC; the “3” refers to GDDS, LMM&FC, and Harris Corporation.
GVT	Ground Vibration Test.
H/W	Hardware.
Harris Corporation	A company located in Melbourne, FL, and an F/A-22 supplier responsible for development and production of a component associated with high speed communication within the CIP system.
HFE	Human Factors Engineering.

Term	Meaning
HP (duration)	Highly Probable — The estimate for task duration that includes sufficient safety to deal with the variability that could occur during the execution of the task. Roughly a 90 percent probable time for the task. HP estimate equates to what is normally the single-point estimate in the CPM approach to project management which typically includes safety to protect individual task completion.
HRIP or HRP	High Rate Initial Production or High Rate Production — Terms previously used with essentially the same meaning as Full Rate Production in DODI 5000.2, May 2003. (See FRP.)
HPS	Hydraulic Power System.
ICAS	Integrated Cost and Schedule System — A proprietary system developed by and implemented within LM Aero to track and report the cost and schedule status of work in progress.
IE	Industrial Engineer.
IFDL	In-Flight Data Link — An F/A-22 system for electronically transmitting and receiving data between F/A-22 aircraft that are part of a flight (e.g., two or four F/A-22s) or between/among F/A-22s in different flights.
IMP	Integrated Master Plan — A document that captures the relationships of key events in an acquisition program. The IMP represents the contractual expectation of the government and contractual commitment by the contractor
IOT&E	Initial Operational Test and Evaluation. AFOTEC is responsible for this process which includes the “final exam”—a comprehensive series of ground and flight tests to assess whether the operational requirements defined by ACC and approved by DOD have been met by the weapon system produced by the contractor (LM Aero for the F/A-22) under the oversight of the F/A-22 SPO
Implementation Stage	One of two stages of the ambidextrous theory of innovation. As further defined in the CHIP model based on Rogers’ formulation, the implementation stage encompasses Redefining/Restructuring, Evaluation, Clarifying, and Routinization phases
IMS	Integrated Master Schedule — A document that captures chronological relationship of key events in an acquisition program. The IMS represents the expectation of both government and contractor for the flow of the program, but it is not a contractual commitment by the contractor (for the F/A-22 program).
Initiation Stage	One of two stages of the ambidextrous theory of innovation. As further defined the CHIP model formulation based on Rogers, the initiation stage encompasses the Agenda-Setting and Matching phases of the innovation process.
Innovation	An idea, practice or object that is perceived as new by an individual or other unit of adoption (Rogers, 2003).
Innovation Decision	The organizational decision to proceed from the initiation stage of an innovation process to the implementation stage.
IOC	Initial Operational Capability — in the USAF, the date associated with the verification by operational test that the first squadron (18 aircraft) of a new airplane is combat ready to assume the role for which it was produced.
IOT&E	Initial Operational Test and Evaluation. See DIOT&E (the “D” was dropped with implementation of DODI 5000.2, May 2003).

Term	Meaning
IPT	Integrated Product Team — The basic, contractually-mandated organizational element of the F/A-22 team structure. Formed in a hierarchical structure, the IPT at any level is a multi-disciplined team of engineers and specialists designed to overcome problems of pure (i.e., single discipline) functional organizational structure of past acquisition programs.
Iteration Variability	Uncertainty in accomplishment of an interrelated series of several steps within a process. An example is in software development, typically described as a series of one or more steps (define requirements, design, code, test, integrate), that could repeat more than once before a particular block of code is developed
Job (maintenance context)	Generic reference to any one of several tasks that might be completed during normal or specialized maintenance on the F/A-22. Besides the Change Requests, Engineering Inspection Requirements (EIRs) to accomplish periodic, often invasive inspections of a particular area or part, Flight Test Requests (FTRs) generally associated with addition of test instrumentation sensors or wiring, Removal and Replacement (R&R) of parts or equipment, etc.
Jump-Start (process)	The name coined within the F/A-22 program for a process to facilitate the rapid development of a Critical Chain project plan that can be approved by appropriate authority, baselined, and tracked.
Jump-Start Week	Descriptor for the period of time during which the Jump-Start (process) is initiated with by a progression of a group within the F/A-22 program from initial training in CCPM concepts to a draft project network plan and schedule that represents approximately 60-80 percent of the work content involved in a particular project.
Kit (maintenance context)	All the parts and procedures for installation of changes assembled into complete packages by the primary site (e.g., Marietta, Ft Worth or Seattle) primarily responsible for the job to be done (e.g., CR, EIR, FTR, etc.).
Known-Unknowns	“Known-unknowns” are problems that may affect development, so that some reserve schedule and funds can be set aside to accommodate them.
LCN	Logistics Control Number.
LE	Lead Engineer (Designates position, as in leader, not an engineering discipline).
Lean or Lean Engineering	A term that is generally associated with activities and efforts across the F/A-22 team that improves effectiveness. The 5 elements of the “lean engineering” process is (1) define Value from customer’s framework; (2) “map” the process to identify the “value stream” to decide what to do better and what to stop doing; (3) improve the flow with various techniques, e.g., work cell layout, single process flow, etc.; (4) generate “pull” from customers avoid unnecessary inventory, just-in-time supply, etc.; (5) continuous improvement (back through the cycle).
LM Aero	Lockheed Martin Aeronautics Company — Prime contractor for development and production of the F/A-22 aircraft, headquartered in Ft Worth, TX, with primary F/A-22 manufacturing operating sites in Marietta, GA, Palmdale, CA, as well as Ft. Worth, TX and subsidiary plants in several other states.
LMM&FC	Lockheed Martin Missiles & Fire Control Company, Orlando FL. An F/A-22 supplier responsible for development and production of a CIP component associated with the Electronic Warfare (EW) system.
LND	Line Need Date — the time established by the F/A-22 Master Assembly Schedule when a particular component, part or process was required to be available on the manufacturing assembly line to assure delivery of the F/A-22 on schedule.
LO	Low Observable — A synonym for stealth.

Term	Meaning
Lot X	Quantity of F/A-22 planned or authorized and funded for production, generally with increasing size of "x" until a stable production rate is reached. Example: Lot 1 = six aircraft; Lot 2 = 10 aircraft, etc.
LRIP	Low Rate Initial Production — Term for the effort intended to result in completion of manufacturing development in order to ensure adequate and efficient manufacturing capability and to produce the minimum quantity necessary to provide production or production-representative articles for IOT&E, establish an initial production base for the system; and permit an orderly increase in the production rate for the system, sufficient to lead to full-rate production upon successful completion of operational (and live-fire, where applicable) testing (DODI 5000.2, May 2003).
LSA	Logistics Support Analysis — Term for a database that encompasses a great deal of information about the technical and logistical support procedures, equipment and support related to the F/A-22 aircraft system.
LT&E	Logistics Test and Evaluation — The process that evaluates F/A-22 support equipment performance, tech order data, human factors engineering, bioenvironmental requirements, reliability and maintainability performance, and diagnostics health management system.
LTMS	Logistics Test Management System
Matching Phase	One of two phases in the initiation stage of the CHIP model based on Rogers' formulation of the ambidextrous theory of innovation. Defined as the phase in the innovation process at which a problem from the organizations agenda is fit with an innovation (Rogers, 2003).
MDAP	Major Defense Acquisition Program.
mega-project	A project which is a conglomerate of several jobs, each of which could be an individual project in a multi-project portfolio for achievement of organizational goals. During planning the several jobs are linked to represent planned sequence, but the links do not represent rigorous finish-to-start relationships.
Merging	A mechanism in Sciforma® PS8™ software which makes separate projects part of a single project.
Milestone	A project event that represents completion an important task (e.g., beginning of flight test), important event (Critical Design Review) or, often, a contractually required event or deliverable product.
Milestone Buffer	A period of time representing variability expected to be encountered in the execution of all activities prior to a milestone. The end of the milestone buffer is the date on which the relevant task or event is expected to occur or be completed.
MLG	Main Landing Gear.
Module	A component of the F/A-22 computer (or CIP) which can be one of several specialized types used in combination to provided necessary computing power.
MS	Master Scheduler or Microsoft, depending on context.
MS-Project™	Microsoft Project — Software developed by the Microsoft Corporation that embodies the Critical Path Method to support project planning/scheduling/ execution.

Term	Meaning
Multi-Project/Dynamic Execution	Descriptor for an application of Theory of Constraints to a situation best addressed with the multi-project form of CCPM, but involving such dynamics over the expected period of multi-project execution that all projects cannot be initiated at the same time.
Multi-tasking	The attempt to work on two or more tasks simultaneously.
Network Diagram	A graphical view of a project that depicts the predecessor-successor relationships between and among all tasks in the project, often highlighting the most critical sequence of tasks (i.e., the critical path in the CPM and the critical chain in the CCPM methodology). Also called a precedence diagram.
Node	An entity in a project network diagram that normally contains a brief description and characteristics (e.g., durations, resources, start date, finish date) of a task or milestone that is part of a particular project.
Off-line	General reference to informal discussions or meetings to resolve misunderstandings or delve into subjects at a level of detail beyond what is deemed appropriate for formal meetings or discussions.
OFP	Operational Flight Program — Software developed to control system functionality on an aircraft (e.g., OFP 3.1 was one version of software to control avionics system functionality on the F/A-22).
Operational innovation decision	A decision in the CHIP model framework made by an Operational-level IPT leader to adopt or reject an innovation under consideration based on multiple inputs and his/her experience
Operational-level	The lower of a two-level structural construct adapted from the “dual-core” theory of organizational innovation. Use of the term “Operational” emphasizes the working level IPT where the innovation must be accepted and implemented in order to generate the desired effects of the innovation in support of the primary work accomplished by the IPT that generates the product.
out-of-bed	Colloquial reference to a difference between a desired, needed or contractually required condition and the current condition or what appears achievable under current assumptions or plans.
Pad	A colloquial reference to safety. (See Safety).
Parkinson’s Law (behavior)	Parkinson’s Law, applied to projects/operations, suggests that workers will typically use all available time (including safety) to finish a task, even if conditions would have permitted accomplishment early. Essentially, the worker uses up safety not needed on his/her task that might have been needed elsewhere to assure completion of the total project on time.
PB	Project Buffer. (See Project Buffer).
PD	Precedence Diagram — see network diagram.
Penetration	See buffer penetration.
Pilot, Pilot Project	An initial body of work to employ a particular part, system, procedure or process for the purpose of evaluation for suitability for application to a wider body of work in the same area or to an area where the nature of work is similar. Also called “demonstration” or “demonstration project”.
PMC	Program Management Council — A corporate entity of LM Aero headed by a senior Vice President and including key program and functional leaders.
PMR	Program Management Review — Within the F/A-22 program, a review at any (but usually senior) management level of the status of an IPT program. PMRs are generally conducted for assessment and possible direction by government and/or contractor personnel with relevant technical or management expertise.

Term	Meaning
PO	Participant Observer.
POCAC	Participant Observer Change Agent Champion –- An acronym unique to this study to capture the several roles played by the author
POD	See “Proof-of-Design”.
Portfolio (CCPM context)	A set of interrelated projects which together constitute a defined scope of work utilizing one or more resources shared across the set of projects.
ProChain (software)	An application produced by the ProChain Solutions Company that adds algorithms mechanizing Critical Chain methodology to MS-Project™ software.
Program-level	The lower of a two-level structural construct adapted from the “dual-core” theory of organizational innovation. Generically relates to the involvement of an acquisition program’s senior leadership in, and influence on, the initiation (or cessation) of innovation use in various team areas and locations. The “Program” structural level initiates, encourages or directs critical activities without which applications of an innovation would likely not happen. Alternatively, a Program-level decision can preclude or terminate consideration/use of an innovation.
PB	Project Buffer — In the context of Critical Chain Project Management, a mechanism (expressed as a period of time) to protect Critical Chain for a particular project from variability expected in the execution of tasks along the critical chain. The beginning of Project Buffer is linked to the last task on the critical chain. The end of the Project Buffer is the date on which the project is scheduled to be completed, since all the variability is normally expected to be consumed during the execution of the project.
Protect your Credibility (“CYA”) (behavior)	Suggests that workers are reluctant to pass on work that is completed in less time than they themselves had estimated. Their fear is that their estimates in the future will be arbitrarily reduced by management. Like Parkinson’s Law and the 3-minute egg rule, the result is that the worker will waste embedded safety time by continuing to tinker with the effort until the estimated time is used up.
Proof-of-Design	A representation, e.g., a prototype or first product, which is used to confirm the necessary functionality is in fact produced by a particular design.
PS8™	Project Scheduler (Version 8) — Project planning/scheduling/execution software produced by Sciforma® Corporation that embodies both CPM and CCPM project planning/scheduling/execution methodologies.
R&M	Reliability and Maintainability — A fairly sophisticated structure of data that can be used to estimate the fault, failure and repair cycles for a weapon system.
R&R	Removal and Replacement.
RAIL	Raptor Avionics Integration Laboratory — Located at LM Aero’s Marietta, GA, plant and an expansion of the original CAIL, this lab is used to support development, test and integration of avionics software and hardware developed for the F/A-22 aircraft.
Raptor	The official United States Air Force nickname for the F/A-22 aircraft.
Raytheon	General reference to Raytheon Systems Company (see RSC).
Red Zone	Descriptor for the last portion (generally the last 1/3) of the Project Buffer sometimes referred to as the “act” zone. If variability encountered in the execution of the Critical Chain has caused penetration into the “red zone” and it represents greater than expected variability (e.g., penetration of the red zone early in the project), managers should “act” to implement one or more of the actions planned when penetration of the buffer was in the yellow zone).

Term	Meaning
Reinventing/ Restructuring Phase or Reinvention/ Restructuring Phase	One of four phases in the implementation stage of the CHIP model based on Rogers' formulation of the ambidextrous theory of innovation. Redefining/restructuring occurs when the innovation is tailored to accommodate the organization's needs more closely, and when the organization's structure is modified to fit with the innovation (Rogers, 2003).
Relay Runner	Metaphor representing the behavior emphasized, encouraged and expected in the execution of tasks within the Critical Chain approach. Like a relay-runner who must complete his "leg" of a race before he can pass the baton to the next runner, CCPM workers employing the relay-runner strategy are directed to concentrate on finishing tasks and passing on the complete result of the task in the minimum time for the conditions at hand.
Resource Buffer	In contrast to other buffers which represent a period of time, this is both an agreement and an "alarm clock." The agreement usually made during the project planning stage is essentially a commitment by the owner of a particular resource (labor, equipment, facility). The commitment is that the resource will be made available to a project when needed if the project manager provides sufficient notice of the date and time needed. The alarm clock is notification to the resource owner by the project manager "lead time away" from the need during project execution.
Resource Contention or Resource Conflict	The simultaneous demand for the use of more resources than are available to execute tasks in the same project or projects that draw on the same resource pool.
Resource Resolution or Resource Leveling	The process of inserting delays between tasks to assure that limited resources are not assigned to simultaneously complete more tasks than there are resources available. For example if two tasks require resource X at the same time and there is only one qualified resource X, one of the tasks will be moved or "pushed" so that the tasks can only occur in series, not parallel. In this context, the resource contention is said to be *resolved, deconflicted, leveled* or *broken.*
RFP	Request for Proposal.
Rolling Wave (project planning context)	An approach for dealing with extremely high variability on a lengthy project. In this approach, detailed planning is generated for a subset of the entire span and connected to spans for the remainder of the project that have less detailed plans. As the next subset of the entire span is approached, detailed planning is accomplished. For example, an initial detailed plan for the next 3-6 months with updates each month which add detail for those months or periods first planned at only a general level.
Routinization Phase	One of four phases in the implementation stage of the CHIP model based on Rogers' formulation of the ambidextrous theory of innovation. Routinization occurs when the innovation has become incorporated into the regular activities of the organization and the innovation loses its separate identity (Rogers, 2003).
RSC	Raytheon Systems Company, El Segundo, CA. An F/A-22 supplier and lead developer of the F/A-22 CIP and CIP-2K modules.
RTT	Ready-to-Test — A term associated with test points signifying that all the information is available to evaluate achievement of a particular requirement established for the F/A-22 aircraft or logistics system.
S/N	Serial Number.
S/W	Software.

Term	Meaning
SAF/AQ	Assistant Secretary of the Air Force for Acquisition — The senior procurement official in Headquarters, United States Air Force, at the Pentagon in Washington, DC.
Safe Duration	A term sometimes to describe the duration within which a task can expect to be completed with a high probability (e.g., 90 percent) of success. Sometimes used in place of highly probable (HP) duration, which is preferred to avoid the connotation that “safe” means certain success (i.e., 100 percent).
Safety	Reserve contained in an estimate of task duration or resources to permit absorption of variability encountered in the execution of a task.
Scope	The total of all products and services to be included in a project or set of projects.
Safety nets	Reference to one or more steps in the CCPM project network building process to assure the validity or improve the robustness of the completed network.
SDD	System Development and Demonstration — The term in DODI 5000.2, May 2003 that essentially replaced the term EMD in the vernacular of the DOD acquisition process.
SE	Support Equipment.
Set-up or Set-down	Descriptive term for the fixed time and resources expended each time a task work is initiated and completed (e.g., obtaining or storing tools, accessing or storing work instructions, clearing the work space). If the task is suspended without completing the task, the recurring need to set-up or set-down acts as a penalty because the total task time is longer than if work on the task had been started and continued to completion.
Situation Awareness	A term, sometimes shortened to the acronym, SA, referring to the extent of one’s knowledge about factors relevant to a given situation or decision.
SOW	Statement of Work.
SME	Subject Matter Experts.
SPD	System Program Director — the official title of the individual responsible for leading the SPO in overseeing the contractor that is developing and producing the weapon system.
SPO	System Program Office — designation of the Air Force Organization, led by the SPD, that oversees the company who was awarded the contract to produce an Air Force weapon system. The F/A-22 SPO is headquartered at Wright Patterson Air Force Base, Dayton, Ohio.
SRB	Strategic Resource Buffer — In the context of the multi-project application of CCPM, the mechanism (expressed as a period of time) to protect the beginning of a task in a subsequent project from delays that might be encountered by the drum or strategic resource in the execution of a preceding task in another project. Whereas Feeder, Milestone and Project Buffers are (normally) physically depicted in the project schedule, SRBs are (normally) not depicted, but rather represented by the stagger or delays between end and beginning of tasks requiring use of the drum resource in a series of projects.
Stealth	In the context of aircraft weapon system, the combination of overall and subsystem design and operation, structural and surface materials and coatings that combine to make the aircraft nearly invisible to opposing detection and intercept systems in certain areas of the electromagnetic spectrum.

Term	Meaning
Step (flight test context)	A subset of Flight Sciences Flight Test Operations test points concerning a range of aircraft flight and aircraft systems performance within a specific part of the F/A-22 flight envelope.
Student Syndrome (behavior)	Suggests that like a student who waits until the last minute to complete an assignment for which more than adequate time was originally provided, a worker who delays the start of a task in the project environment (because he/she knows that there is safety embedded in the task duration estimate) may find it impossible to complete the task in the remaining time if any problems arise (since there is insufficient safety left to permit the worker to deal with the problems).
Suitability (testing context)	The ability to logistically support a weapon system (e.g., F/A-22) under operational conditions.
Supplier	Company under contract within the F/A-22 program to provide a given service or product directly or indirectly to a LM Aero Integrated Product Team
SWBS	Schedule Work Breakdown Structure.
Synchronize	In the context of the application of Critical Chain approach to multiple projects that share scarce resources, synchronize, synchronizing or synchronization relates to the conscious staggering of projects to deconflict and avoid simultaneous demands on one or more of the most heavily tasked shared resources.
Task	The basic project element representing a portion of the work that must be performed. Normally described by a short description, expected duration(s) and expected resource requirements.
Task Variability	Accounts for the uncertainty in a single task or in subsequent execution of a particular task.
Technology Cluster	A grouping of one or more distinguishable elements of technology that are perceived as being closely interrelated.
Template	In the context of CCPM, a series of tasks with a particular set of interrelationships that represents a repeating pattern, though some of the characteristics (e.g., durations, resources, and product) may differ from application to application. Examples: the series of steps application of finishes (prep surface, apply materials, cure materials, inspect cured result) or a generic flight test mission (pre-mission planning, briefing, fly mission, debrief, analyze data).
Tier	A reference to a level in a hierarchy. For the F/A-22 program structure, Tier 1 is the level where the top program leadership and supporting staffs reside led by the SPD for the government and the his counterpart, the VP/GM for the LM Aero prime contractor. At the next lower tier, Tier 2, are the major Integrated Product Teams, e.g., Air Vehicle, Support Systems, etc. For the F/A-22 supplier structure, Tier 1 includes suppliers under direct contract to either LM Aero or its primary subcontractor and major partner, Boeing. Beyond Tier 1, is a hierarchy of suppliers that are under contract to a supplier at the next higher level, but not directly with LM Aero for a particular product or service. .

Term	Meaning
Tiger Team	Generic title for a multi-disciplined, ad hoc working group that may be formed at any level in any government or contractor organization for a specific purpose of providing an independent view external to the particular organization with a problem or challenge. At any level, normally includes members with highly respected expertise and experience with problems similar to the subject of the Tiger Teams mission or charter.
TIM	Technical Interchange Meeting.
TOC	Theory of Constraints, a management philosophy first developed by Dr. Eliyahu Goldratt whose central premise is that only one or a small number of constraints are preventing achievement of goals. TOC provides the tools and concepts that can help make people and organizations more productive according to their goals. (Adapted from Newbold).
TOD	Tech Order Data — The information that describes systems and all the procedures associated with maintaining, trouble-shooting and repairing a weapon system.
TODCR	Technical Order Data Change Request.
TPO	Team Program Office — The top level contractor organization that leads the contractor Integrated Product Team structure. Leader of the TPO is the Lockheed Martin Aeronautics Vice President and F/A-22 Program General Manager.
Traveled Work	Manufacturing assembly work planned to be completed at one point in the process that is delayed until a later point.
TSC	Technical Support Contractor - Acronym used to refer to a source of CCPM expertise for both training and support during the CCPM implementations in the F/A-22 program; TSC is not the name of a company.
Unknown-Unknowns or Unk-Unks	Unk-unks are problems that cannot be anticipated in terms of their nature, timing or impact. A colloquial description might be: Unk-unks are the problems that you know will arise, but you just do not know exactly when they will arise or what their nature will be. The only way to allow for unk-unks in planning is to reserve funds and spans of time to deal with unk-unks when they occur in the development and testing process.
USD(AT&L)	Under Secretary of Defense (Acquisition, Technology, and Logistics), USD (AT&L).
V&V	Verification and Validation.
VIM^{5}DO	Virtual Integrated Multi-level/lateral/organization/team/product Development Organization. A term to characterize the broader F/A-22 development organization and differentiate it from VMDO, standing for virtual multi-lateral (multi-organization, multi-team) development organization, coined by O'Sullivan (2003) from study of a lead firm and its suppliers developing one product.
VP/GM	Term that combines corporate rank, Vice President (VP) with program responsibility, General Manager (GM).
VTC	Video Tele-Conference — Within the F/A-22 program, an television network permitting classified and unclassified discussion among the primary team sites at Wright Patterson AFB, OH, Ft Worth, TX, Marietta, GA, Seattle, WA, Edwards AFB, TX. Other locations can be included depending on requirements.
WBS	Work Breakdown Structure — Hierarchical structure building from tasks to subsystems to the overall weapon system.

Term	Meaning
What-If	A term used to describe what essentially sensitivity analyses are exercised to assess the impact of different variations on a particular plan or series of events. For example, in project planning, if there are indications of long project span due to high demands for scarce resources, a “what-if” exercise might assess the impact on project duration of resequencing work or of incrementally increasing the level of the scarce resource.
Wicky Board	Nickname for both a physical display panel and a system used by maintenance personnel in the F/A-22 CTF at Edwards AFB, CA to depict and modify detailed tasking—jobs and personnel assigned—on a day-to-day basis for the next few days.
Work-around	General reference to efforts which accomplish a particular objective despite the absence of one or more key elements originally expected to be available. Missing elements can be in the form of physical parts, equipment, data or specialized personnel. May also refer to activities during project execution which overcome the impacts of occurrence unanticipated when the project was originally planned.
Work-shifts	The regular periods (typically 8 or more hours) of work in a factory. Usually associated with a descriptor that indicates when the period takes place. For example, day-shift, night- (or graveyard-) shift and “swing-shift” (that occurs between day and night/graveyard).
WSU	Washington State University, Seattle, WA
Yellow Zone	Descriptor for the second portion (generally the middle 1/3) of the Project Buffer, sometimes called the “plan actions” zone. If variability encountered in the execution of the Critical Chain schedule has caused penetration into the “yellow zone,” project managers should plan actions related to current or future tasks that could offset greater than expected variability in previous or remaining tasks. If this penetration occurs quite early in the project, implementing one or more of the actions may help avoid crisis later.

APPENDIX B - Discussion and Survey Forms

Discussion Questions
Final Finishes Demonstration of CCPM

Name___________________Phone number____________ Date__________

Current Position______________________ Time in position_____________

Purpose of the Discussions: Gather information and opinions of individuals involved in, or affected by the pilot implementation of Critical Chain Project Management in the F-22 Final Finishes.

1. **How much training did you receive regarding the concepts and use of CCPM?**

2. **How would you assess the quality of the training?**

3. **How has the implementation of CCPM affected your understanding of conflicts or problems in Finishes?**

4. **How has CCPM affected your confidence in your team’s ability to deliver products as promised or as needed?**

5. **A key goal of CCPM is reduced lead or total cycle times – has this goal been achieved in Finishes?**

6. **Every project is challenged to provide full content on time and within budget. Has CCPM had any impact on your ability to manage this "iron triangle?"**

7. **How has the implementation of CCPM affected your understanding of resource requirements (both labor and non-labor) and resource conflicts?**

8. **How has CCPM affected your decisions about resource allocation?**

9. **Did the CCPM networks affect your understanding of the work-flow/content?**

10. **The TOC/CCPM solution for project management talks a lot about behavior modification, e.g., less multi-tasking and avoidance of Parkinson's Law and Student Syndrome which use valuable safety time. Has CCPM had any impact on these kinds of behaviors?**

11. **What was your assessment of the CCPM software tool (PS8™)?**

12. **What outputs from the CC process did you use and how did you use them?**

13. How would you assess the utility of CC process outputs on a scale of 1-10 (1=best)?

14. How did the strategically placed buffers affect your schedules?

15. What was your impression of the size of the buffers?
Way too short? Too short? About Right? Too Long? Way too long?

16. How did you use Buffer Management?

17. Did Buffer Management live up to advertised promises regarding early warning and impact of actions on delivery?

18. Given that the Finishes IPT operates in a somewhat chaotic schedule environment, what impact did CCPM have on dealing with and in that environment?

19. How does decision-making based on CCPM and associated schedules compare with decision making before CCPM?

20. How has your overall credibility with internal/external customers been affected by CCPM?

21. What are some of your lessons learned from your initial exposure to CCPM?

22. What would you say are the weaknesses and strengths of Critical Chain?

23. What is your recommendation regarding continued use of CCPM in Finishes?

24. Do you think CCPM would be useful elsewhere in the F-22 program?

25. If "yes" to #24, where would you recommend CCPM is used next?

Form Used for Survey of
CIP-2K Project Personnel on the Impact of CCPM

Participant info (highlight box & use "fill color" to respond)	LM-Marietta	SPO	Raytheon	GDDS	LMM&FC	LM-Ft Worth	Boeing	Harris
Which of the following best describes your current job (pick closest)			Tech Lead	Project Lead	Manager	Scheduler		
Years in current job			<1	1-3	4-6	7-9	10-15	>20
Years in aerospace system development			<1	1-3	4-6	7-9	10-15	>20
Most familiar scheduling tools used			MS-Project	Crtical Path	Milestone	MS-Power Pt		
Training on Critical Chain Project Management (CCPM) concepts & reports			none	< 2 hrs	2hrs-2 days			
Do you use Critical Chain software?			Yes	No				
If "yes" how much training on the software			none	< 2 hrs	2hrs-2 days			

Please answer all the following questions based on your perception of the Critical Chain approach to scheduling, tracking, managing and delivering F/A-22 products RELATIVE/COMPARED TO APPROACHES BEFORE CRITICAL CHAIN WAS IMPLEMENTED

In your view, how has the Critical chain approach affected you or your own team's:	reduced	same	improved
a. Confidence in meeting deliveries?			
b. Ability to meet commitments?			
c. Ability to reduce time it takes to deliver quality products			
d. Understanding of resource requirements			
e. Ability to allocate resources to assure on time delivery?			
f. Ability to set prioritize activities based on data instead of "gut feel"?			
g. Capability to identify the most important tasks today?			
h. Understanding of current status relative to the delivery commitment?			
i. Efficiency in assigning workers to tasks?			
j. Ability to decide whether to react when work exceeds estimated time			
k. Ability to identify problems before they become crises?			
l. Understanding of how problems in development are related to each other			
m. Understanding of the priority order for working problems/issues			
o. Ability to quickly analyze impact of work-arounds to decide which is best?			
p. Ability to decide when to direct actions to respond to problems?			
q. Coordination with personnel on other shifts			
s. Ability to avoid overreacting to identified problems (I.e., avoid chaos)?			
t. Ability to reduce multi-tasking by those you supervise or manage?			

Note: Suggest you highlight the cell and use a fill color or "X" to indicate your response

Please answer the following questions based on your view of the Critical Chain approach to scheduling, tracking, managing and delivering F/A-22-CIP2K products RELATIVE/COMPARED TO APPROACHES ON OTHER CROSS-TEAM ACTIVITIES BEFORE CRITICAL CHAIN

In your view, how has the Critical Chain affected work across the CIP-2K team	reduced	same	improved
r. Communication/coordination w/ personnel in other companies on CIP-2K			
s. Heads-up on changes in hand-offs in time to deal with impacts			
t. Understanding the status of all activites on the CIP-2K project			
u. Mutual accountability for work/hand-offs			
v. Confidence in ability of other suppliers to meet delivery commitments			
v. Identification of action items requiring resolution to keep CIP-2K on track			
w. Timeliness of closure on action items to keep CIP-2K on track			
x. Confidence in meeting project goal: On-time delivery w/ full content			

How do you assess the utility of:	not used	Utility on scale of 1-10 (10 = best)
a. Network information?		
b. Gantt / milestone charts?		
d. Buffer management reports?		
c. Buffer management - response to problems based on % Project Buffer used		

From an overall perspective

How do you assess the utility of the Critical Chain approach to planning, scheduling, tracking and managing?		<--Utility on scale of 1-10 (10 = best)				Note: Suggest you hi-light the cell and use a fill color to indicate your answer
What was avg ***cost*** performance on like projects b/4 Critical Chain implemented? (circle one)	< budget	on-budget	10% over	20% over	>20% over	
What is status of ***cost*** performance where Critical Chain applied	< budget	on-budget	10% over	20% over	>20% over	
What was avg ***schedule*** performance (vs *originally committed* deliveries or major milesotnes) on like projects b/4 Critical Chain implemented? (circle one)	early	on time	< 30 Days late	30-60 days late	>60 Days late	
What is avg ***schedule*** performance (vs deliveries or major milesotnes) where Critical Chain has been implemented implemented? (circle one)	early	on time	< 30 Days late	30-60 days late	>60 Days late	
Do you plan to use or encourage use on future projects (Circle one)	Definitely	Probably	Unlikely	No		

Fill in the blank questions

What is/are the one or two most important strengths of Critical chain?	
What is/are the one or two most important weaknesses of Critical chain?	
Where do you think Critical Chain Project Management should be used next?	
Any recommendations for other suppliers who might use CCPM?	
What change(s) would you make to improve CCPM or its use on the program (CIP-2K or F/A-22)?	
Bonus: Why do you think the Critical Chain approach works?	

Use the space below to add any other thoughts or address subjects not covered in the questions above

APPENDIX C – CCPM Methodology with CPM Contrasts

The purpose of this appendix is to provide greater insight on the CCPM innovation for those interested in the contrasts between and among Critical Chain Project Management concepts and those of the Critical Path Method (CPM), the traditional basis for scheduling and management of projects. While Critical Chain sounds like Critical Path, there are fundamental philosophy and algorithm differences, including CCPM's explicit consideration of resource constraints, variability, and aspects of human nature which can adversely affect results.[1]

Instead of adopting the fundamentally flawed CPM assumption that all tasks can be completed on time or that resources are unconstrained, the Critical Chain system is designed so that even when most of the tasks take longer than expected, no action may be required. This approach and the explicit, up-front incorporation of realistic resource constraints—whether people, parts, facilities, etc.—allows the project manager to deliver required content on time, within budget with focus on far fewer tasks. The "far fewer tasks" are those on the Critical Chain.

The Critical Chain Network Building Process

Critical Chain begins with a planning process that first identifies objectives (what is the purpose of the project?), deliverables [what product(s) will the project deliver?], and success criteria (how will we know when we are done?). Then the planning process requires development of a detailed, credible network of tasks representing the work and precedent relationships between/among tasks necessary to accomplish the objectives and deliver the required products within clearly defined success criteria. In contrast to CPM's flow from "what do we do first" to eventual production of the product, Critical Chain often begins with the product and works backwards, considering "what is

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[1] This appendix is intended to stand alone and, therefore, is largely redundant to the description of the CCCPM process in Chapter 3.

absolutely necessary" immediately before the product can be generated. The network is then built "in reverse" considering what is necessary before each task under consideration can be accomplished.[2]

Central to the Critical Chain approach is emphasis on the equal importance of the interdependencies associated with resources and tasks. This contrasts with the treatment of resources as always or easily available as was generally the case when CPM was originally conceived and applied during the Cold War era.[3] Critical Chain draws on the knowledge of those who will do the work to establish or verify the interdependencies and key integrations points in the task network as well as establish the number and types of resources required to accomplish the tasks.

This emphasis on resource dependencies is a key and constantly emphasized element of the difference between the Critical Path Method and the Critical Chain Project Management approaches, especially when the key definitions are considered:

> The *Critical Path* is the longest sequence of task-dependent activities in a project.
>
> The *Critical Chain* is the longest sequence of task- and resource-dependent activities in a project.

Estimating Durations for the Critical Chain Project Network

Critical Chain also more clearly recognizes the nature of variability associated with task accomplishment in operations and project environments. Though both may ask the worker (or work group) to obtain task estimates, the information is solicited and used differently. The CPM approach typically uses a single number to estimate task durations which includes an allowance for safety to hedge against variability in the actual

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[2] This approach toward network development in reverse is often referred to as the "necessity-based approach" vs. the "flow-based approach" starting from the beginning as is common with CPM.

[3] It can be argued that this assumption was founded on recognition that in the development of military capabilities to compete in the Cold War "arms race", minimizing the span to produce the new weapons that provided advantage was the key emphasis. That being the case, resources—money, people, etc.—could always be made available to minimize times to accomplish the "critical path" of task interdependent events.

time required to complete the task. Alternatively, the CPM approach or uses a deterministic "start date" and "finish date" to establish the task duration, again including a measure of safety.

In contrast, the CCPM approach expects that the range of estimates from the workers will occur within a skewed (vs. normal) distribution as reflected in Figure C-1. Instead of assuming that variability will occur evenly about the middle figure, Critical Chain recognizes that a given task might take less time than the mean or median estimate, but if variability occurs, it might drive the task time well beyond the median. The range of estimates extends from "aggressive-but-possible" (ABP) on the low end to "highly probable" (HP) on the high end.

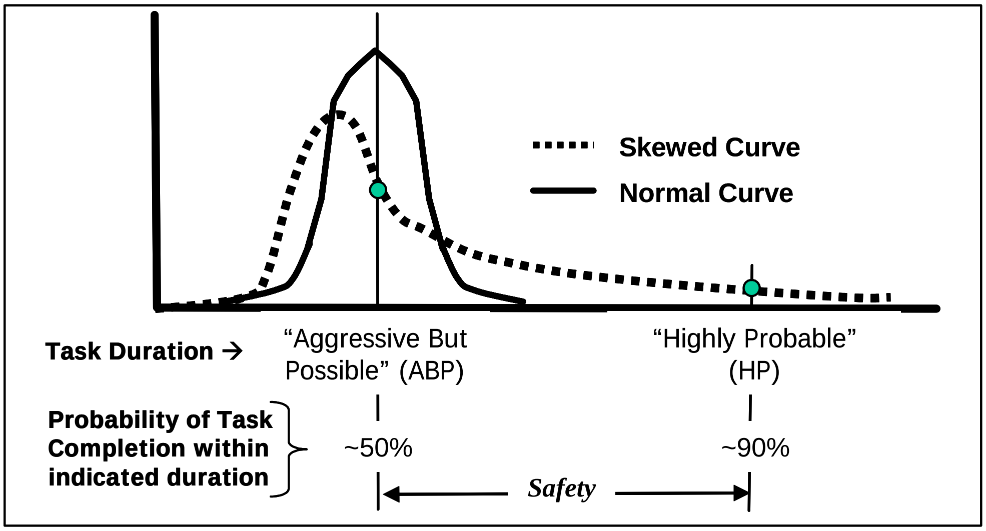

Figure C-1. Assumed distribution of task durations and completion probability.

The *highly probable* estimate is the duration that equates to what is normally the single-point estimate in the CPM framework. That is, the HP duration includes sufficient safety to deal with the variability that could occur during the execution of the instant task based on past experience with the same or similar tasks. Variability might be caused by delayed or quality-deficient parts, parts that have to be repaired, situations requiring engineering direction that must be clarified before the task can be completed, or lack of proficiency or unavailability of a particular labor specialty. Any of these sources of variability will use up some, all of, and occasionally more than, the safety that is embedded in the HP estimate.[4]

At the other end of the estimating range, the *aggressive-but-possible* estimate, referred to simply as the aggressive or ABP estimate, is the duration that would occur if all the required resources—parts, personnel, engineering drawings, etc.—are available when needed. Also, given these prerequisites, the worker (or work group, if applicable) is allowed to avoid multi-tasking (i.e., no other competing or simultaneous tasking) and focus entirely on this task. This ABP duration is thought of as having an approximately "50/50" or 50 percent probability of success. In most cases, the ABP estimate can also be estimated as half of the HP estimate. Statistically, an estimate derived in this way will have an approximately 70 percent probability of success.

The difference between the two estimates is a measure of the uncertainty (or variability or risk) in task accomplishment, and regarded by Critical Chain as safety. Essentially this is the same safety that is embedded in each task in the CPM method; in essence, the CPM task durations equate to the HP durations in the CCPM process. However, instead of embedding the safety in each task-duration like CPM, Critical Chain aggregates this safety into a system of "buffers," mainly Feeding Buffers (FBs) and a Project Buffer (PB). Because less safety is needed at the project level than the total safety embedded in each task (since early finishes in one task can offset late finishes in another), Critical Chain uses a portion of total safety in these buffers and strategically places the buffers to assure that the project or operation is completed on time.

Essentially, the buffers represent protection against problems in the accomplishment of tasks due to "common causes" (variations in duration that predictably

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[4] The "highly probable" (HP) estimate is sometimes termed the "safe" estimate in other references. HP is preferred herein to avoid the connotation that the estimate is somehow so "safe" as to be certain. In fact, as HP more correctly implies, this estimate will occasionally be exceeded.

occur because they are part of the system within which projects are performed).[5] The Project Buffer provides protection from normal variability for the sequence of the Critical Chain tasks The Feeding Buffers protect the Critical Chain from variability on the "feeding chains"—the sequences of tasks leading to input to or integration with the Critical Chain. By definition, since the Project Buffer represents variability that will occur with a high degree of certainty, the time in the Project Buffer will progressively be consumed as the project moves to completion at a time represented by the end of the Project Buffer.

Given an accurate, necessity-based network loaded with the required durations and resources at the task level, and supported by appropriate subject matter experts (SMEs) and enabled by appropriate software algorithms, the Critical Chain approach generates a schedule set back from the projects completion/delivery date that is used as the anchor. Once any resource contention is resolved[6] to remain with any resource constraints, the Critical Chain is identified and Project and Feeding Buffers are inserted.

Comparing Project Networks: Critical Path Method vs. CCPM

The foregoing discussion underscores fundamental differences between a project plan embodying the "critical path" within the CPM approach and one embodying the "critical chain" within the CCPM approach. Besides the definitions covered earlier, the appearance of the resulting project networks are different.

In Figure C-2 the same project is depicted based on the two approaches to project planning. For purposes of illustration only one of each type resource is available. As depicted, the "aggressive" (ABP) times in the Critical Chain network are

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[5] Buffers capture the philosophy of Edwards W. Deming, the great quality advocate of the 20th century, regarding the handling of "common cause" and "special cause" variation and predictability. An individual task taking longer than estimated is likely within the realm of common cause variation. A series of tasks that have all taken much longer than expected are in the realm of special cause variation (Kerzner, 2003)

[6] The meaning of *resolved* here is that limited resources are not allowed to be simultaneously assigned to more tasks than there are resources to support. For example if two tasks require resource X at the same time and there is only one qualified resource X, the tasks will moved or "pushed" so that they can only occur in series, not parallel. In this context, the resource contention is said to be *resolved, deconflicted,* or *broken.*

assumed to be half the durations shown in the critical path version of the network. The CCPM network shows the resolution of the conflict between the demand for Resource A on the top and bottom paths of the network. The Feeding Buffers (FBs) are inserted to assure that the non-Critical Chain tasks are begun sufficiently early to assure that those tasks will be completed in time there is no delay in the integration of the products from A10 and A25 with the result of C25. Importantly, the use of FBs is intended to assure stability in the Critical Chain tasks and overcome the common phenomenon in the CPM approach where the “critical path” changes or bounces around when variability is encountered in the completion of one or more tasks.

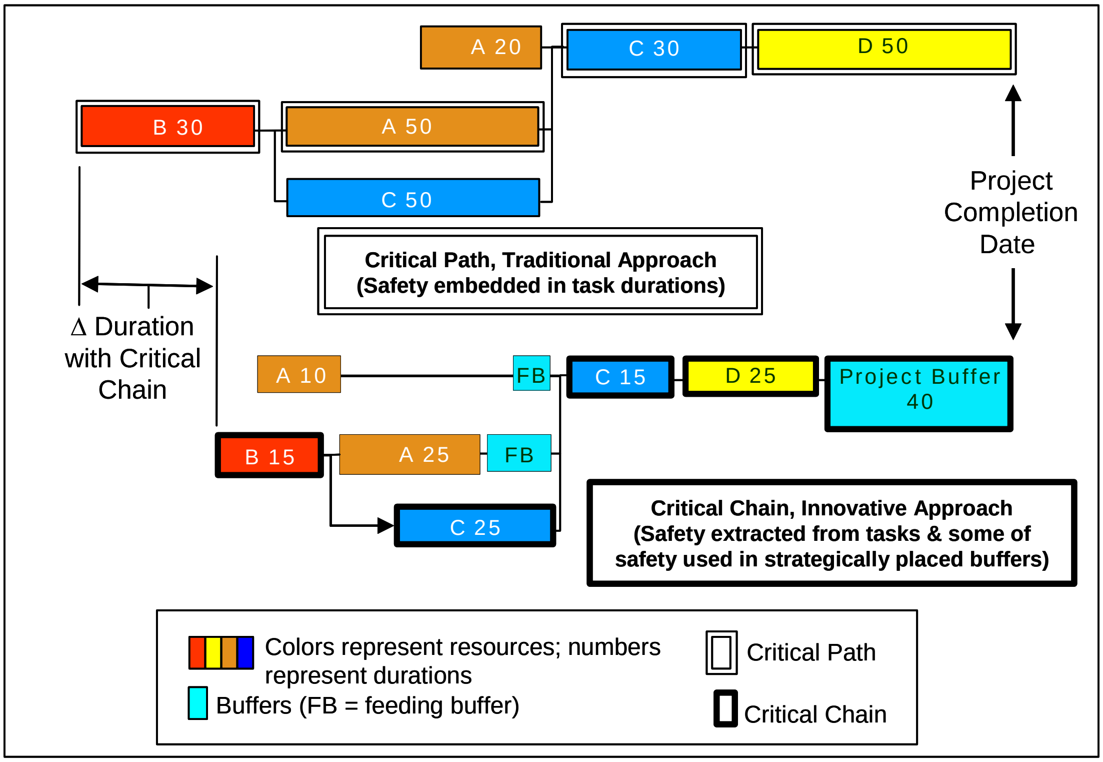

Figure C-2. Depiction of project networks: Critical Path vs. Critical Chain (adapted from Kendall , 2004).

Regarding the shorter total span for the CCPM project compared to the span for the CPM version of the same project, it should be recalled that all though both project start with the same amount of safety, the CCPM approach uses less of the safety, by taking advantage of the fact that a late finish in one task can be offset by an early finish in another task. That important difference in the way safety is used can often lead to a shorter schedule as shown in the diagram. However, it does not *always* lead to a shorter project span because the intense CCPM emphasis on the interdependencies—whether task or resource—may generate a *different* network and longer span for the same project than the CPM process.

APPENDIX D - Learning Curve Applied to Finishes

The comparison of the application of F/A-22 finishes to the major aircraft components before and after the adoption of the Critical Chain Project Methodology produced the following graphical comparison of results:

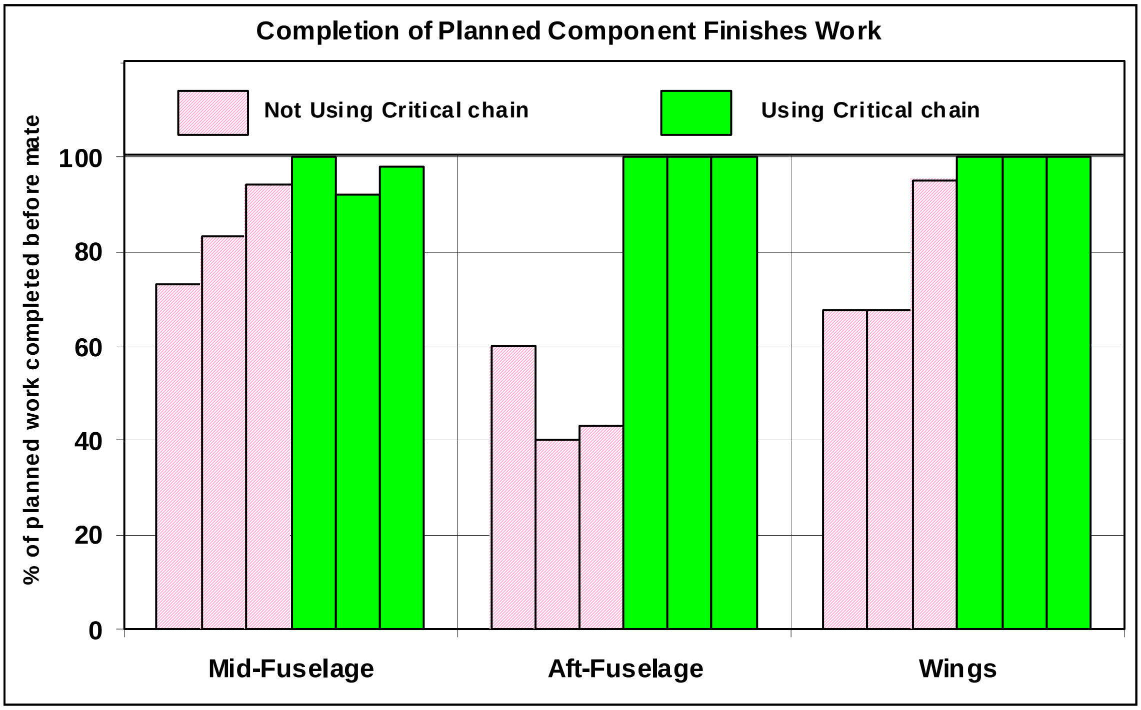

Figure D-1. Comparison of percent of work completed before and after CCPM.

Especially for the Aft-Fuselage and Wing components, the results appear to suggest that use of CCPM had a significant and positive effect on the results. However, as encouraging as the post-CCPM picture for components is, it is important to assess whether CCPM is the only or dominant factor in meeting the finishes objective—100 percent of the work completed on time. A classic way to look at results is through the lens of the learning curve calculation.

A "learning curve" is the result of a mathematical assessment over time of the extent of improvement or reduction in the amount of labor required to execute a stable, repeatable manufacturing process. Essentially, it is expected that qualified workers will be able to complete a given process in less time as they "learn" and become progressively more proficient. Typical improvement in common manufacturing processes follows a 90 percent learning curve; that is, each time the number of units produced doubles, the time to complete the process is 10 percent less than before.[1]

When the learning curve algorithm is applied to the data associated with the finishes labor for the Aft-fuselage and the Mid-fuselage, the results are reflected in Figure D-1.[2] The graphs show somewhat of a saw-tooth pattern of "actual" experience for both components prior to the implementation of Critical Chain Schedules and tracking. Only after the scheduling and execution of the schedules using CCPM commenced did the lines that plot actual labor hours for both components show a noticeable (and desirable) downward trend.

For the Aft-fuselage, it can be observed that only after implementing CCPM did the "actual" curve make sustained progress toward the 90 percent learning curve, actually dipping below the 80 percent curve for aircraft 4013. For the Mid-fuselage, where the pre-CCPM actuals seem closer to the 90 percent line, the post-CCPM actuals seem to be converging closer to the 80 percent learning curve.

It is possible that the impact of CCPM is even more substantial since it assisted in improvements despite the fact that the learning curve methodology assumptions of a "stable, repeatable manufacturing process" and "qualified workers" were not fully active. However, because changing processes, materials and increasing proficiency on the part of the workers cannot be denied as factors—along with Critical Chain—it appears that "technology cluster" mechanism is again at work. The presence of several factors precludes certainty regarding the contribution of each to the change in the learning curve.

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[1] Specifically, if T_i represents the time to complete any given unit, then, T_2 is $.9 * T_1$, T_4 is $.9*T_2$, T_8 is $.9* T_4$, etc.

[2] The title of each graph notes that finishes work did not begin with the components for 4004, but rather those for a "pole model" used for preliminary testing of the F/A-22 stealth characteristics at a special range. As a result, some learning is assumed to have occurred prior to 4004, which was considered T2 in the learning curve calculation.

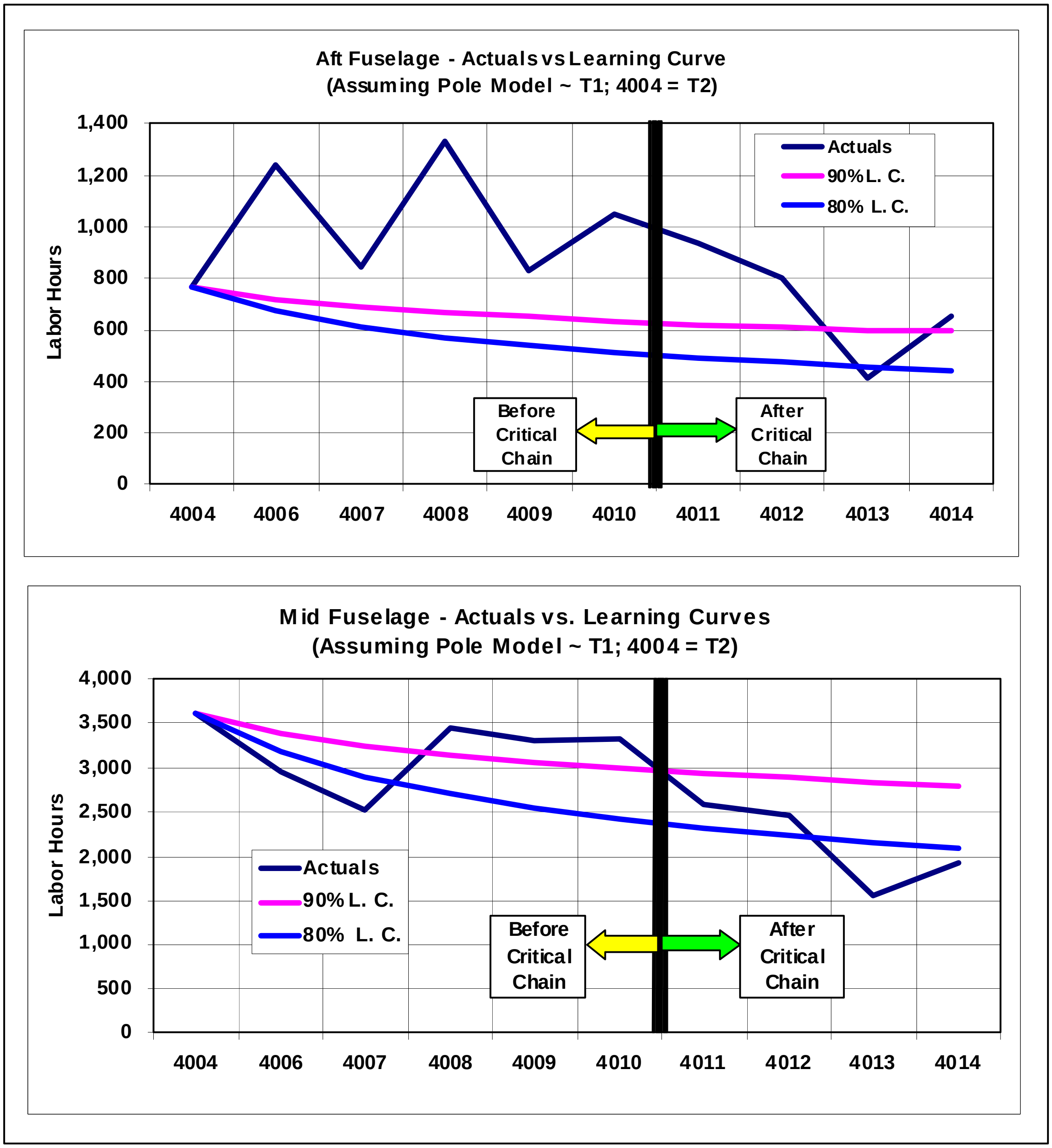


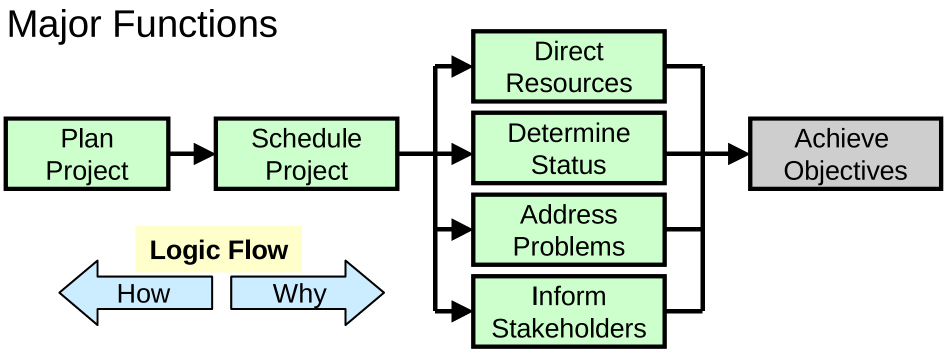
Figure D-1. Depiction of learning curves and actuals for Finishes IPT labor (derived from Finishes IPT 4006 project file archives, June 2001).

It is possible that the impact of CCPM is even more substantial since it assisted in improvements despite the fact that the learning curve methodology assumptions of a “stable, repeatable manufacturing process” and “qualified workers” were not fully active. However, because changing processes, materials and increasing proficiency on the part of the workers cannot be denied as factors—along with Critical Chain—it appears that “technology cluster” mechanism is again at work. The presence of several factors precludes certainty regarding the contribution of each to the change in the learning curve.

APPENDIX E - Summary of CCPM-CPM Trade Study at CTF

In response to tasking from a general-officer led Tiger Team in the Fall of 2000, a trade study comparing the proposed CCPM approach and the then current approach using Microsoft Project™ software driven by the Critical Path Method was conducted. Based on its successful use in association with studies conducted in other areas of the F/A-22 program under the Lean Engineering program, the “Function Analysis System Technique” or FAST approach was adopted as a framework for the evaluation of the two approaches. The FAST conceptual approach and the specific functions of the flight test planning and execution process to be evaluated by the trade study using the FAST approach are shown in Figure E-1, below. Two qualitative criteria were chosen to evaluate the functions listed in the figure, utility and effectiveness. The utility criterion was meant to capture study group views on the cost of implementation of either approach versus its utility in supporting the objectives of the flight test organization. The

Function Analysis System Technique (FAST)
Diagram for Program Mgmt



Functions evaluated in Flight Test Planning and Execution Trade Study

- **Planning**
- **Scheduling**
- **Tracking**
- **Reporting**
- **Resource Allocation**
- **Effective Resource Use**
- **Revising plans/schedules**

Figure E-1. FAST program management diagram & trade study functions.

effectiveness criterion encompassed the capability to meet project objectives, and specifically included the capability to address unplanned work and a high degree of variability or risk, since the Tiger Team and the CTF had expressed concern about the dynamic environment affecting prospects for success.

To mitigate the impact of the distances among the home locations of study participants in Ohio (SPO), Georgia (LM Aero) and California (CTF), maximum use was made of e-mail, video-teleconferences (VTCs) and telephone conferences (telecons). Because of the demands on the CTF members for support of the daily flying schedule, the task to develop and distribute drafts and integrate reviewer comments through several e-mail iterations fell to Casey and Pennington. The reviewers commented by responding e-mails and then all concerned participate in a VTC for final revisions. The results of the extensive discussion on the evaluation of the two approaches were then integrated into primary and back-up charts to support the presentation form that had been agreed to for capturing results. Table E-1 below summarizes the final results.

Ratings* Summary	**CURRENT APPROACH (Critical Path Method)**		**CRITICAL CHAIN Project Management**	
FUNCTION	**UTILITY**	**EFFECTIVENESS**	**UTILITY**	**EFFECTIVENESS**
Plan Project	MED	MED	HIGH	HIGH
Schedule Project	MED	LOW	HIGH	HIGH
Allocate Resources	LOW	MED	HIGH	HIGH
Determine Status	LOW	MED	HIGH	HIGH
Address Problems	MED	LOW	HIGH	HIGH
Inform Stakeholders	MED	LOW	MED-HIGH	HIGH

* Ratings are on management approach--<u>not performance</u>

***Table E-1*. Results of trade study on CTF management options for Tiger Team.**

As reflected in the table, the results strongly favor the CCPM methodology. This top-level summary was presented to the Tiger Team and the CTF leadership at the October meeting of the Flight Test Tiger Team and led to the decision to implement the use of the CCPM innovation on the F/A-22 program at the CTF.

APPENDIX F – Development of F/A-22 CCPM Jump-Start Process

In late June 2001, the decision was made to implement the use of the CCPM innovation for the development of a new module for F/A-22 computer known as CIP-2K. The purpose of this appendix is to provide a detailed description of the process by which the CCPM innovation was tailored, or "reinvented" in the vernacular of the CHIP model based in the Rogers formulation of the ambidextrous theory of organizational innovation, to satisfy the needs of the CIP-2K project up to the point that the plan was implemented and began tracking.[1]

Development of the CCPM "Jump-Start" Plan at Raytheon

During July 2001, Casey and Colby worked with the Avionics IPT leaders, RSC CIP-2K managers, CIP-2K integration project leader (designated as CCPM lead for the CIP-2K group at Raytheon), contacts at Raytheon headquarters in Tucson, Arizona, the TSC involved in the Finishes and CTF efforts, the Sciforma® representatives and contracting personnel at all sites. The objective was to get the CIP-2K CCPM implementation effort under way as quickly as possible.

The first and foremost concern was to develop a technical approach capable of getting to a plan that could be baselined much quicker than had been the case in the F/A-22 Finishes CCPM pilot application at Marietta. Most helpful in that regard were the individuals from Raytheon's "Chain Gang," a subset of Critical Chain enthusiasts within that corporation's larger group which bears responsibility for continuous improvement efforts of all kinds within the Raytheon Corporation. An early-July telecon with representatives from Raytheon's offices in Tucson and Dallas led Casey and Colby to the conviction that a tailored version of what Raytheon called the "Blitz Week" approach

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[1] Details of this section are based on the author's Memorandum for Record: Summary of CCPM Jump-Start Week at Raytheon Company, 23-27 July, 31 July 2001 and Memorandum for Record: Follow-on Support to Raytheon after Initial Blitz-Week for CIP-2K, 13-15 Aug, 20 August 2001

to implementing CCPM should work in the CIP-2K program. The approach was especially appealing because the objective was to conduct an intense initial week of effort leading to a schedule that workers and management could commit to and begin tracking in just a few weeks.

Content for this approach evolved from the initial and several other discussions and drove the preparation and structuring of the vitally important first week activities that came to be called “Jump-Start” in the CIP-2K application.[2] Some of the key steps and considerations that led to the presentations are as follows.

- The first step was to provide some level of training on Critical Chain concepts. Here, the TSC was very helpful in providing Casey and Colby with modifications and teaching notes for the TSC’s standard package of presentation materials, including class participation “games” that reinforced key points made in the presentation.[3] The CCPM leads further tailored the introductory training package with wrap-up slides that outlined the Jump-Start week plan and emphasized the need for behavior changes associated with CCPM execution of the plan once it was developed. This was estimated to likely require the full first day of the Jump-Start week.
- The importance of getting the customer (in this case, LM Aero) involved meant that besides getting Avionics leaders approval for use of CCPM, it was important that those closest to Raytheon at the working level should participate in the training to assure their understanding, agreement, timely involvement in decisions and, in any case, support of the decisions prompted by CCPM during both the planning and

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[2] “Jump-start” was adopted as the descriptor of this and other LM Aero F/A-22 applications to avoid the connotation that the term “blitz” had taken on. As used in references to “events” such as KanBan or Kaizen that are part of Lean Engineering techniques, “blitz” has come to imply that the effort is essentially “done” in one week except for required documentation. The intent of using Jump-Start is to convey the idea that the first week is a very solid and substantial start, but there is a fair amount of work to do before baselining a schedule and executing the project.

[3] In particular, the “bead game,” originated by Tony Rizzo of The Product Development Institute, was used to convey the serious negative impacts on project goal achievement of player “multi-tasking.” Though embedded in a highly simplified assembly process, the game compellingly conveys the value of focusing on and finishing one task at a time instead of trying to multi-task, i.e., the effort to simultaneously make progress on two or more tasks.

execution phases. As a result, the LM Aero Core IPT leader (responsible for managing RSC activities) agreed to attend the training. In addition, the Avionics IPT leader (who had already become familiar with CCPM during familiarization training at Marietta) arranged his schedule to visit RSC during the Jump-Start week.

- The second step in the process involved discussion to gain consensus on the overall project objectives, deliverables, and success criteria. This step would set the direction and pace of the overall effort, and also act as an important consensus-building effort to get the RSC implementation group and its customer (the Core IPT leader) on common ground.
- The next step—development of the initial task dependency network build—required only a smaller, core group of planners, thereby permitting the rest of larger group (i.e., others that participated in the earlier training and setting of objectives deliverables and success criteria) to return to normal duties to be “on call.”. This smaller group was planned to include the CIP-2K integration project leader, one or two other technical leads as seen appropriate by the project leader and one or two schedulers who would use the software. Casey and Colby would facilitate the effort of this core group to develop a good “first cut” at laying out the network including tasks arranged in appropriate relationships, estimated durations (where known) and resource requirements. This was expected to take approximately the next two days of the Jump-Start week.
- The fourth step was to call in other members of the group originally trained on the first day to help “fix the logic” (i.e., add/delete tasks and correct task relationships as appropriate) and add or revise the roughly estimated durations (to include both “aggressive-but-possible” and “highly probable” or “safe” estimates), and to refine or add any resource assignments as appropriate. This effort was planned to consume most of the rest of the Jump-Start week.

- Overall, Casey and Colby had some trepidation about achieving the first week objective of significant progress on the task dependency network to something on the order of a “60-80%” of the plan that would eventually become the baselined schedule. The Raytheon “chain gang” helpfully noted that their experience was that the plan outlined would achieve the objective and the size of typical network produced in their experience was about 3-400 nodes for a relatively small program. In response to the CCPM leads’ concern that the RSC effort avoid the kind of huge network that proved unwieldy in the finishes effort, the “chain gang” representatives suggested the use of an approach described by a TSC-trained CCPM expert at a TOC-oriented conference.[4] The approach suggested use of natural handoff points. An example is the point at which the product of one resource (whether an individual or a particular team) leaves control of that resource. Such a point is typically an appropriate termination for one task and the beginning of the next. Regarding task length, the discussions suggested that spans from one day to even months could be expected, but interdependencies and hand-offs were more important than spans.
- Especially as a result of experience and elite personnel discussions in the Finishes IPT area, CCPM software training was recognized as important for the few project personnel that would actually maintain and update the schedule using the software. After the Raytheon project lead identified the individuals assigned to the schedule maintenance/update role, Casey arranged with the Sciforma® representative for download and extended use of demonstration copies of the PS8™ software as well as familiarization training sessions via “web-demos” prior to the actual conduct of the “jump-start.”

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[4] Austin, K. A. “Simple rules for network building.” APICS Constraints Management Conference, March 1991.   .

- The jump-start planning discussions reviewed the plan for network development, namely, the use of small Post-it© notes to develop the network, using the same process as described and used during the Finishes pilot effort at Marietta. The Raytheon "chain gang" representatives suggested that the facilitators would normally plan on inputting the results of each day's network development effort into the computer in the evening to be ready the next day. However, CCPM leads modified that approach to plan, instead, on using the scheduling member of the Raytheon group to input the network information into the computer using the software. Then, Casey and Colby would offer "over-the-shoulder" help to assure the RSC team would be comfortable with the software and largely self-sustaining after the Jump-Start week.
- Regarding "aggressive times" the "chain gang" experience suggested that Casey and Colby not overemphasize the absolute accuracy of initial estimates. The Raytheon experience during planning and execution showed that many personnel, especially engineers, like to retain a substantial measure of "pad" or safety, thus leading to schedules that were initially longer than necessary. However, the same experience proved that this estimating inflation tended to work itself out during execution. As an example, one group was six weeks ahead of schedule when only 3.5 months into a 23-month schedule (that included a four-month buffer).
- The last point emphasized by the "chain gang" representatives was that where behavior change must occur is not the workers, but rather the managers. The "chain gang" lead estimated that 80 percent of the Raytheon change management skills training was aimed at managers. The "chain gang" lead also emphasized that an earlier attempt at a CCPM implementation at El Segundo on an Army-funded program had failed because there had been no CCPM "policeman"—i.e., no CCPM-

versed person—on the premises or in close contact with the implementing team to assure the CCPM procedures and behaviors were emphasized.

Table F-1 summarizes the plan that was developed based on the foregoing considerations.

“Jump-Start” Plan

- Jump-Start begins with a week-long activity on location with right attendees
- Monday:
  - Critical Chain training for larger group, followed by development of project Objectives, Deliverables & Success Criteria
- Tuesday - Thursday:
  - Smaller group develops *initial* project network using Scitor PS8 software
    - *Includes all tasks, durations and resources*
  - Work force augments small group to do safety checks and “fix the logic”, finalize & buys-in to durations, task dependencies, etc.
- Friday Morning:
  - Review progress, develop plan to go forward
- Following “jump-start” week
  - Local team expands plan as needed to refine & validate (2-3 weeks)
  - “Coaches”/Facilitators return after 3-4 weeks to help finalize plan & present to management who agree plan is a “go”
  - Implement schedule
  - Update frequently, track and report progress on a weekly basis
  - Institute Buffer Management

Table F-1. Summary of CCPM Jump-Start plan developed for CIP-2K project.

With the formulation of the Jump-Start game plan, Casey and Colby worked with the Core IPT lead, the Raytheon CIP-2K integration project lead and contracting and management personnel at LM Aero and RSC to refine and finalize the approach funding requirements and time-table for the CCPM implementation at Raytheon. The plan called for Casey and Colby to act as facilitators for the execution of the Jump-Start week during the week of 23-28 July 2001. Then further work on the network would be accomplished by the CIP-2K team at Raytheon over two to three weeks with electronic and telecon support from Casey and Colby at Marietta. Thereafter Casey and Colby would return to RSC for 3-4 days to help finalize the network and assist in development of a briefing for

Raytheon and Core IPT team managers on 15 August. This plan was tentatively agreed to by the RSC deputy lead for CIP-2K and the Core IPT leader and approved for go-ahead by the Avionics IPT leader.

Initial Execution of the CCPM "Jump-Start" Plan at Raytheon

The plan was carried out as outlined above, a Training Day, followed by three network development days and one day of network refinement and planning for further development. The Training Day (23 July 2001) included six hours of training presentations by Casey and Colby and the class-participation exercises. Thirteen personnel participated, including the CIP-2K program managers from Raytheon and LM Aero, the project manufacturing and integration leaders and their deputies, leads or representatives from hardware, software and firmware design, product testing, system engineering, and the local representative of the Raytheon 6-Sigma group. The class was uniformly impressed by the participation exercises that emphasized (1) the penalties associated with multi-tasking (the "bead game") and (2) the step-by-step "walk-through" and discussion of a buffer management scenario.

At the end of the day, the CIP-2K Integration (and CCPM) Lead provided an overview of the CIP-2K project, including both the primary Raytheon responsibilities and the interaction with the other members of the overall CIP-2K project. Her briefing led to a discussion that quickly identified the objective (and deliverable) of the project to be Raytheon's delivery of a particular product, the Circuit Card Assembly or CCA,[5] to the LM Aero Cockpit-Avionics Integration Laboratory (CAIL) for further testing. The success criterion was identified to be the inclusion of full assembly functionality.[6] The short term objective of the "jump-start week" was agreed to be an initial "80 percent answer" for the

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[5] The CCA was important because it was a common element of virtually all modules that make up the F/A-22 CIP.

[6] To avoid compromise of classified terms or capabilities as well as to avoid descent into what might be confusing technical jargon, parts and functions of the CIP-2K module will be referred to in general terms. The level of detail nevertheless permits full description of the application and results of CCPM use.

CCPM network and schedule. This was defined as a network that fairly represented the bulk of the work necessary to accomplish the objective, with a clear road-map for refining and improving the “80 percent answer” and completing the last 20 percent of the schedule so the total package could be baselined in the near term and tracked through execution.

Jump-Start Day 2, the start of the actual network development, began with a small, core working group as planned. Included were the CIP-2K Program Manager, particularly knowledgeable about the hardware “build” or assembly process, the CIP-2K Integration Lead and her deputy, the deputy hardware design lead, the scheduler, and Casey and Colby. Also observing the process and responding to occasional questions were the LM Aero Avionics IPT Manager, the CIP-2K IPT leader and the Avionics System Manager (ASM) IPT leader. Though the group was organized to maximize use of Post-it”© notes on white paper, the CIP-2K team was very quickly and effectively using the white-board and overhead projector to construct a super-structure of the network that involved the hardware build and assembly, integration of firmware development and build, software build and internal testing leading to the required delivery.

Casey and Colby facilitated the discussion and network development by asking questions about other tasks to support those that were identified, additional dependencies, etc. The group made good progress that seemed so clearly on the right track that Casey and Colby began working with the scheduler to begin inputting tasks into the Sciforma® PS8™ software on the Raytheon computer and an LM Aero laptop computer. By late morning, Colby and the RSC Integration/CCPM lead facilitated discussion among experts on design and integration tasks that related to two key firmware and specialized module components. Casey was working with the CIP-2K Program Manager on the hardware assembly process that led to three progressively more complete versions of the modules required to support internal RSC "proof of design" (POD) testing, further development and testing by the so-called "Group 1/3" suppliers.[7] The day concluded with a discussion of the hierarchical (parent-child) organization of the network, which at the time included some 180 task "nodes".[8]

Jump-Start Day 3 continued network development with fewer Raytheon people involved than the previous day, but good steady progress was made in refining and expanding the network throughout the long day. Casey worked with the hardware Subject Matter Experts (SMEs) to revise the hardware-build process for the basic module to clarify dependencies and add tasks. The effort took the better part of the morning, but produced a "template" that was quickly transformed into tailored versions of the same process for the eight other specialized modules needed by the Group 1/3 suppliers.

Meanwhile, Colby and Raytheon's CIP-2K Integration/CCPM lead reworked and expanded the firmware and network Gantt structure with the nearly all-day help of the SMEs from the firmware build area. The template that emerged in the firmware area was then duplicated and tailored to account for the eight specialized sets of firmware. The dedicated perseverance and drive of the Raytheon CIP-2K Integration/CCPM lead was reflected in her work well into the evening to document the results of the discussion.

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[7] Group 1/3 was a shorthand term used to refer to tasks that required a Raytheon component on one side of the "board" that was the heart of the module (reflected in the "1"), but which were the responsibility of the three other suppliers that built a specialized component to fit on the other side of the "board." The three suppliers were General Dynamics Decision Systems (GDDS), Scottsdale, AZ, who built the component associated with protection of classified information; Lockheed Martin Missiles and Fire Control (LMM&FC), Orlando, FL, who built a component associated with the Electronic Warfare (EW) system, and Harris Corporation, Melbourne, FL, who built a component associated with high speed communication within the CIP system.

[8] It is worth noting that though largely passive, the presence of the LM Aero IPT leads was beneficial. The Avionics IPT leader noted he was glad he was there for two reasons: (1) he realized that the kind of internal coordination he had assumed had not taken place and he realized better where RSC actually was; and (2) he recognized the Critical Chain process was providing the catalyst for the kind of dynamic interaction and coordination essential for progress.

At that time, the two separate hardware and firmware networks totaled some 800 task nodes.[9]

Jump-Start Day 4 involved extensive network refinement and integration of the hardware and firmware task networks using the “merge” function of the Sciforma® software. The straight-forward dependency links were very quickly made and by mid-morning the dependency network comprised some 850 task nodes. The Raytheon CIP-2K Integration Lead then worked with the individual hardware, firmware and integration test leads to detail the aggressive and safe task duration efforts and identify the required resources. Late in the day as the team was just about in position to begin initial checking of total project duration, a substantial expansion in detail for the test sequence was required and expeditiously accomplished. By the end of another long day, while recognizing durations and resource assignments needed to be added and all rechecked in the network that had stabilized at some 925 nodes, the team was able to “run” the critical chain functions of the software.

Though initial runs indicated the span was considerably beyond the desired span, this situation was not unexpected based on both the LM Aero experience with the Finishes CCPM project at Marietta and the Raytheon “chain gang” experience in several applications. Prior to exercising the automated algorithms that generate the Critical Chain and buffers, the group reviewed diagrams of resource needs over time (called “resource histograms,” (see Figure F-1) and recognized some potentially serious overloads without even exercising the Sciforma® PS8™ critical chain software functions.

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[9] While the CCPM network building efforts were proceeding, senior Avionics IPT leaders were separately considering strategies for possible options to answer program management certain questions about the plan to overcome CIP-2K problems. Unfortunately, the CCPM effort was incomplete, and therefore could not contribute usefully to their discussions at that time. The situation suggests that leadership must anticipate the decision “crunch” to permit sufficient lead time for CCPM Jump-Start support—probably no less than 30-40 days from program reviews. The remaining period after the jump-start week itself can be devoted to network refinement, “safety-net” revisions, what-ifs, and appropriate build-up of buy-in by supplier and customer hierarchy before iron-clad commitments to program are made on the plan of action.

As expected, the limited personnel availability generated "stretch-out" of project task spans in order to complete tasks within manpower limits. To demonstrate the software flexibility for the CIP-2K Integration/CCPM Lead, the team then exercised several "what if" scenarios.

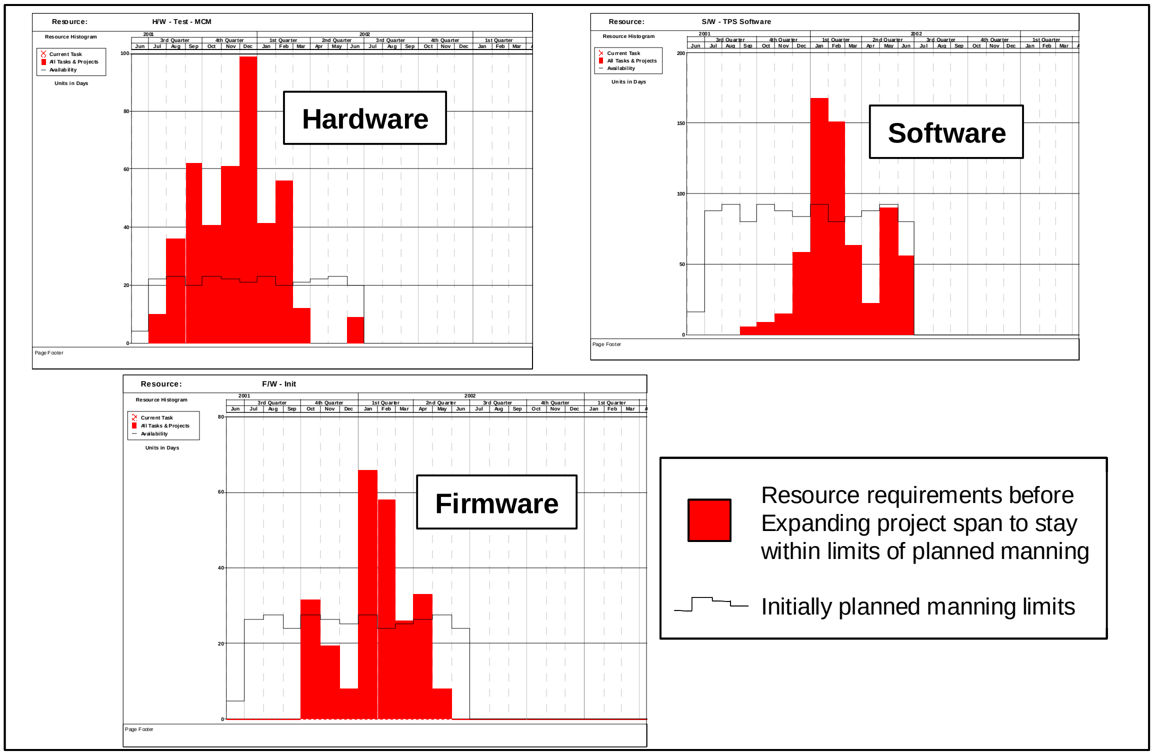

Figure F-1. Illustrative initial Raytheon CIP-2K personnel needed vs. planned.

Jump-Start Day 5, the last day of the initial week, began with some additional network clean-up and refinement, but focused on the "go-forward" plan. The LM Aero and Raytheon CCPM leads agreed that the goal of an "80 percent answer" had been achieved in the structure of the nearly 1000-node network. All agreed that the network could grow by more than 20-40 percent in terms of task nodes, but those additions would primarily involve more detail than changes in structure or flow. Plans were made for Raytheon to continue to expand the network by refining tasks, durations, relationships and resource assignments and, importantly to gain "buy-in" from the SMEs who would do or supervise the work. This was expected to take approximately two additional weeks, so the LM Aero CCPM leads agreed to reconvene in the same location during the third week to finalize the network, prepare for baselining the schedule and to jointly pre-brief first level Raytheon and LM Aero CIP-2K management in preparation for an impending Program Management Review by LM Aero program Management. All agreed that it was important to avoid sharing too much of the detailed results with the hierarchy until the CCPM team had more confidence in the validity of the network through additions corrections already known to be needed and further efforts to use the safety nets of review and refinement. Equally important was to avoid the temptation to "make it fit" to a mandated delivery date that the most credible task dependencies and durations clearly indicated was not technically feasible.

Prior to their departure, the LM Aero and Raytheon CCPM leads provided status via telecon with the Avionics Core Products IPT manager, responsible for the CIP-2K development and sponsor of the CCPM initiative. The discussion covered the progress made and the go-forward plan developed after the manager had departed two days earlier. A caution was raised that the absence of details of the other Group 1/3 suppliers (GDDS, LMM&FC and Harris) would require further discussions and "buy-in" to the plan from them before the current or fully developed plan could be considered credible. Though disappointed that an "answer" was not yet available, he understood that the process would require more time and acknowledged the Group 1/3 concern. Besides agreeing with the strategy and plan to move forward toward closure on a CIP-2K schedule that could be baselined, he expressed his own and the Avionics IPT recognition that much of the progress should be credited to the Raytheon CIP-2K Integration/CCPM leader. Her enthusiasm, perseverance, technical expertise, driving leadership and strong belief in the Critical Chain process and initial and foreseeable products generated a commitment and seriousness about "getting it right" that pervaded the entire effort.

The actual follow-up working session at El Segundo, California, was conducted during 13-15 August. The substantial Raytheon revisions during the 30 July – 10 August period[10] resulted in a network of some 1600 task nodes and primarily involved the hardware build. Because of the process of refining one major module sections of the network and then using the “block and copy” function to assure the other module sections were updated and tailored as appropriate, the Raytheon CIP-2K Integration/CCPM lead knew that key relationship links were missing from the network. As a result, the majority of the first day was dedicated to establishing the proper predecessor/successor relationships and adding additional tasks as needed. In fact, this was one of several steps in the checklist (see Table F-2) developed by Colby to permit a rigorous review of the process and product. The key tasks focused on getting dependencies right and resources assigned to all Raytheon tasks, to permit running several “what-if” scenarios on the following day.

<u>CIP-2K Jump-start Network Evaluation Checklist</u>

- Check Logic Does the logic ring true? (use some of the 5 safety nets)
  - Dependency, necessity, resource definition & allocation, SME buy-in to tasks and durations
- Check Resource allocations
  - Review resource histograms for heavy resource dependency?
  - Any missing allocations / assignments
- Check Calendars
  - Holiday’s? Overtime? Shifts 8 hrs? 10 hrs?
  - Calendars applied to project file
- Dependencies
  - Check for missing predecessors / successors
  - Check for missing parent / Child summations
- Understand Group 1/3 activities of Harris, Motorola, LM Orlando
  - Ascertain availability of necessary software tools
  - Check on structure of the integration activities and flow
  - Rigorous review of all ASICs
- Subject Matter Experts (SMEs) have bought into tasks, durations and assignments
- Discuss options for Buffer Calculations
  - consider three scenarios for % of safety removed:
    - 50% = general rule of thumb
    - 75% = more conservative hedge against some uncertainty in estimates
    - 100% = most conservative to account for high uncertainty in estimates
- Run “what-if’s” looking at different shifts, resources, and buffer calculations.
  - What about completed activities? How about target date?

Table F-2. Checklist for CCPM Jump-Start follow-up.

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[10] During the period, files were frequently exchanged and several telecons took place between Raytheon Casey and Colby to resolve questions, occasionally drawing on the ready technical support from Sciforma® experts.

Efforts on the next day began by running the first scenario with what was thought to be a reasonably complete and accurate network. Somewhat as expected, anchoring the delivery to the 28 June 2002 desired date for delivery of the first products to the LM Aero Integration Lab indicated that current tasks should have been accomplished two years earlier. Review of the resource histograms (illustrated earlier in Figure F-1) showed that heavy overloading of the limited resources required to accomplish most tasks were a large part of the expanded span. Addition of resources for periods of high demand eased the overloading and reduced the span, though several other actions were required to reduce the span further.

Unfortunately, the day was marked by delays for numerous operator-generated software problems[11] and problems with configuration control of the "best" scenario due to confusion between the use of local and network drives. Despite these problems, there was considerable progress made.

The third day of the working session started with resolution of the configuration tracking problems and continued running of additional scenarios to prepare for the mid-morning review with Raytheon and LM Aero Avionics leaders. In a preliminary review, the LM Aero Avionics Core Products IPT manager raised questions about key deliveries to the Group 1/3 suppliers. The emphasis on these deliveries had not been picked up as an element of the "deliverables" discussions on the first day, and as a result it created a flurry of activities to get the answers to the questions at the same time that the group was preparing for the briefing to the leaders.

Despite the effort to reduce spans, in the end, as reflected in the progression of scenarios (Table F-3), the only way to generate a start date in August 2001 was to

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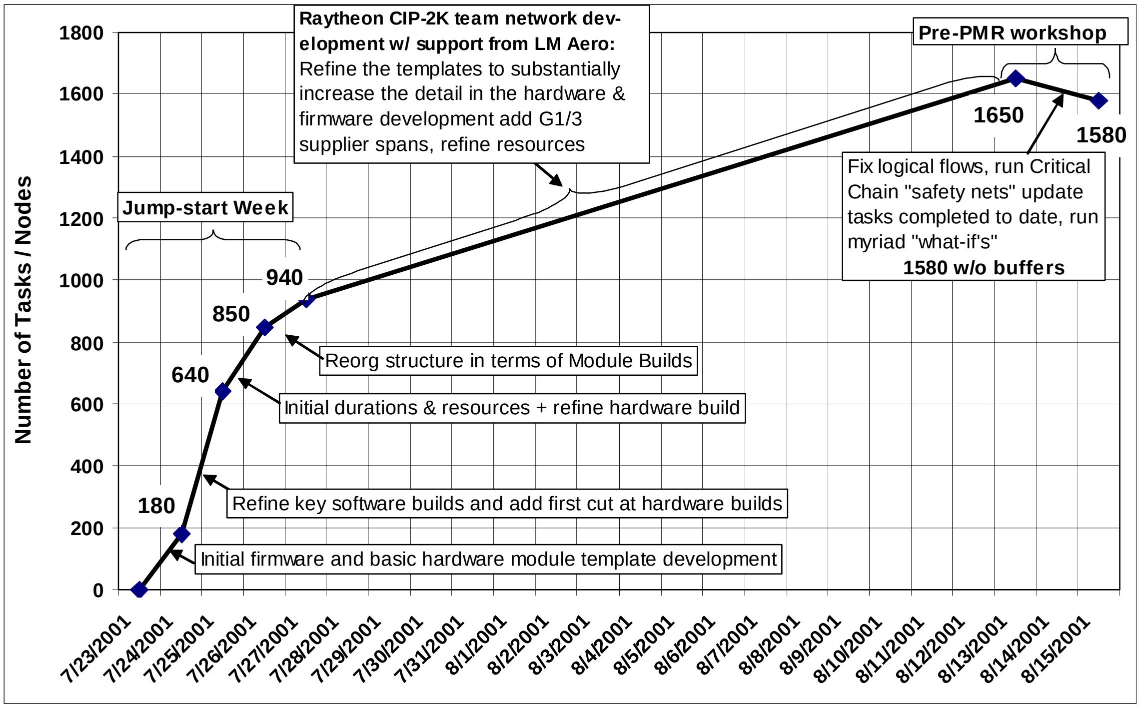
[11] Complexity of the network and less than full knowledge by those present of Sciforma® software reflected probable need for Sciforma® on-site assistance or more extensive software training for LM Aero and Raytheon operators.

	Scenario Description Scenarios #1-6 Based on 6/02 Raytheon product delivery to the LM Aero Integration Lab	Tasks w/ Buffers	Project Start date	Project Buffer Start	Project Buffer Length	Observations
1	First run with initial network	1680	8/13/1999	8/31/2001	204 days	Heaviest resource overload (push left) in firmware, other overloads in software and hardware test.
2	Increase key resources in firmware, software, and hardware overload areas. Check with management suggests it is feasible for periods of need. Eliminated completed tasks	1654	9/7/2000	2/8/2002	101 days	some overloads remain
3	Updated ~25 completed tasks; changed some unrealistic dependencies	1646	2/5/2001	4/22/2002	50 days	Result not entirely reasonable; project buffer duration uncomfortably short, some very long feedng buffers.
4	Eliminate supplier spans that seemed excessively long.	1620	2/13/2001	4/11/2002	60 days	New supplier spans require concurrence from Gp 1/3 leads.
5	Reduce assembly span at Raytheon plant in TX	1620	3/1601	3/25/2002	70 days	Makes sense but more analysis required.
	Run Scenario shooting for mid-Aug 01 Start					
6	**Secnario 5 with 12/20/02 end date; split Feeding Buffer to protect first delivery to GDDS**	**1620**	**8/17/2001**	**8/26/2002**	**85 days**	**Depicts realistic start date of NOW. Does not detail Group 1/3 activities & relationship to AIL**

Table F-3. CIP-2K Critical Chain planning scenarios.

“anchor” the product delivery date in December 2002. That scenario was chosen to be the core schedule for the briefing and the major finding of the entire effort, namely, that based on everything discovered in the CCPM network and schedule building process, delivery to the LM Aero Integration lab on 28 June 2002 was not feasible and would likely have to be slipped to December 2002.

The presentation of the status of the CCPM effort to the Raytheon and LM Aero CIP-2K managers fairly captured the details of the plan and schedule development effort. Figure F-2 shows the progression of the network build in terms of task nodes). There was natural interest in the credibility of the duration estimates because the leaders were concerned that the delay in delivery could be even longer than six months. The Raytheon CIP-2K Integration/CCPM lead indicated that experience on earlier F/A-22 efforts favored the “safe” duration efforts. Though this would suggest some over-optimism in the schedule, Casey and Colby noted that the earlier experience was based on traditional schedules and management approaches which did not consistently emphasize what was now recognized and emphasized as the critical chain tasks. They



Raytheon CIP-2K team network development w/ support from LM Aero: Refine the templates to substantially increase the detail in the hardware & firmware development add G1/3 supplier spans, refine resources

Pre-PMR workshop

Jump-start Week

Fix logical flows, run Critical Chain "safety nets" update tasks completed to date, run myriad "what-if's"
1580 w/o buffers

Reorg structure in terms of Module Builds

Initial durations & resources + refine hardware build

Refine key software builds and add first cut at hardware builds

Initial firmware and basic hardware module template development

Figure F-2. Evolution of Raytheon CIP-2K network over time.

emphasized what might be most important was the embrace by management of the new paradigm requiring them to foster the "relay-runner" mentality,[12] to give real priority to Critical Chain tasks and the workers engaged in them, and to make the CC schedule updates frequent and the center of weekly reviews and the basis for actions.

In response to question about what actions were required to close on a schedule the team could begin tracking to, the Raytheon CIP-2K Integration/CCPM lead suggested there were "a lot of things to be added." This suggested that the network lacked validity and raised the specter of an oft-observed problem: the fear/perception on the part of the managers of never being "done" with a schedule, thereby delaying team commitment and forestalling the chance for relief from senior management pressure for "the answer." It also related to pervasive questions about level of detail, the true definition of a project, single versus multi-project structure, accounting for the details of

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[12] As noted in Chapter 3, this is the effort to infuse the idea across the work force the idea of starting a task as soon as it is made available, completing the work as expeditiously as possible (without trying to work back-and-fourth between two or more tasks), and passing on completed work to the next task as soon as possible.

interaction between and among Raytheon and the other suppliers and, finally the integration of the Raytheon network into a larger network that provides sufficient insight and tracking of activities for all suppliers, leading to successful delivery of modules to the aircraft to support first flights and all of production.

Despite the absence of unequivocally clear answers to all these questions, the leaders were quite pleased with the progress and the interim product, and all agreed on the need to quickly focus on the issues related to Group 1/3 hand-offs prior to the Program Management Review (PMR) the next week, chaired by the LM Aero VP and General Manager of the F/A-22 program.

At the PMR, the CIP-2K Integration/CCPM lead presented essentially the same briefing as described above. She candidly identified areas of focus for continued refinement of the CCPM network and schedule. She made it clear that the refinements would likely not change the conclusion that late 2002 delivery of the common cluster assembly (CCA) was considered the realistically feasible date, not the originally targeted date of late June 2002. Regarding the absence of detail and commitments related to the Group 1/3 suppliers, the briefing indicted that discussions were already underway to resolve these uncertainties. Though the extension of the feasible delivery date was disappointing, the LM Aero VP/GM regarded the detailed planning that supported the new estimate as quite compelling. In fact, he was convinced that the only way to fully understand and confidently project total system delivery was to expand the scope of the Critical Chain effort. As a result, he directed that the Critical Chain focus be expanded beyond Raytheon’s effort to include the efforts and interfaces associated with the Group 1/3 suppliers (see Figure F-3), considerably expanding both the technical and geographic scope of the project (see Figure F-4). Accordingly, the LM Aero CIP-2K IPT leader was assigned the action to develop a plan and funding requirements to expand the Critical Chain planning effort.

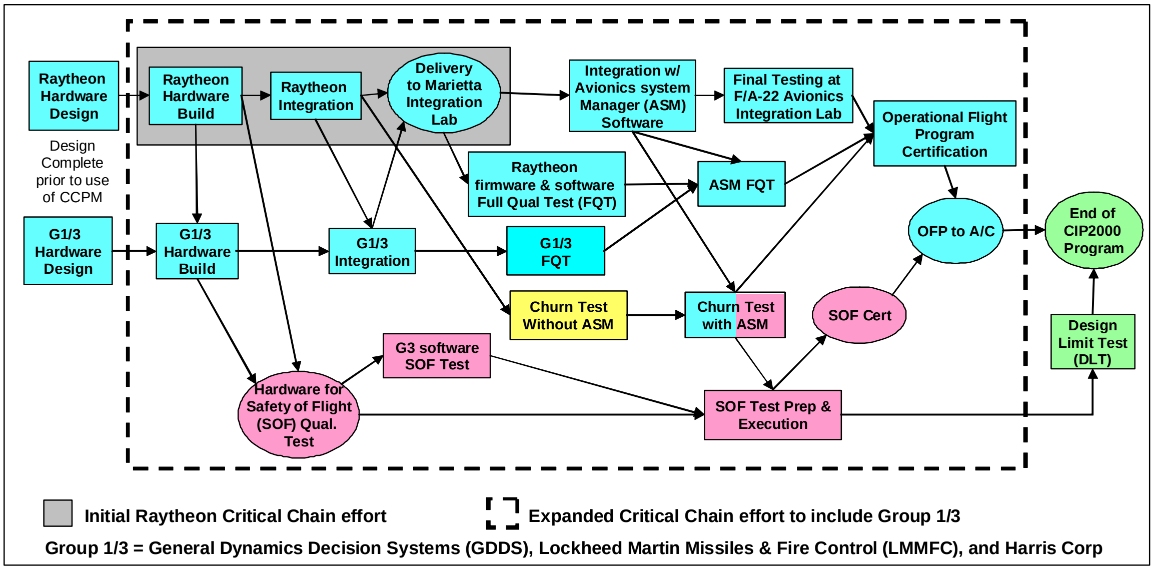

Figure F-3. CIP-2K project with initial and expanded Critical Chain effort.

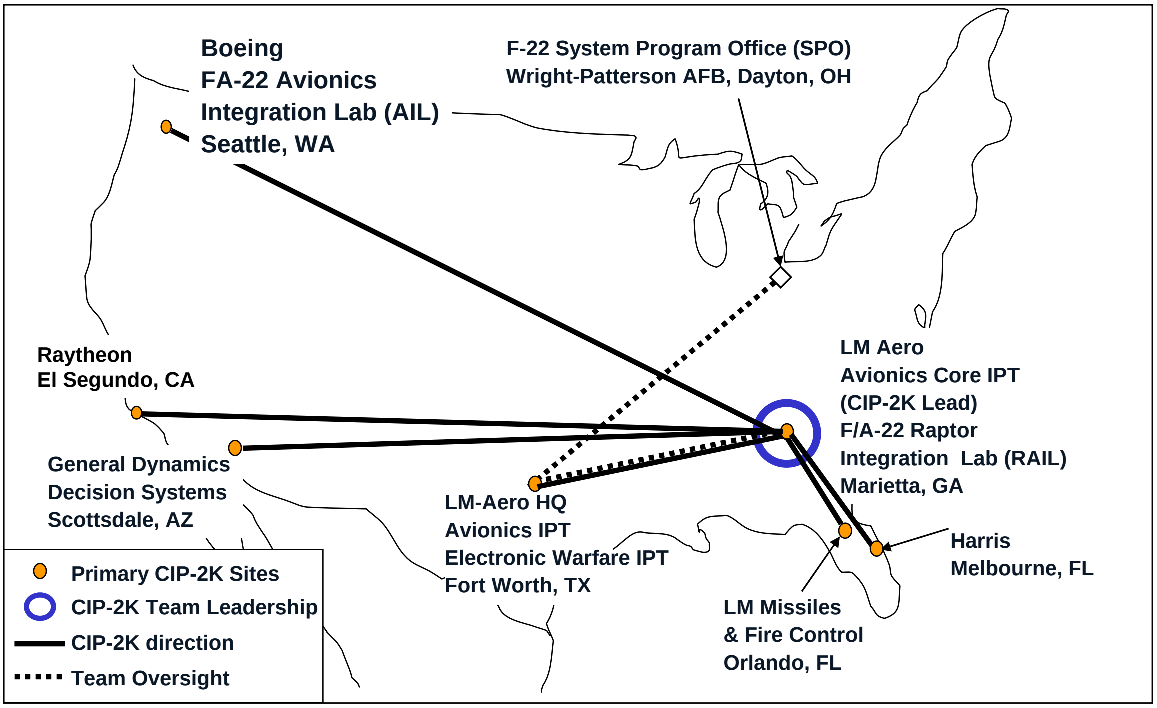

Figure F-4. Location of key players in expanded CIP-2K Critical Chain effort.

Expanded Application of CCPM Jump-Start Process to Group 1/3 Suppliers

Over the next two weeks, Casey and Colby contacted the Group 1/3 suppliers to discuss windows of availability for initiatives at the supplier locations. This included General Dynamics Decision Systems (GDDS), Scottsdale, AZ, Harris Corporation, Melbourne, FL, and a sister company to the prime contractor, Lockheed Martin Missiles & Fire Control Corporation (LMM&FC). Simultaneously, the CCPM leads worked with Sciforma® technical consultants to understand the options for moving ahead with a fully integrated Critical Chain plan that included not only Raytheon, GDDS, LMM&FC and Harris, but the critical integration activities at avionics labs at both Marietta and Seattle. Since the basic options both included the development of separate Critical Chain networks and schedules at all locations, it was clear that the jump-start approach would be appropriate for that step. Once preliminary arrangements were briefed by the LM Aero Core IPT leader to the Avionics IPT manager, the Avionics IPT leader approved the plan and directed immediate implementation.[13]

Over the next three months, the approved plan was followed by the CCPM leads. The order of Group 1/3 supplier CCPM jump-starts and the detail developed in their separate schedules generally followed the priority order of importance apparent from Raytheon's original schedule. GDDS was first, largely because the both the Raytheon CCPM plan and experience to date with the development of computer security modules indicated that the iterative series of product hand-offs would be key to achieving the project goals. LMM&FC was a close second in priority and timing, because the electronic warfare modules for which the LMM&FC team was responsible were quite complex and the hand-offs were also quite frequent. The Harris Corporation modules were lower priority because they were more straightforward than the others.

Similarly, the integration lab schedules for the F/A-22 Avionics Integration Lab (AIL) at Seattle and the Raptor Integrated Laboratory (RAIL) at Marietta were lower priority. Not because they were less important, but because all players felt less detail would initially be required for activities nearly a year away. At worst, a "placeholder" task

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[13] Unpublished briefing, Ken Seeling, "CIP-2K Lot 1 Critical Chain Implementation Plan," 7 September 2001

with an overall span all could agree to could be used. The “as executed” plan is displayed in Figure F-5.

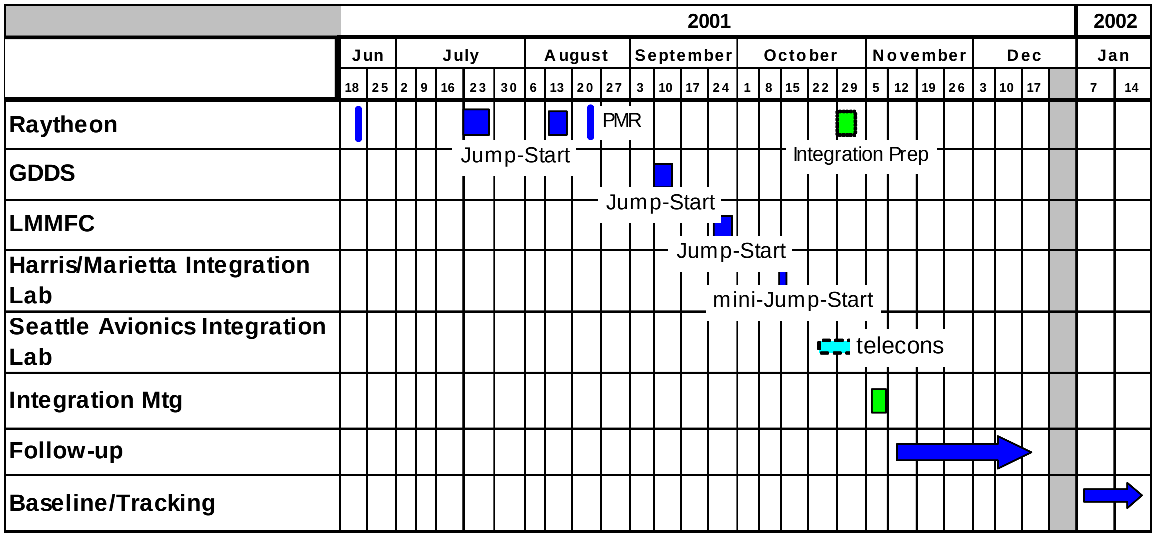

Figure F-5. Chronology of activities to develop integrated CCPM CIP-2K plan.

The jump-start plan used for Raytheon was used in a similar way for the GDDS and LMM&FC locations. For Harris and the Marietta Integration Lab, a “mini-jump-start” approach was used. Specifically, since Casey and Colby were collocated with the RAIL personnel, the process was less formal and extended over a longer period. A training session was conducted for RAIL personnel and attended by the LM Aero liaison representative to Harris. Objectives, deliverables and success criteria (for the RAIL and Harris) were agreed on at the end of training. However, the development of a simple representative network populated with durations that reflected integration experience on the previous CIP module occurred over the next few weeks. The products of these efforts were then integrated, along with other plans to produce a “merged” single project plan prior to the integration meeting in November. Before discussing that important meeting, it is useful to discuss differences that occurred in the jump-start process at the larger Group 1/3 suppliers, GDDS and LMM&FC, as a way of pointing out that as is true with most innovations, some tailoring or “reinventing” is required.

In the jump-start at GDDS, beyond the same training as presented at Raytheon, the construction of the task dependency network was less “free-flowing” because the iterative interaction with Raytheon to exchange hardware, firmware and testing procedures raised a number of contractual issues.[14] GDDS managers wanted to be helpful in developing the network, but felt somewhat limited in identifying tasks that were different from those for which they were under contract.

To break the conflict, the project manager agreed to permit logical development of the task interdependency network with the caveat that any resulting product could only be used as a “working paper,” pending any necessary contract changes. For purposes of the CCPM process, this approach was perfectly acceptable, and progress in developing the network accelerated immediately. As a point of departure, GDDS was already operating with a 1200-node MS-Project™ schedule at a very detailed level. A subset of those tasks were extracted and used to construct the Critical Chain network to the same level of detail as used at Raytheon. When the MS-Project™ and Sciforma® Critical Chain schedules were compared, the Critical Chain schedule established that realistic lead times for Raytheon products extended the span for GDDS work ten months beyond that planned by GDDS. The other difficulty encountered was that some of the task durations were so lengthy that the final CIP-2K project would be delayed well beyond that projected based on the Raytheon plan, which had assumed shorter spans for the GDDS work. After working several “what-if” scenarios, the minimum “disconnect” between needed and projected deliveries of the GDDS products was ten months. It appeared that some of the aggressive durations were excessive compared to similar tasks in the Raytheon network, but higher priority tasking prevented the CCPM working group from access to experts who could explain the reasons for differences or agree to

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[14] The GDDS contract with LM Aero was a Firm Fixed Price (FFP) contract, with less flexibility for change than the Cost Plus Incentive Fee (CPIF) contracts established with Raytheon and other suppliers.

reduce them. As a result the jump-start week ended with the substantial 10-month “out-of-bed” condition, though GDDS agreed to continue to refine the network and revise durations to the extent possible.

The LMM&FC jump-start week was shorter than either of the Raytheon or GDDS efforts. Unlike either of the other sites which had to assign responsibility for the Sciforma® software as an additional responsibility to one of the project engineers, the LMM&FC IPT structure included a master scheduler who was familiar with an earlier version of the Sciforma® software. Both his experience in developing schedules and software knowledge greatly compressed the time required to adapt to the Critical Chain approach to planning and scheduling. In addition, similar to GDDS, an available project network developed using the MS-Project™ Critical Path Method (CPM) greatly streamlined the process for building the Critical Chain network. When resources and durations were incorporated and the Critical Chain algorithms exercised, the project spans appeared quite compatible with the original Raytheon schedule.

Integrating Jump-Start Results and Moving to Plan Execution

Once the initial separate CCPM plans were developed, the options for “connecting” the major players were: (1) a single project approach in which all the schedules would be “merged,” or (2) a multi-project approach, which left the schedules separate with links that represented hand-offs of hardware and software across project boundaries. After extensive discussion, the CCPM leads concluded that the single “merged” project would be the best approach for the following reasons:

- A single project approach would assure that all players were using the same plan to guide their actions, where a multi-project approach might generate too many disconnects over time.
- Multiple project plans owned by the several players might encourage a divisive “we-they” environment where each company might claim to have the only “right” plan.

- Communication and mutual accountability would be enhanced. When the dynamics of the development environment generated early deliveries or forced delays, the ripple effects on all could be better understood within a single project plan.
- As work-arounds and "what-ifs" were required, the analysis of options of what actions would best suit the overall project needs would be simpler with a single project plan.
- Updates of progress would be simpler if everybody was operating from a single plan.

Though the logic was believed sound, it was also clear that changes and modifications of the separate plans would likely be required when the plans were merged into a single project plan. This added importance to what was already recognized as perhaps the most critical component of the overall plan: an integration meeting at which all primary CIP-2K team-members would reach consensus on the plan to deliver CIP-2K to the F/A-22 team.

Given the products of all three of the suppliers, combined with the less detailed for the RAIL and Harris, Colby developed the merged single project schedule which incorporated all tasks. The product was the result of a learning process with multiple iterations resulting from interactions with the suppliers. One significant change was that the Raytheon CIP-2K Integration/CCPM Lead had restructured her network and plan, substantially reducing the number of task/nodes to approximately 1000. This number was the practical minimum required to permit internal management of the Raytheon work while still permitting required visibility of the numerous hand-offs between Raytheon and all the other players. The electronic exchange, review and modification of the merged CIP-2K file resulted in a 1470-node network (see Table F-4, below). The total span was some 24 months longer than the span required to support delivery of the CIP-2K products to support the first F/A-22 in Lot 2, S/N 4028. Even so, the network was the “going-in” plan for the crucially important integration meeting held at the LM-Aero F/A-22 facility in Marietta, Georgia, 6-8 November 2001.[15]

Input Networks	Tasks in Separate CCPM Networks	Tasks in Merged Network
Raytheon	**998**	**943**
Motorola	**242**	**188**
LMMFC	**248**	**239**
Harris	**35**	**54**
RAIL/AIL	**25**	**46**
Total tasks in Merged Network	**1548**	**1470**

Table F-4. Differences in separate and merged CCPM CIP-2K networks.

The integration meeting in November 2001 was held to reach consensus on a plan for CIP-2K development that included sufficient detail to validate feasible delivery dates and to permit active management throughout the period of execution. Besides the Avionics Core Products IPT manager (host), the LM Aero CCPM leads and the F/A-22 SPO Chief, Avionics Systems Development IPT, all the key players were represented by both managers and technical leads. A primary objective and significant challenge for the group was to focus on the number and details of company-to-company hand-offs to minimize misunderstandings during execution that could undermine the potential for success. Even more challenging, was the need to do everything possible to reduce the overall project span to support the earliest possible support of the F/A-22 production plan. If the span resulting from reduction efforts could not support delivery of 4028 in August 2003, then the group was tasked to identify which airplane delivery *could* be supported by CIP-2K development.

For purposes of this paper, the day-by-day details are not as important as the solid involvement and cooperation of all the players and the value of the integrated plan as the focus of all the discussions. There were myriad changes in the nature and

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[15] Primary differences in number of tasks by company is the result of eliminating generalized “level of effort” tasks and adding tasks as required to generate “to” and “from” tasks for each company to every other company. (Author’s unpublished briefing, “CIP-2K Integration Meeting, 6-8 Nov 2001”)

number of the company-to-company changes. In some cases it was a simple mismatch between numbers of software, firmware of hardware products planned and needed. The total number of hand-offs increased because of several changes to permit the compression of spans by use of earlier versions of different hardware and software products. For example, there are several steps from an initial engineering version of a product to a final, fully tested and qualified released version. Planning to share with another company what would otherwise be an internal engineering version for the originating company was recognized and included in the plan as a way of permitting downstream developments to begin earlier than if a fully qualified release were required.

Significant progress was made on the GDDS tasks and interfaces/hand-offs with both the RAIL and AIL teams. On GDDS task durations, internal GDDS discussions prior to the integration meeting and discussions with other company technical leads permitted substantial reductions (25-50 percent) of fabrication and testing tasks.

Separate “off-line” meetings among the technical leaders of RAIL and AIL facilities with the LM Aero CCPM leads were also valuable in generating sharply increased fidelity and agreement on the integration process. Since this was the first face-to-face involvement of the AIL representative from Seattle, the discussions were vital to the credibility of a phase of the development process that had, for a number of reasons, not been given adequate attention.

As the group continued to work on refining some of the details of the network, the Avionics Core Products IPT manager urged the group to entertain options that might encounter more risk in order to increase the possibility that aircraft 4028 could be supported. This led to a spirited brain-storming session that resulted in a list of assumptions about key inputs that could, indeed increase the chances for support of

4028.[16] The other significant change resulting from the discussions was to expand initiatives based on common recognition of the utility of phased development to permit more work in parallel than series. This approach affected such things as the plan for building and testing by Raytheon of modules delivered to the CAIL/AIL, the qualification testing by GDDS, the sequencing at the AIL of integration and certification of the software for use on test aircraft, and the integration at LMM&FC of the electronic warfare components.

All these actions had a favorable impact on the durations for the individual company product developments and a net reduction in total project span of some 16 months, as reflected in Table F-5. It is important to note that while a substantial reduction in total span, the project end date shown—August 2003—did not include any project buffer. When the project and feeding buffers are included, the most feasible date for delivery of a tested and fully qualified CIP-2K product set was determined to be May 2004, some seven months later. As reflected in the high-level overview of the working group's analysis in Figure F-6, based on the F/A-22 production schedule at the time, this delivery would support the last aircraft, S/N 4037 in Lot 2. Though disappointed that the

	Aggressive Spans (in Mos)			
Input Networks	**Day #1**	**Day #3**	**Delta**	**Handoffs**
Raytheon	**26**	**23**	**-3**	**33**
Motorola	**38**	**22**	**-16**	**9**
LMM&FC	**26**	**20**	**-6**	**10**
Harris	**20**	**16**	**-4**	**5**
CAIL/AIL	**22**	**9**	**-13**	**13**
CIP 2K Program* (spans shown exclude buffers)	**Jun 00-Aug03**	**Oct 01-Aug03**	**-16**	**70**

***Note: Total program handoffs are numerical sum of other handoffs; span is net result (i.e., not sum)**

Table F-5. Results of Nov 6-8 2000 CIP-2K integration meeting.

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[16] Examples of factors that could benefit the CIP-2K development were priority for scarce development assets and the absence of changes in internal electronic to F/A-22 sensors with in the overall Avionics suite.

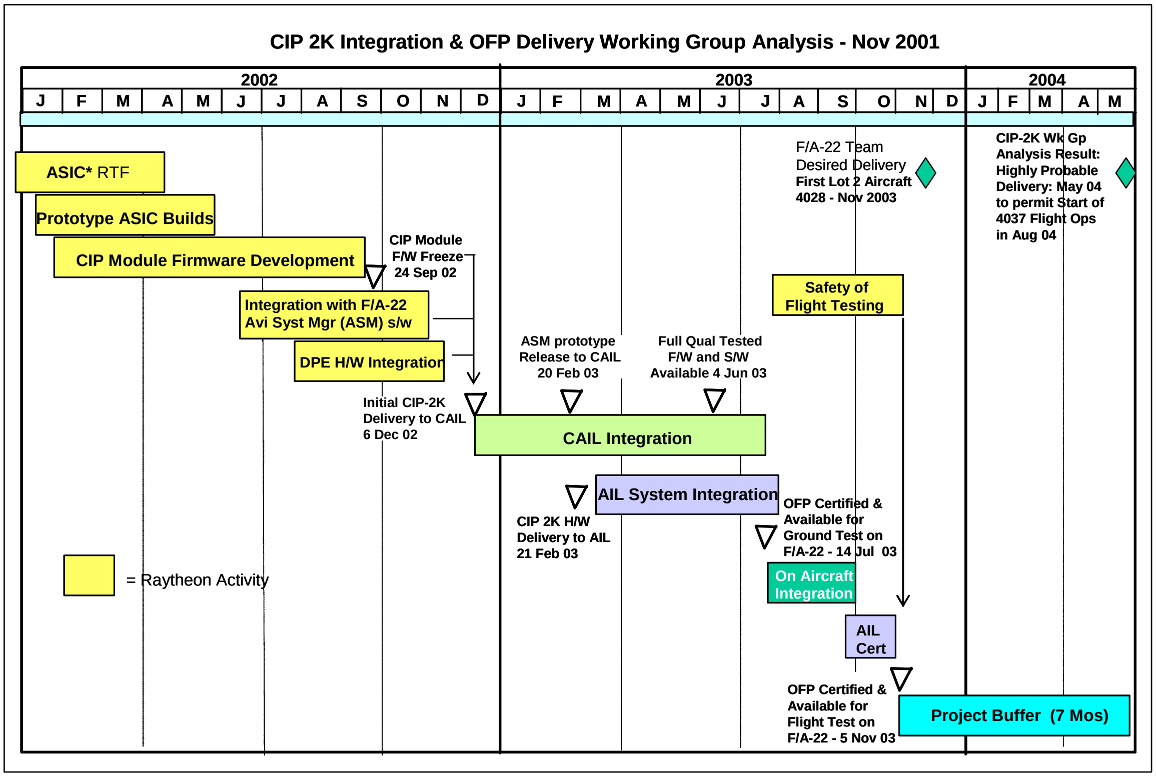

Figure F-6. CIP-2K CCPM working group estimate of feasible delivery schedule.

program objective could not be satisfied, the group was convinced that the rationale that supported the May 2004 date was very solid, pending validation of some assumptions. Some 15 action items were assigned to clarify or resolve several issues related to hardware, software and company-to-company handoff products. To assure consistency of tracking and reporting was accomplished with software common across the team, LM Aero CCPM leads provided loaner copies of the Sciforma® software to lead representatives for each of the primary participants for use until the companies could obtain their own copies. They also targeted early January 2001 as the period for additional training on Critical Chain concepts and software for those representatives who would be most responsible for tracking and updating the Critical Chain schedule during execution of the plan.

The results of the foregoing process were briefed to the Core IPT leader and by him to the Avionics IPT leader who approved the plan for implementation in January 2002

Summary of the Development & Use of the F/A-22 Jump-Start Process

As noted at the outset of this appendix, the somewhat ponderous detail is intended to convey two very important points. First, the tailoring of an organizational innovation is very important, and to some extent, in the complex environment of the multi-corporate government/industry F/A-22 organization, quite iterative. Through careful planning and the cooperation of the Raytheon “chain gang” and the TSC, the Jump-Start process was specifically designed to incorporate some lessons learned in the earlier implementations of the CCPM innovation regarding the start-up time and the level of detail. Second, even with a process that seemed to mature as it was used through network and lower level plan development at the Group 1/3 suppliers, there was still a significant effort and several iterations. In addition, a major integration meeting was required to converge on a plan that could gain the consensus support of all the major “players”, win the approval of management, and be implemented (up to the point of suspension for reasons unrelated to CCPM) with significant success.

APPENDIX G – Selective Survey of Participants in CCPM/CIP-2K Project

During the execution of the project in which the CCPM innovation was used for planning and executing the schedule for the development of the CIP-2K computer module, there were some who challenged claims by Avionics Team managers and some CIP-2K Team members that the CCPM approach was a central element in the sustained success of the CIP-2K process. They suggested that “any” scheduling system would have worked given the process and attention established for planning and executing the CCPM CIP-2K schedule. However, that suggestion failed to acknowledge that the CIP-2K process prior to the use of CCPM was judged a failure despite the application of intense attention, manpower and multi-player, multi-management-level efforts. The same can be said of the overall Avionics program which involved even more intense planning and management efforts.

In any case, to respond to claims of “essentially no CCPM value added” a survey was developed to generate additional information and insight on the potential value of the use of CCPM compared to previous planning/scheduling and execution processes. Besides responding to disbelieving critics, the survey was conceived as a way to simultaneously find out “how well CCPM worked” and capture a cross-section of views for dissemination to others contemplating the use of CCPM

Survey Candidates & Respondents

To achieve these purposes a small “executive survey” was conducted involving a cross section of those key players directly involved and familiar with the CCPM concepts and application to the CIP-2K process. Source company and role in the CIP-2K process of those surveyed for their opinions on the use of CCPM is reflected in Table G-1, below. Even more important than knowledge of CCPM, the survey participants were tasked with substantial responsibility for their company’s performance in the CIP-2K process. Personnel were selected in the three roles most key to the employment of CCPM. Schedulers were required to sustain the update process[1] and the first to identify progress (or lack of progress) to the local team. Technical leaders where the individuals at the working level who were responsible for “making things happen” both in terms of completion of task and delivery actions and in terms of taking or directing actions deemed necessary by the team during the weekly CCPM/CIP-2K telecons. Managers, those for whom the technical leads and schedulers worked, were important, because they provided oversight to the process, sometimes needed to take action to support the team, and were the ones who reported progress to higher management.

The right column of the table reflects that in aggregate, among the small number (20) of CCPM-CIP 2K project participants surveyed, 10 people or 50 percent responded, A slightly higher percent for the prime contractor, LM Aero (56percent) responded than for the supplier group (45percent), but of the 10 that did respond were evenly divided between LM Aero and the supplier group. As to the roles represented, the top rows of Table G-1 show that for the categories of interest, the percent of respondents in each category was quite close to the percent of respondents in the total polled. The fact that both were

Selective Survey on CCPM use in CIP-2K development (R=response; NR=non-response)										
		Managers		**Technical Leads**		**Schedulers**		**Total**		
	#/% of polled-->	**5/25%**		**12/60%**		**3/15%**		**20/100%**		
	#/% of respondents	**2/20%**		**6/60%**		**2/20%**		**10/100%**		
Organization	**Prime**	**R**	**NR**	**R**	**NR**	**R**	**NR**	**R**	**R+NR**	**% R**
	LM Aero	1	2	4	2			5	9	56%
	Supplier									
	Raytheon		1		2	1		1	4	
	GDDS	1			1		1	1	3	
	LMMFC				1	1		1	2	
	Harris			1				1	1	
	Boeing			1				1	1	
	Supplier Totals	1	1	2	4	2	1	5	11	45%

Table G-1. Role and home company of CIP-2K survey group.

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[1] As a CCPM change agent with a strongly biased view of CCPM, Colby was not asked to complete a survey, even though he was the individual responsible for transforming inputs into the aggregate schedule.

dominated by the technical leads was intentional, in that a primary interest in the survey was the utility of the information to the decision maker on the scene at each site. Other than that, by both source (prime/supplier) and role, the respondents fairly represent the select group asked for a response. As to the experience base, those who responded had from 1 - 9 years and an average of 3.6 years ranged on the F/A-22 program, and from 2 – 15+ years and an average of 10.2 years in the aerospace industry. Regarding the most familiar planning and scheduling systems against which CCPM would be compared, 7 identified Microsoft Project™ (embodies the Critical Path Method), and one each respondent identified CPM, milestones (essentially Gantt chart), and Microsoft PowerPoint.

At two levels, within their own company and across the multi-company team, the respondents were asked to consider their past and current experience and grade the impact of CCPM on the capability to deal with several issues as *reduced, the same, or improved.* The survey focused on execution aspects of the plan to assess CCPM-claimed advantages over previous processes (especially Critical Path Method) and to assess CCPM's contribution to the team's ability to make decisions and manage the project, the most important characteristic of any scheduling system according to F/A-22 Team and Avionics IPTs leadership.

Internal Company Level: Subjects of Interest and Results

The issues, the basis of interest and capabilities assessed regarding the impact of the CCPM process on *internal (i.e., own company) capabilities* were as follows:

- Situation Awareness: Included because the ability to understand and assess the current situation is vitally important to the management and decision making process. As noted earlier, to add value to the overall F/A-22 development process, whether at the CIP-2K level, the Avionics IPT level or the overall team, the scheduling execution system must provide the foundation for good management decisions. Many capabilities can help make the decision-makers aware of their current situation and its relation to the overall goal. Especially important in the Theory of Constraints paradigm embedded in CCPM is consideration for the project goal (in contrast to the task emphasis in the Critical Path Method). CCPM's process of managing in relation to the project status as represented in the project buffer forces constant attention to the project goal. Elements intended to capture the relative contribution of CCPM to situation awareness were:

-- Ability to identify problems before they become crises
-- Speed in analyzing work-arounds to decide which is best
-- Understanding the interrelationship of development problems
-- Understanding of current status relative to the project goal
-- Understanding of the priority order for working problems

- Management and Decision Making: Included to check the contribution of CCPM as a scheduling system to the most important aspect of project management from the perspective of Team and Avionics IPT leadership. Specific elements of this area assess the CIP-2K team's perspectives on the relative contribution of CCPM to project management within the respondent's own company. The capabilities assessed in the survey were:

-- Ability to set prioritize activities based on data instead of intuition
-- Capability to identify the most important tasks today
-- Understanding of the priority order for working problems/issues
-- Ability to reduce time it takes to deliver quality products
-- Ability to avoid overreacting to identified problems (i.e., avoid chaos)
-- Ability to reduce multi-tasking by those you supervise or manage
-- Confidence in meeting deliveries

-- Ability to meet commitments

- Resource Management. Broken out separately because of the concern for assuring resource needs are understood and scarce resources are properly allocated against those needs. Also, CCPM places heavy emphasis on allocation of resources and resolution of any resource conflicts. The capabilities assessed in the survey were:
  -- Understanding of resource requirements
  -- Ability to allocate resources to assure on time delivery
  -- Efficiency in assigning workers to tasks

Figure G-1, below, reflects the results on the overall impact of CCPM on the capability within the respondent's company. Because no one assessed their company's capability as "reduced" for any area assessed, only "same" or "improved" capability is depicted. Relative to the three general areas assessed, the results are mixed. In the area of Situation Awareness, respondents were split regarding CCPM's impact on the speed of work-around analysis and understanding the priority for working problems. However, the majority agreed that CCPM generated improvements in three very

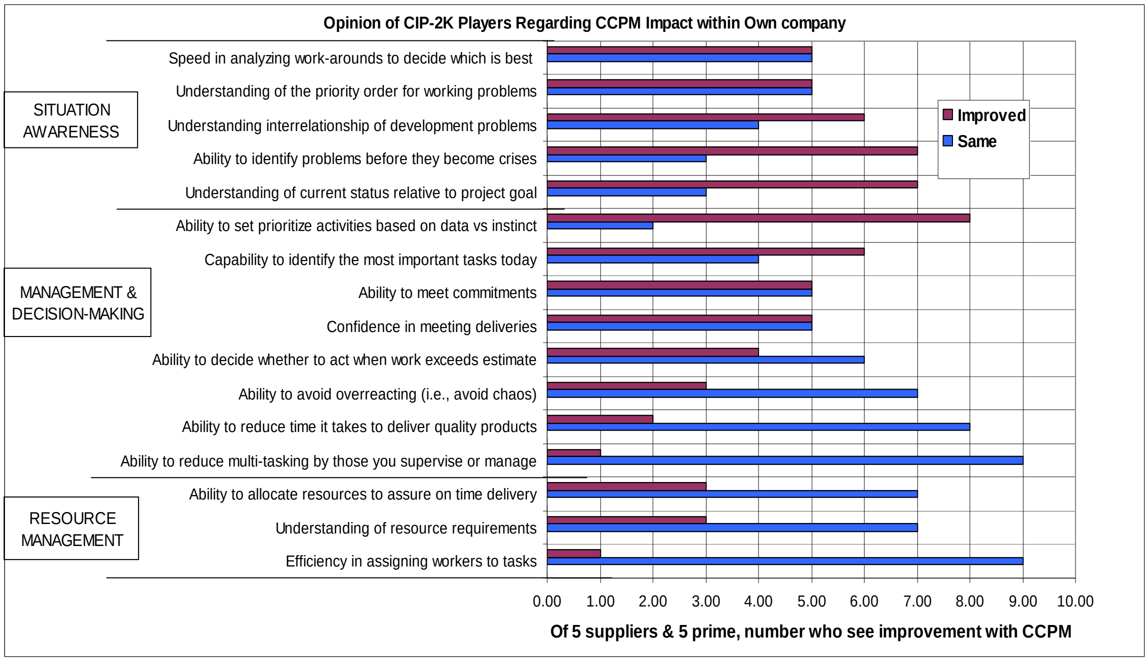

Figure G-1. CIP-2K survey: Impact of CCPM on own company capability.

important areas, the interrelationship of development problems, ability to identify problems before they become crises and where the company is relative to the project goal. In the area of management and decision-making, the results suggest that regarding impact on one's own company management and decision-making and even more so for resource management, the majority of respondents thought the capability with CCPM was the same as with previous systems with which the respondents were familiar. Even so, those areas seen by the majority as "improved" with CCPM, the "capability to identify the most important tasks today" and, especially, the "ability to set priorities based on data vs. instinct" are certainly positive votes for the contribution of CCPM to the management process.

Interestingly, the picture changes considerably when the data is arranged to compare views of the LM Aero prime contractor group of respondents versus those of the supplier respondents, as reflected in Figure G-2. Here, the focus is on the numbers of respondents who assessed CCPM capability in the various areas as improved. Clearly, both groups view CCPM impact on Resource Management as essentially the

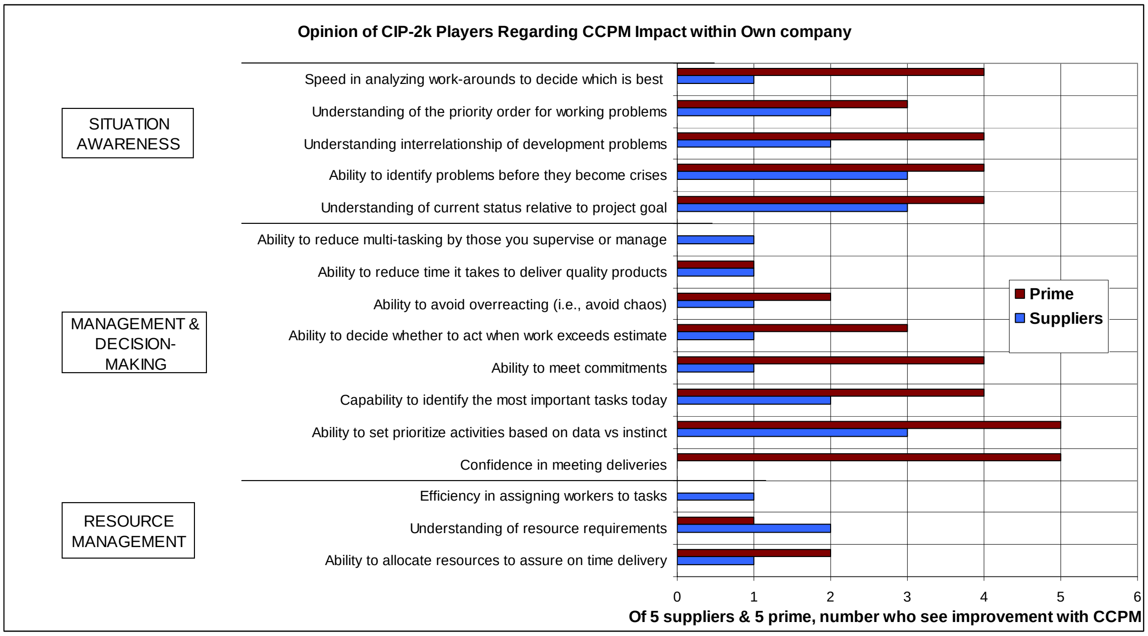

Figure G-2. CIP-2K survey: Supplier vs. prime view of "improved" areas.

“same” as with other approaches, since there were only a couple of votes for “improved.” However in the other areas, it is equally clear that the prime respondents are much more positive about the impact of CCPM, and the suppliers much more muted in their view of the impact of CCPM.

Regarding Situation Awareness, the prime respondents voted almost unanimously that CCPM had improved the LM Aero capability in all areas. Regarding Management and Decision Making, at least three out of five prime respondents agreed that CCPM improved LM Aero capabilities in five of the eight elements of the area. Perhaps the most striking contrast between prime and supplier respondents is “confidence in meeting deliveries.” Here every supplier respondent indicated their confidence in meeting deliveries for their company was the “same” as before CCPM, but every prime respondent said their confidence in meeting deliveries was “improved.” This dichotomy might be explained by the fact that the prime respondents were mainly concerned with the delivery of the entire CIP-2K product for which LM Aero was ultimately responsible. From that perspective, the fact that the project was substantially on track at the time of the survey (March 2003), might have provided the level of confidence reflected in prime responses. The suppliers on the other hand, were much more focused on the shorter term deliveries, and as noted in earlier paragraphs of this section, consistently on-time deliveries was problematic.

Team Level: Subjects of Interest and Results

As noted earlier, the other area of interest in the survey was the impact of CCPM on activities across the multi-company/player team. Here, the interest focused in two areas, as follows:

- Situation Awareness. Essentially the same name as for the “own company” section of the survey. However, the simple elements of this area from a team perspective related to interest in the impact of CCPM on knowing about and being able to react to changes across the team. Specific elements were:

-- Understanding the status of all activities on the CIP-2K project

-- Heads-up on changes in hand-offs in time to deal with impacts

- Teamwork. As noted earlier, the CCPM schedule and the special section on hand-offs provided the focus for the weekly telecons to discuss CIP-2K status and generate action items when appropriate. The knowledge derived from these telecons contributed to the Situation Awareness component of team activities, but the elements of this area of the survey were intended to assess whether the CCPM schedule and process actually contributed to aspects of team operation, i.e., teamwork. The elements included for assessment by the respondents were:

-- Communication/coordination w/ personnel at other suppliers on CIP-2K

-- Identification of action items requiring resolution to keep CIP-2K on track

-- Mutual accountability for work & hand-offs

-- Timeliness of closure on action items to keep CIP-2K on track

-- Confidence in ability of other suppliers to meet delivery commitments

-- Confidence in meeting project goal: On-time delivery w/ full content

Figure G-3, below, presents the results of the survey on the issues of Situation Awareness and Teamwork for the CIP-2K team as a whole. Compared to the somewhat mixed results for the “own company” part of the survey, the results at the team level are quite dramatic in that the majority of all respondents believed that CCPM “improved” capabilities across the board. The improvement in Situation Awareness over prior systems is especially impressive given the scope and complexity of the CIP-2K project. In the Teamwork area, it is equally impressive that 8, 9, or 10 respondents felt that CCPM “improved” CIP-2K team capabilities in four of the six areas assessed. For consistency with the foregoing “own company” graphs, the breakout and comparison of

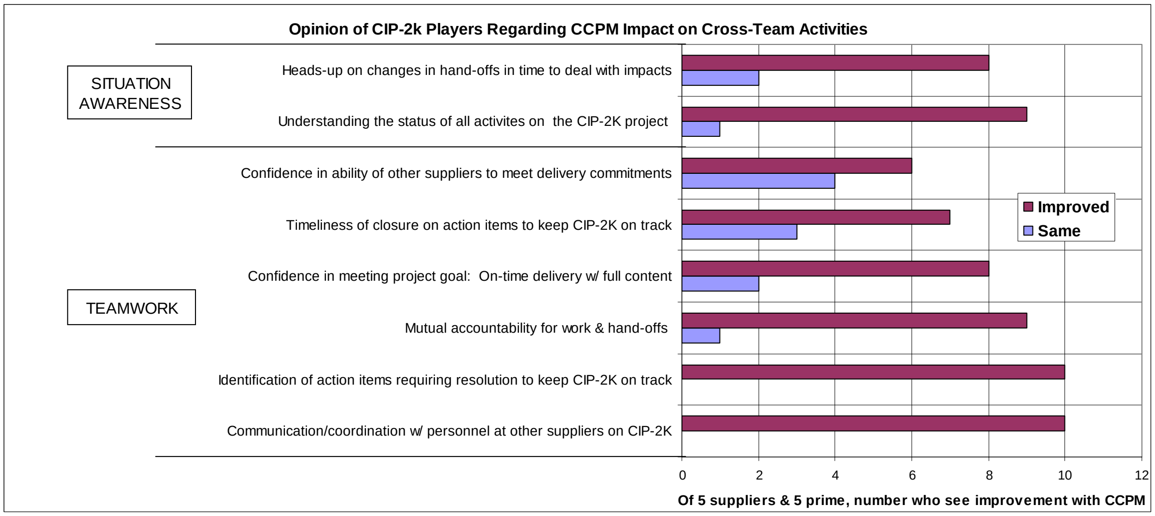

Figure G-3. CIP-2K survey: Views of CCPM impact on team activities.

prime and supplier perspectives on the areas assessed are presented in Figure 91 below. Though the data in Figure G-3 above suggests that likely would not be much difference between prime and supplier views, the uniformity of the data in Figure G-4 nevertheless presents an almost amazing consensus on the positive value of CCPM from a team perspective compared to the often conflicting view of the impact on “own company” capabilities.

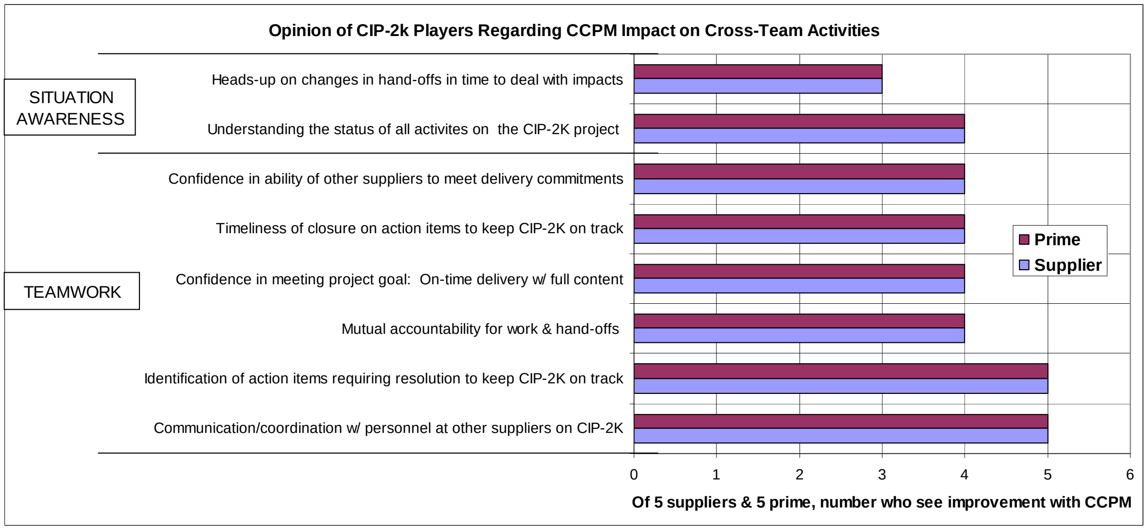

Figure G-4. CIP-2K survey: Supplier & prime views on team activities.

Special Subjects: Strengths and Future Uses

Beyond the assessments of CCPM impact on own company and team capabilities, the survey also asked for short answers to a number of questions, though not all respondents provided answers in all areas. Of particular interest are the responses to two of the questions. The first was: “What is/are the one or two most important strengths of CCPM?” The responses are presented in Table G-2, below, broken out by prime and supplier. Other than the somewhat tepid comment by the last supplier response, the general message that the comments convey include two general perspectives that are extremely beneficial to a project. The first is captured in the several prime responses, namely, the vital management aspects of any project—risk management, tasks trade-offs, intercompany handoff coordination, and, perhaps most important, the right priorities. The second is captured in the supplier responses. The consistent citing of CCPM’s strength in conveying the interdependencies and priorities of the individual supplier task *relative to others* may well be one of the primary explanations of the solid performance of the CIP-2K project team.

What is/are the one or two most important strengths of Critical chain?
Prime Responses
Risk management, schedule management
1. Allows early identification of critical tasks IF data has sufficient detail. 2. Allows task tradeoffs.
List of upcoming handoffs and milestones
1. Defines a clear set of tasks to be worked on presently. 2. Coordinates intercompany hand-offs. 3. Allows top level oversight via buffer incursion metric
Buffer mgmt and right priority attention.
Supplier Responses
Schedule details; all know other's tasks
Knowing how my project tasks interact with Team's milestones
Understanding priorities and how they affect other activities
Critical Chain is helpful during the planning stage of building a schedule.

Table G-2. CIP-2K survey: Short answers on CCPM strengths

The other short answer question of interest is: “Where do you think CCPM should be used next?” Responses are shown in Table G-3 below. Again, with the exception of the last, somewhat tentative supplier response, the scope and breadth of the responses speaks well for the respondent's view of the potential of CCPM. In the case of the prime respondents, virtually all want to expand the use of CCPM to all modernization projects, the Avionics program as a whole or, even, "everywhere." The same sense of CCPM's ability to handle projects with broad scope come through in the supplier responses. The suggestion for use in airframe development suggests confidence in the application of CCPM beyond avionics. Suggestions for use in any multi-supplier, multi-team situation seem consistent with the supplier comments on CCPM strength. The supplier comments are especially noteworthy given some initial trepidation about the use of this new and quite unfamiliar process, CCPM, for the CIP-2K process.

Where do you think Critical Chain Project Management should be used next?
Prime Responses
Use for development of future F/A-22 modernization programs/projects
The overall F/A-22 Avionics devopment and production program
Everywhere possible
Future F/A-22 modernization and all other new projects.
Integration and release new avionics software and F/A-22 site activations
Supplier Responses
Airframe Flight Test and Data analysis.
Anywhere that Multi-Team Management all agree to adhere to Team Schedule Milestones
All development programs requiring interaction between multiple suppliers.
Critical Chain should be used on smaller programs with some success before being used on larger programs.

Table G-3. CIP-2K survey: Short answers on potential CCPM application areas.

Overall Observations

Overall, the survey suggests that CCPM has, in fact, provided some unique value which has been a very positive factor in the success of the CIP-2K project reflected in the performance reported and assessed in this report. In response to the claim by some that "any scheduling system would have worked" the survey indicates that CCPM does add value for Situation Awareness and some own-company management and decision-making, especially as viewed by the prime. More important and impressive is the strong consensus regarding value-added by CCPM to Situation Awareness and Teamwork in this very complex, multi-company, multi-stakeholder team project. As noted at the outset, the sample size for the survey, though small, represented a good cross-section of prime and supplier personnel most knowledgeable about the utility and impact of CCPM and the CCPM process on the CIP-2K project.

Besides the strong consensus on CCPM value added for the multi-player team, conclusions on the “own company” part of the survey should not focus on just the mixed results and conclude there was little CCPM value perceived there. True, the absence of support for CCPM’s improvement in the ability to manage resources or reduce multi-tasking or “chaos” might be regarded as disappointing, given the emphasis on those areas in TOC and CCPM concepts. It may be that those areas did not receive enough emphasis during implementation or, alternatively, that those problems are especially difficult to reduce in the dynamics of complex system development. However, that uncertainty should not cloud other very important points. That is, the CCPM strengths perceived by the prime contractor respondents. Surely, any prime contractor senior management would want their tech leads and managers responsible for a key development to strongly believe that the planning and scheduling system in use provides valuable support in key areas of situation awareness and management/decision making, specifically:

- Understanding of current status relative to project goal
- Ability to identify problems before they become crises
- Understanding interrelationship of development problems
- Speed in analyzing work-arounds to decide which is best
- Confidence and ability to meet deliveries,
- Ability to prioritize activities based on data vs. instinct, and

- Capability to identify the most important task today

And finally, though they did not participate in the survey, the government representatives strongly supported the use and *value* of Critical Chain in managing and developing the CIP-2K system. The F/A-22 SPO counterpart to the Avionics Core Processing lead who spearheaded the effort said he "…appreciated the efforts to keep the CIP 2K program on track, best we have done on the F-22.." At the next higher level in the government management structure, the Chief of Avionic Systems Development IPT, said of the CCPM process: "I consider this [the CCPM planning and execution management process] one of our biggest successes in the CIP 2K development effort."[2]

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[2] Peet, Bruce, E-mail message, 25 February 2003, Subject: Comment on Value of CCPM to CIP-2K Project.