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THESIS

THE IMPACT OF LONG-TERM AIRCRAFT CARRIER MAINTENANCE SCHEDULING ON THE FLEET READINESS PLAN

by

Matthew H. Hall

September 2004

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Maintaining the Fleet Readiness Plan (FRP) construct of six aircraft carriers available within 30 days, plus two additional carriers available within 90 days is a difficult task. Maintenance requirements on carriers alone make satisfying the FRP a challenging scheduling problem. We develop a carrier maintenance scheduling model with a goal to meet, as best as possible, the FRP requirements over a ten-year period, while obeying simple maintenance facility constraints. This model allows us to anticipate gaps in coverage and also quantitatively assess the benefit, or burden, of re-sizing the fleet. We conclude that by increasing the average cycle time for a Carrier Strike Group (CSG) to 27 months we can meet the FRP requirements continuously after an initial maintenance adjustment period of 62 months.

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THE IMPACT OF LONG-TERM AIRCRAFT CARRIER MAINTENANCE SCHEDULING ON THE FLEET READINESS PLAN

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requirements for the degree of

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Maintaining the Fleet Readiness Plan (FRP) construct of six aircraft carriers available within 30 days, plus two additional carriers available within 90 days is a difficult task. Maintenance requirements on carriers alone make satisfying the FRP a challenging scheduling problem. We develop a carrier maintenance scheduling model with a goal to meet, as best as possible, the FRP requirements over a ten-year period, while obeying simple maintenance facility constraints. This model allows us to anticipate gaps in coverage and also quantitatively assess the benefit, or burden, of re-sizing the fleet. We conclude that by increasing the average cycle time for a Carrier Strike Group (CSG) to 27 months we can meet the FRP requirements continuously after an initial maintenance adjustment period of 62 months.

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EXECUTIVE SUMMARY

The end of the Cold War and the consequent absence of a single, predictable adversary has forced policy makers to consider the manner in which our Naval Forces train, maintain and deploy. Recent increases in force demands for Iraq and the Global War on Terror (GWOT) require that our forces be deployed in a manner that supports the National Military Strategy (NMS) and maximizes the effective employment of our troop presence and combat power. Deterrence strategies driven by continuous carrier forward presence have given way to response strategies that require Naval Forces to potentially surge to multiple conflicts throughout many different regions of the world.

The transition to a response based focus is realized in the 2003 Naval Operating Concept for Joint Operations (NOC). This concept demands the joint capability to defend the homeland, deter aggression in four critical areas and swiftly defeat the effort (SDTE) in two overlapping wars with the ability to defeat one of the aforementioned adversaries decisively. [Naval Operating Concept for Joint Operations, 2003]

To meet the NOC requirements, the Navy has developed the Fleet Readiness Plan (FRP) and the Fleet Readiness Training Plan (FRTP) construct. The FRP and FRTP are built upon a series of progressive readiness states that are designed to provide a highly responsive, sustainable force that has the ability to reconstitute and deploy rapidly. Specifically, FRP requires the capability to provide six aircraft carriers within 30 days of a crisis and an additional two carriers within 90 days of that same crisis.

This thesis discusses the personnel preparedness and maintenance factors that constrain the carrier force's ability to support these force requirements and concentrates on the affect of depot-level maintenance on the Carrier Strike Group's (CSG) employment under the FRP construct.

We initially investigate two 24-month training schedules in which the period for *employment*, that time in which a combatant is able but is not required to deploy, is varied between three and 18 months. We then explore two 27-month training schedules wherein the *employment* period is varied between three and 21 months. Under each of these training schedules, we model three unique scenarios. The first scenario is the *baseline* scenario, which models the ability of the current 12 carrier force structure to meet the FRP force requirements. The second scenario, the *loss* scenario, models the affect on FRP of losing an Atlantic Fleet (LANTFLT) CSG and the third scenario, the *gain* scenario, models the affect on FRP of gaining a LANTFLT CSG. Additionally, we investigate the affect of gaining a dry-dock facility and dropping the "6+2" requirement to "5+2." The scenarios begin in August 2004, end in July 2013, and follow the aggregate carrier maintenance schedule of 12 May 2004 provided by the NAVSEA maintenance office.

The results of this analysis show that if one lengthens the duration of time an aircraft carrier is available for *employment* to 15 months, the percentage of time one can meet the "6+2" requirement increases. Under the "6 to 21" 15-month *employable (D)* state training plan, "6+2"can be met, undeniably, by October 2009.

If one lengthens the duration of time an aircraft carrier is available for *employment* to 15 months and in addition, decreases the FRP requirement to "5+2," the current force structure can meet this goal, unquestionably, by February 2007. The benefit of this analysis is that we quantify the affects of potential policy changes and weigh the advantages and disadvantages of each.

I. INTRODUCTION

A. BACKGROUND

Scheduling ships' maintenance and training cycles to meet operational commitments is a complex decision making process that demands efficient planning and execution. The fundamental problem is how to allocate a scarce resource, in this case Carrier Strike Groups (CSGs), in a manner that maximizes their deployment availability or "surge" readiness. Specifically, this entails the Carrier Strike Group's ability to meet Fleet Readiness Plan (FRP) demands under the operational and material constraints of depot-level maintenance. Current scheduling tools range from manual enumeration to the use of the Program Evaluation and Review Techniques (PERT) or Critical Path Method (CPM) applications. This thesis provides a quantitative analysis of the scheduling impact of waterfront time constraints, training objectives and material preparedness, on the FRP. Additionally, it provides Type Commanders (TYCOMs) and Fleet Commanders (C2F/C3F) with a responsive scheduling tool that will enable them to enumerate various scheduling possibilities and the effects these possibilities impart on asset availability and assured readiness.

1. Navy Deployment Strategy

Since the United States Navy's founding on October 13, 1775, the deployment strategies used to employ our naval forces have changed a number of times. The employment goal, however, has remained much the same, "power projection ashore as well as sea control." [Swartz, 2002] Although the size of the Navy has grown from two armed sailing vessels to today's figure of approximately 300 surface combatants, the Navy's responsibilities have grown from the thirteen colonies' coastlines to the waters of the entire globe.

A single deployment strategy has not prevailed throughout U.S. naval history. As domestic and international issues have changed, the Navy has adapted to meet its commitments. Consequently, whereas the Navy of the late eighteenth century deployed from ports along the Atlantic coast, today's Navy has the ability to surge from ports worldwide. Integrated U.S. force operations were not the norm prior to WWII, but such operations are now the key to any successful mission.

Currently, American forces are widely dispersed throughout five operational Areas of Responsibility (AORs) in over 140 different countries across the globe. [Buzby, 2004] As illustrated in Figure 1, the Navy maintains forward presence on a near continual basis in three of these AORs: the U.S. Pacific Command (USPACOM), the U.S. Central Command (USCENTCOM) and the U.S. European Command (USEUCOM). With recent increases in force demands for Iraq and the Global War on Terror (GWOT), it is paramount our forces be deployed in a manner that supports the National Military Strategy (NMS) and maximizes the effective employment of our troop presence and combat power.

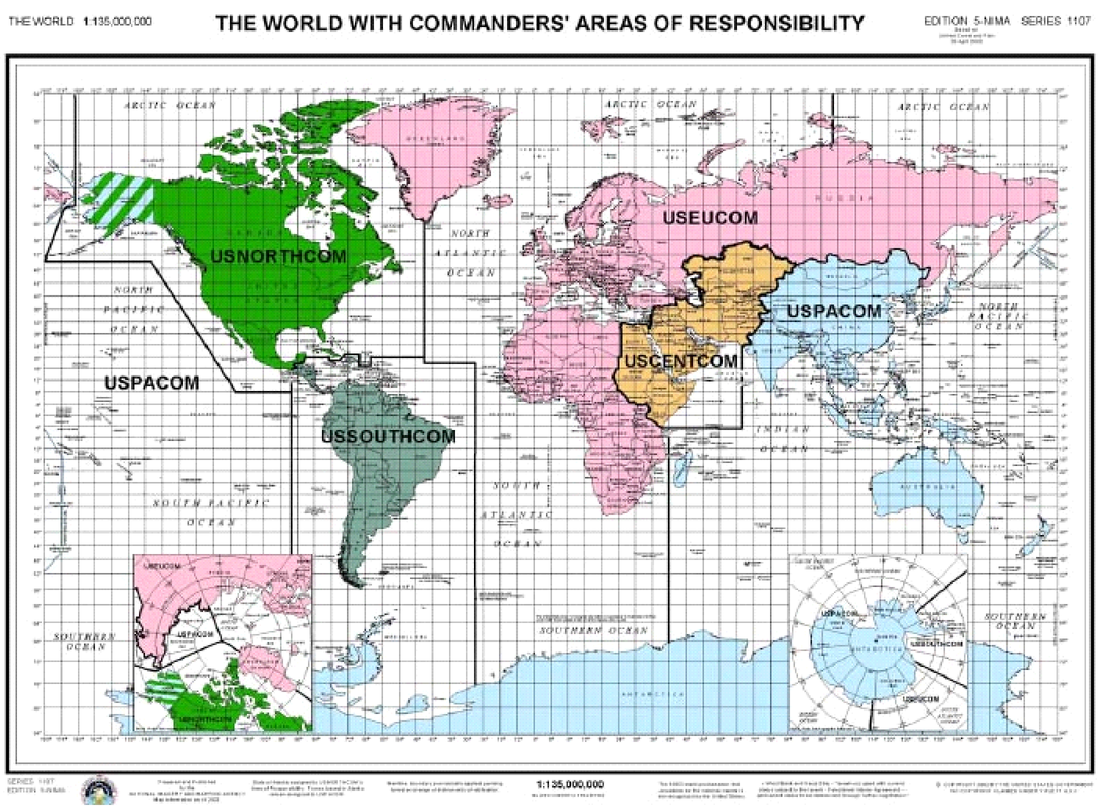

Figure 1. The Unified Command Plan establishes the missions and geographic responsibilities among the combatant commanders. The five Unified Commands are USNORTHCOM, USSOUTHCOM, USPACOM, USCENTCOM and USEUCOM. [Unified Command Plan, 2004]

2. Carrier Strike Group (CSG)

The U.S. Navy's Carrier Strike Group (CSG) remains the primary military instrument for maintaining global forward presence and conducting national security strategy. At the heart of the CSG lie the conventional or nuclear powered aircraft carrier (CV/CVN) and its associated carrier air wing (CVW). In addition to their force structure, the training and maintenance cycles of the CVs/CVNs and CVWs limit the number of CSGs available for employment and, as such, are the focus of this analysis.

As presently configured and shown in Tables 1 and 2, there are 10 CVNs, 2 CVs, 10 CVWs and 1 Naval Reserve Air-wing (CVWR).

Aircraft Carrier	Hull #
USS KITTY HAWK	CV 63
USS ENTERPRISE	CVN 65
USS JOHN F. KENNEDY	CV 67
USS NIMITZ	CVN 68
USS DWIGHT D. EISENHOWER	CVN 69
USS CARL VINSON	CVN 70
USS THEODORE ROOSEVELT	CVN 71
USS ABRAHAM LINCOLN	CVN 72
USS GEORGE WASHINGTON	CVN 73
USS JOHN C. STENNIS	CVN 74
USS HARRY S. TRUMAN	CVN 75
USS RONALD REAGAN	CVN 76

Table 1. Present CVN Forces. [Sea Waves, 2004]

Carrier Air-Wing (CVW)	Fleet
CVW-1	LANT
CVW-2	PAC
CVW-3	LANT
CVW-5	PAC
CVW-7	LANT
CVW-8	LANT
CVW-9	PAC
CVW-11	PAC
CVW-14	PAC
CVW-17	LANT
CVWR-201	LANT

Table 2. Present CVW Forces. CVWR-20 is a Naval Reserve Air-wing based at NAS Atlanta, Marietta, GA. [Sea Waves, 2004]

A notional CSG and her respective capabilities are shown below in Figure 2.

Notional Carrier Strike Group (CSG)	
CVN (Aircraft Carrier, Nuclear Propulsion)	1
CVW (Carrier Air Wing)	1
CG (Guided Missile Cruiser)	1
DDG (Guided Missle Destroyer)	1
FFG (Fast Frigate, Guided Missile)	1
SSN (Attack Submarine, Nuclear Propulsion)	1
T-AOE (Fast Combat Support Ship)	1

Notional CSG Characteristics	
VLS Cells	212*
Strike/Fighter Aircraft	44-46
Airborne Early Warning Aircraft	4
Electronic Warfare Aircraft	4
Anti-Surface/Tanker Aircraft	8
Helicopter Squadron (ASW/CSAR)	1
Helicopter Squadron (Logistics)	1
Sustained strike sorties/day	100+
Explosives Ordnance Disposal (EOD) Mobile Unit	1
SEAL Platoon/element	1

Notional Carrier Strike Group (CSG)

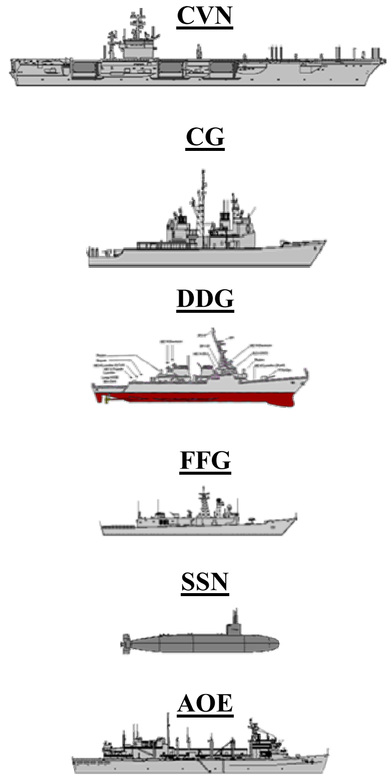

Figure 2. Notional Carrier Strike Group (CSG). Two Air Defense (AEGIS) Surface Combatants are required, i.e., a combination of CGs/DDGs. The number of available Vertical Launch System (VLS) cells will change accordingly: 1 CG (122 Cells), 1 FLT I/II DDG (90 Cells) and 1 FLT IIA DDG (96 Cells). * [OPNAV, 2003c]

Forward deployment of the CSG combat team affords the nation the option of a rapid crisis response without the commitment of forces ashore and provides "the capabilities of tactical aviation without the need for immediate access to bases ashore." [Perin] In the end, the CSG presents a wide range of possible responses across a conflict's full spectrum. As Congressman Robert C. Scott (D-VA) stated, "Ultimately, aircraft carriers are the instrument called upon most frequently when the aggression must be stopped. More importantly, they are diplomatic instruments used to contain conflict and prevent wars from breaking out in the first place." [Scott, 1993] The importance of the CSG and the nature of its mission are further characterized below:

> The CSG is intended to be a flexible, heavy strike Navy group that can operate in a low-to-high threat environment, in the littorals or in open ocean, during day and night, in a variety of weather conditions, and under restricted EMCON. CSG capabilities support success of initial crisis response missions and are assumed to be undertaken in non-permissive environments characterized by multiple threats including, but not limited to anti-ship missiles, fighter/attack aircraft, electromagnetic sensors and jammers, cruise missile equipped surface combatants, submarines (both nuclear and diesel types), and terrorist threats.[OPNAV, 2003c]

3. Fleet Readiness Plan (FRP)

Prior to December 2003, the method by which the Navy maintained, trained and deployed its surface forces was referred to as the Inter-Deployment Training Cycle (IDTC). The IDTC was essentially divided into five recurring phases: Deployment, Maintenance, Basic Training Phase, Intermediate Training Phase and Advanced Training Phase. Upon completion of the maintenance phase, forces concentrated on unit-level readiness and would progress to multi-unit and then battle group training as specific readiness milestones were achieved. In this cycle's early phases, readiness degradation was accepted as maintenance was conducted and as new crew members came aboard. The training cycle's culmination was deployment – at which point the battle group was properly prepared to deploy, fight as a unit, and integrate into a joint force effectively.

Although this training/deployment template was used through the Cold War's later years, it limited flexibility to surge United States Naval Forces to multiple regional conflicts for extended periods of time. Over the long run, the IDTC restricted deployment options as well as our ability to use naval assets that had achieved high levels of readiness. Loren Thompson, a navy consultant and defense analyst at the Lexington Institute said, "The navy is migrating away from the static deployment patterns of the Cold War in order to be more flexible and responsive to unpredictable threats." [Quicker and Stronger, 2003]

Change prevailed soon after Operation Enduring Freedom (OEF)/Operation Iraqi Freedom (OIF) when surge deployment of seven CSGs provided the new model for the future. Admiral William J. Fallon, Commander, U.S. Fleet Forces Command (COMFLTFORCOM), discusses the Navy's role in OIF/OEF below.

> We deployed seven aircraft carriers, nine 'Big Deck' assault ships, and a total of 182 ships in support of OIF/OEF. This surge of Navy capability taught us that the methodology used during the Cold War for manning, maintaining, and training our fleet would not produce surge readiness required in the 21st century security environment. [Commander U.S. Fleet Forces Command, 2004c]

In response to this new reality, the doctrine under which naval forces, train, maintain, and deploy was revamped. Admiral Vern Clark, USN, Chief of Naval Operations (CNO), developed a new training and deployment construct named the Fleet Readiness Plan (FRP). The FRP and the associated Fleet Readiness Training Plan (FRTP) effectively replaced the Inter-Deployment Training Cycle (IDTC) on December 1, 2003. This transformation from the established and predictable days of the IDTC forced decision makers to inspect and to alter the manner in which scheduling on the waterfront was conducted. Below, Admiral Fallon addresses the importance and advantages of the FRP.

> The current global security environment requires that we provide the President and SECDEF with scalable options of combat capability. FRP and its associated Fleet Readiness Training Plan (FRTP) are designed to give operational commanders the flexibility to utilize naval assets in innovative ways to enhance regional deterrence, meet specific combatant commander requirements, including security cooperation activities, multi-CSG fleet exercises, and rotational forward operations while building a viable and credible surge capability. In short, FRP is all about fleet readiness and the navy's ability to provide significant combat power in response to a crisis. It is not about keeping the fleet deployed longer or sending the fleet to sea without notice. [Commander U.S. Fleet Forces Command, 2004a]

4. "6+2" Construct

The 2003 Naval Operating Concept for Joint Operations (NOC) mandates how the Navy and Marine Corps team "will operate across the full range of military operations in the near, mid, and far terms through 2020." [Naval Operating Concept for Joint

Operations, 2003] This concept demands the joint capability to defend the homeland, deter aggression in four critical areas and swiftly defeat the effort (SDTE) in two overlapping wars with the ability to defeat one of the aforementioned adversaries decisively. [Naval Operating Concept for Joint Operations, 2003]

To meet this requirement, under the FRP and FRTP, the Navy developed the "6+2" Carrier Strike Group (CSG) surge employment construct. This concept promises six CSGs available for employment within 30 days and an additional two CSGs available for employment within 90 days. Under this construct a series of progressive readiness states have been established: *surge ready, deployable*, *sustainment* and *emergency surge*. The *depot-level maintenance* and *post-maintenance "shake down"* states are hard constraints that do not change and are determined in accordance with the type of depot-level maintenance conducted. A notional 24-month FRTP is shown in Figure 3 below.

2004												2005											
J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Surge Ready				Deployable						Sustainment		PIA Maintenance						Post-Maintenance "Shake Down"			Emergency Surge		
Employable (D)												Depot Level Maintenance (M)						Proficiency Training (P)			E-Surge (E)		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Figure 3. Notional 24-month FRTP. In addition to the four progressive readiness states are the Maintenance and Post-Maintenance "Shake Down" states.

The milestones for each readiness state are described in Table 3. While the "6" CSGs are drawn from the *surge ready*, *deployable*, or *sustainment* states, the additional "2" CSGs are drawn from the *emergency surge* state. These readiness states are cyclical and revolve around established maintenance requirements for each of the aircraft carrier classes. Depending on the type and length of the maintenance period the time to achieve emergency surge status will vary. For instance, under the Incremental Maintenance Program (IMP) for CVN 68 Nimitz class carriers, following a six-month Planned Incremental Availability (PIA) a carrier would have 90 days to meet the emergency surge requirements. Using the same strategy however, following a 10.5 month Docking

Planned Incremental Availability (DPIA), five months are required to meet the emergency surge requirements. Table 4 illustrates the notional progressive readiness states from which the "6+2" carrier force is drawn.

State	Minimum Training Requirements
"Surge Ready"	• All units obtained C-2 Readiness or better. • Completion of basic warfare commander/composite warfare commander integration training. • Completion of Blue Water Certification. • Completion of COMPTUEX/Final Battle Problem (FEP). • Completion of Air wing(s) CVW Fallon qualifications. • Refresher training completed as required.
"Deployable"	• "Surge Ready" status has already been met. • In addition, specified advanced training has been met, namely: (1) Completion of Advanced Phase training. (2) Completion of Joint Task Force Exercise (JTFEX). (3) Refresher training completed as required.
"Sustainment"	• All group / unit training and certification requirements have been successfully completed. • Unit / group is fully certified and capable to perform all required missions. • To include: fulfillment of all training and exercises to support applicable Strike Groups/Squadron integration.
"Emergency Surge"	• Status attained for individual units or groups that have completed minimum training requirements and have the unit/group level proficiency to be mission capable. • Completion of Tailored Ship Training Availabilities (TSTAs). • Completion of Final Evaluation Problem (FEP). • Completion of Advanced Readiness Phase (ARP). • Completion of unit level proficiency for air wing/helo detachments and certified mission capable.

Table 3. FRP Progressive Readiness States. [OPNAV, 2003c] The minimum training requirements are listed for each state.

"6+2" CSG Employment	
Carrier Strike Group (CSG)	Readiness States
CSG 1	Deployable - Surge Status met - Advanced Training Completed
CSG 2	Deployable - Surge Status met - Advanced Training Completed
CSG 3	Deployable (FDNF) - Surge Status met - Advanced Training Completed
CSG 4	Surge Ready - All units have obtained C-2 level of readiness
CSG 5	Surge Ready - All units have obtained C-2 level of readiness
CSG 6	Sustainment - Post Deployment
CSG +1	Emergency Surge - Available w/in 90 days upon conclusion of PIA type Maintenance.*
CSG +2	Emergency Surge - Available w/in 90 days upon conclusion of PIA type Maintenance.*

Table 4. "6+2" CSG Employment. *Timeframe varies by type of availability involved – 90 days for post Planned Incremental Availability (PIA), five months post Docking Planned Incremental Availability (DPIA), seven months post Reactor Complex Overhaul (RCOH), and nine months post new construction. [OPNAV, 2003c]

A key factor in determining the Navy's ability to meet FRP guidelines is the consideration of the Forward Deployed Naval Forces (FDNF). These forces are stationed in Yokosuka, Japan; Sasebo, Japan; and Guam and for the purposes of this analysis, we will concentrate on the CSG presence in Yokosuka, Japan. The unique characteristic of the FDNF is that it will always be counted in either the "6" or "+2" category, depending upon its location in the maintenance cycle. This force never falls out of the "6+2" equation and in the worst case scenario will be available within 90 days.

As a rule, FDNF platforms have higher Operational Tempo (OPTEMPO) rates and demand greater flexibility in their schedules in order to provide near continual presence in the Western Pacific Theatre. The present FDNF carrier, CV 63 USS Kitty Hawk, operates under the Progressive Maintenance (PROG) maintenance schedule. "This maintenance philosophy is designed to support ships with reduced manning, limited organizational level maintenance, and operational tempos that limit availability periods."[OPNAV, 2003b] CV63 was commissioned in September of 1968 and unofficially expects to decommission in December 2008. Upon its retirement from service, theoretically, another carrier will replace it and serve as the next FDNF carrier.

The Navy's ability to meet the 2003 NOC requirements while using the FRP and FRTP construct was demonstrated during the naval exercise "Summer Pulse 04," conducted between June and August of 2004. The Navy simultaneously deployed 7 of the nations' 12 CSGs throughout the five operational AORs, and although specific results of the exercise were not released to the public, the exercise tested the logistics and shore infrastructure, joint and coalition interoperability and most importantly validated the sound construct of the FRP and FRTP. The seven CSGs which deployed simultaneously included the USS George Washington (CVN 73 - Norfolk), USS John C Stennis (CVN 74 - San Diego), USS Kitty Hawk (CV 63 - Yoko), USS John F Kennedy (CV 67 - Mayport), USS Harry S Truman (CVN 71 - Norfolk), USS Enterprise (CVN 65 - Norfolk) and the USS Ronald Reagan (CVN 76 -San Diego). [Commander U.S. Fleet Forces Command, 2004c]

B. SCHEDULING UNDER THE FRP

This thesis provides a quantitative analysis of the scheduling impact of waterfront time constraints, training objectives and material preparedness, on the FRP. It aids schedulers in maximizing the number of aircraft carriers available for employment at a specific time. Additionally, it provides Type Commanders (TYCOMs) and Fleet Commanders (C2F/C3F) with a responsive scheduling tool that enables them to enumerate various scheduling possibilities and the effects they impart on asset availability and assured readiness. A critical distinction that must be made when discussing FRP and FRTP is that it is a maintenance, training and deployment construct. It does not dictate how units deploy or when they should surge. It simply supplies or provides the units for potential "employment."

As an aid to the reader, Figure 4, which is shown below, represents two years of an aggregate carrier maintenance schedule. The USS Kitty Hawk (CV 63), a Forward

Deployed Naval Force (FDNF), accounts for the 12th carrier and is not listed in the CONUS maintenance schedule.

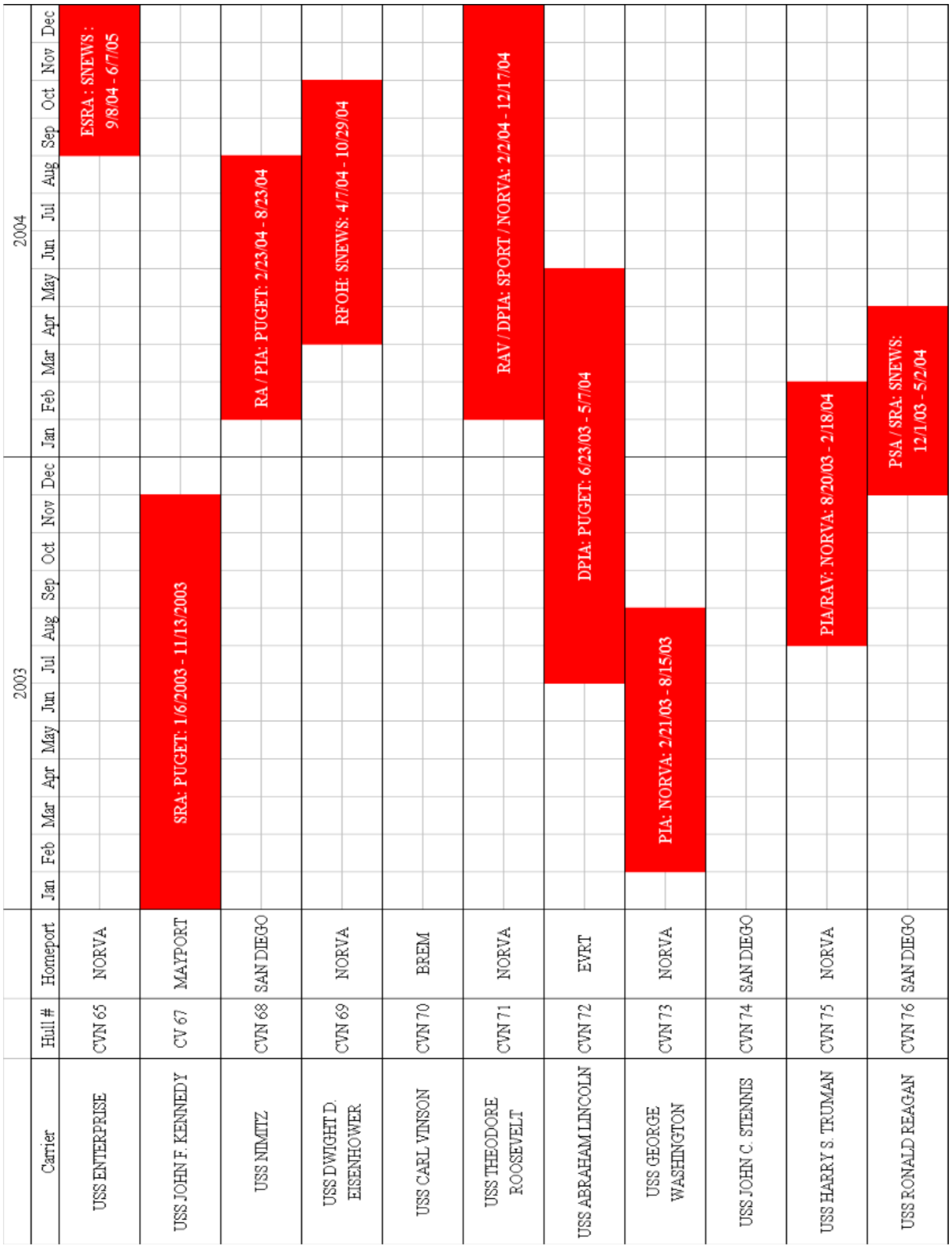

Figure 4. Two years of an aggregate carrier maintenance schedule dated May 2004. The shaded blocks represent maintenance periods and the associated text describes the type, location and length of the maintenance period. *CV 63 is not listed due to FDNF status. [Naval Sea Systems Command (NAVSEA), 2004]

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II. CARRIER EMPLOYMENT CONSTRAINTS

A number of factors affect naval combatant's ability to respond to a crisis. The principal factors are classified in one of two categories, material or personnel preparedness. Maintenance is the primary material consideration, specifically depot-level maintenance, while Personnel Tempo of Operations (PERSTEMPO), Operational Tempo (OPTEMPO) and Turn-Around Ratio (TAR) account for the personnel preparedness factors. When these constraints are met, the remaining planning consideration that affects a carrier's employment is the location of its intended operations. If the ship is responding to a crisis, time and distance calculations are critical. Even though we do not specifically address PERSTEMPO, OPTEMPO and TAR in this model, these factors are discussed because they certainly affect the CSG's ability to deploy. These constraints are soft constraints, in the sense that they can be violated in a time of crisis; however, they do provide quality-of-life (QOL) guidelines to be followed in the steady-state environment. This analysis concentrates on the affect of depot-level maintenance on the employment of the CSG under the FRP construct.

A. MATERIAL PREPAREDNESS

1. Depot Level Maintenance

OPNAVINST 4700.K, the maintenance policy instruction for U.S. Navy ships, identifies three levels of maintenance: organizational-level, intermediate-level and depot-level maintenance. Organizational-level maintenance refers to the set of maintenance actions that lie within the capability of the ship's force. Intermediate-level maintenance demands "higher skill, capability or capacity than that of the organizational-level." [OPNAV, 2003a] The third maintenance level has the greatest potential to affect a CSG's employability and therefore is the focus of this work. Depot-level maintenance is defined as:

> that maintenance which requires skills or facilities beyond the level of the organizational and intermediate levels and is performed by naval shipyards, private shipyards, naval ship repair facilities, or item depot

activities. Approved alterations and modifications which update and improve the ship's military and technical capabilities are also accomplished. [OPNAV, 2003a]

Table 5 displays a segment of a notional depot-level maintenance schedule. The schedule shown represents the Incremental Maintenance Plan (IMP) maintenance strategy used by the Nimitz Class (CV 68) aircraft carrier. The comprehensive maintenance strategies to include Progressive maintenance (PROG) and the Engineering Operating Cycle (EOC) are illustrated in Appendix B.

<table>
<tr><th>SHIP CLASS</th><th>MAINT STRATEGY</th><th>TYPE AVAIL</th><th>REP INTERVAL (MOS)</th><th colspan="7">TIME–LINE NUMBERS INDICATE MONTHS</th></tr>
<tr><td>CVN 68</td><td>IMP</td><td>RCOH</td><td></td><td>PSA-SRA |</td><td>--------</td><td>| PIA1 |</td><td>--------</td><td>| PIA1 |</td><td>--------</td><td>| DPIA1 |</td></tr>
<tr><td>NOTE C</td><td></td><td>DPIA1</td><td>66</td><td>0</td><td></td><td>19 - 24</td><td></td><td>43 - 48</td><td></td><td>67 - 76.5</td></tr>
<tr><td></td><td></td><td>DPIA2</td><td>66</td><td>--------</td><td>| PIA2 |</td><td>--------</td><td>| PIA2 |</td><td>--------</td><td>| DPIA2 |</td><td>--------</td></tr>
<tr><td></td><td></td><td>DPIA3</td><td>66</td><td></td><td>95.5 - 100.5</td><td></td><td>119.5 - 124.5</td><td></td><td>143.5 - 153</td><td></td></tr>
<tr><td></td><td></td><td>PIA1</td><td>18</td><td>| PIA3 |</td><td>--------</td><td>| PIA3 |</td><td>--------</td><td>| DPIA3 |</td><td>--------</td><td>| PIA3 |</td></tr>
<tr><td></td><td></td><td>PIA2</td><td>18</td><td>172 - 177</td><td></td><td>196 - 201</td><td></td><td>220 - 229.5</td><td></td><td>248.5 - 253.5</td></tr>
<tr><td></td><td></td><td>PIA3</td><td>18</td><td>--------</td><td>| PIA3 |</td><td>--------</td><td>| RCOH |</td><td>--------</td><td>| PSA-SRA |</td><td>--------</td></tr>
<tr><td></td><td></td><td>PSA-SRA</td><td></td><td></td><td>281.5 - 277.5</td><td>296.5</td><td>0</td><td></td><td>5 - 8</td><td></td></tr>
</table>

Table 5. Representative Intervals, Durations and Repair Mandays for Depot Level Availabilities. A segment of the notional Representative Intervals, Durations, Maintenance Cycles, and Repair Mandays for Depot Level Maintenance Availability for a Nimitz Class (CVN 68) Aircraft Carrier. [OPNAV, 2003b]

Generally, in each of the maintenance strategies there are three significant types of availabilities: Planned Incremental Availabilities (PIAs) or Extended Selected Restricted Availability (ESRAs), which last six months, Docking Planned Incremental Availabilities (DPIAs) or Extended Dry-Docking Selected Restricted Availabilities (EDSRAs), which last 10.5 months, and Refueling Complex Overhauls (RCOH), which last approximately 33 months.

Below, Table 6 lists the CNO allowable deviations for carrier depot availabilities. The CNO allowable deviations for Carrier Depot Availabilities as they apply to the notional segment illustrated in Table 5 are shown in Table 7. Maintenance terms and definitions, according to OPNAV Notice 4700, are listed in Appendix A.

Period from start of maintenance cycle to start of Representative Availability	Allowable Deviaiton
0-36 months	+/- 3 months
37-48 months	+/- 4 months
49-60 months	+/- 5 months
61-72 months	+/- 6 months
Greater than 72 months	+/- 7 months

Table 6. CNO Allowable Deviations for Carrier Depot Availabilities. "To ensure compatibility with ship's employment schedule and to facilitate depot work loading, deviation from the representative depot availability interval is authorized." [OPNAV, 2003b]

SHIP CLASS	MAINT STRATEGY	TYPE AVAIL	REP INTERVAL (MOS)	TIME–LINE NUMBERS INDICATE MONTHS						
CVN 68	IMP	RCOH		**PSA-SRA**	--------	**PIA1**	--------	**PIA1**	--------	**DPIA1**
		DPIA1	66	0		19 - 24		43 - 48		67 - 76.5
						+/- **3**		+/- **4**		+/- **6**
		DPIA2	66	--------	**PIA2**	--------	**PIA2**	--------	**DPIA2**	--------
		DPIA3	66		95.5 - 100.5		119.5 - 124.5		143.5 - 153	
					+/- 7		+/- 7		+/- 7	
		PIA1	18	**PIA3**	--------	**PIA3**	--------	**DPIA3**	--------	**PIA3**
		PIA2	18	172 - 177		196 - 201		220 - 229.5		248.5 - 253.5
				+/- 7		+/- 7		+/- 7		+/- 7
		PIA3	18	--------	**PIA3**	--------	**RCOH**	--------	**PSA-SRA**	--------
		PSA-SRA			281.5 - 277.5	296.5	0		5 - 8	
					+/- 7				+/- **3**	

Table 7. Applied CNO allowable Deviations. A segment of the allowable deviations that correspond to the notional Representative Intervals, Durations, Maintenance Cycles, and Repair Mandays for Depot Level Maintenance Availability for a Nimitz Class (CVN 68) Aircraft Carrier. [OPNAV, 2003b]

2. Repair Facilities

The repair facilities that conduct depot-level maintenance of aircraft carriers for the U.S. Atlantic (LANTFLT) and Pacific Fleet (PACFLT) are as follows: Newport News Shipbuilding Company (NEWS) and Norfolk Naval Shipyard (NORVA) for LANTFLT; Puget Sound Naval Shipyard (PUGET) for PACFLT. The Forward Deployed Naval Force (FDNF) receives maintenance at the Yokosuka Ship Repair Facility (YOKO). The capabilities and constraints of each U.S. shipyard are listed below:

> There is now only one dry-dock in PACFLT and two in LANTFLT capable of performing a DPIA. The first 7 to 8 months of each DPIA are spent in dry-dock. The first 14 months of each RCOH are also spent in dry-dock in LANTFLT. Therefore, if two consecutive carriers need DPIAs, the second one will (always in PACFLT and often in LANTFLT) have to wait for the first one to finish the dry-dock portion of its DPIA before it can go into the yards. This could push a ship's whole schedule back, possibly forcing it to delay its next deployment. [Behrens, 2001]

3. Repair Mandays

In addition to facility availability, there must also be an "available" workforce. Notional mandays or workforce-planning measures are provided for each aircraft carrier class in Appendix B. These figures are notional and "changes to the mandays may be required based on actual ship material condition, actual shipyard estimates, or for additional services associated with extended duration availabilities." [OPNAV, 2003a] Although labor is generally "available," in this case, cost efficiency is the driving factor and presents a very real constraint.

B. PERSONNEL PREPAREDNESS

1. Personnel Tempo of Operations (PERSTEMPO)

The manner in which we train, maintain, and deploy our forces is changing, yet the principles that confine our ability to do so remain constant. In order to support national objectives while maintaining a reasonable quality of life for naval personnel, the CNO has established the PERSTEMPO program for all U.S. Navy commands/units. [OPNAV, 1990] This program is bound by the following guidelines:

(1). Maximum deployment length of six months, portal to portal,

(2). Minimum 2.0: 1 Turn-around Ratio (TAR) between deployments,

(3). Minimum of 50% time in homeport for a unit over a 5-year cycle calculated three years back and two years forward based on current schedules. [OPNAV, 1990]

By definition, PERSTEMPO is "A comparison of a unit's days not in homeport (NHPO) over a specific period of time, expressed as a percentage of time away from homeport." [OPNAV, 1990]

2. Turn-around Ratio (TAR)

According to OPNAV guidance, Turn-around Ratio (TAR) is the ratio between the numbers of days a unit spends at home between deployments and the length of the last deployment in days calculated to the nearest tenth. [OPNAV, 1990]

Deployment length is essential to understanding TAR and is defined as the "months spent deployed (portal to portal) without respect to operational control (OPCON) or en route stops." As defined in Naval Warfare Publication (NWP) 1-03.1 (Operational Reports), any unit away from homeport for more than eight weeks (56 days) is considered deployed. [OPNAV, 1990]

3. Operational Tempo (OPTEMPO)

Operational Tempo (OPTEMPO) – There are two types: deployed OPTEMPO and non-deployed OPTEMPO. Deployed OPTEMPO is the fraction of time a ship spends at sea while deployed and non-deployed OPTEMPO is the fraction of time a ship spends at sea while not deployed.

C. TIME AND DISTANCE CALCULATIONS

For the sake of demonstration deployment origins have been limited to Norfolk, VA, San Diego, CA, and Yokosuka, Japan. The destinations are vital areas of interest and include the Panama Canal, Caribbean, Mediterranean, Persian Gulf, Western Pacific and Singapore.

The calculations in Table 8 were made with a speed of advance (SOA) of 14 knots, the standard Navy SOA. Although CSGs can and do execute higher transit speeds, an over-all 14 knot SOA toward an AOR allows for flight operations en route that frequently require multiple courses and speeds.

Origin	Destination	Transit Distance (NM)	Time (hrs)	Time (days)
Norfolk	Caribbean	1,279	91.4	3.8
	Mediterranean (Naples)	4,336	309.7	12.9
	Persian Gulf	8,794	628.1	26.2
San Diego	Panama	2,843	203.1	8.5
	Western Pacific (Japan)	4,917	351.2	14.6
	Singapore	7,736	552.6	23.0
	Persian Gulf	10,955	782.5	32.6
Yokosuka	Persian Gulf	6,102	435.9	18.2

Table 8. Transit Distances. Transit distances are a primary consideration in the event of a crisis. This table has been adapted from a 1994 study by William F. Morgan of the Center for Naval Analyses (CNA). [Morgan, 1994]

III. LITERATURE REVIEW, CONCEPTUAL FRAMEWORK AND MODEL FORMULATION

A. PREVIOUS WORK ON CARRIER MAINTENANCE MODELS

The problem of aircraft carrier maintenance scheduling is a deterministic scheduling problem—there is a finite number of carriers to be scheduled and a single objective—meeting established Department of Defense (DOD) planning requirements. This problem has been approached in the past as a set partitioning problem or a multi-commodity network flow model. [Ayik, 1998] A review of previous studies that use these techniques are described below.

In the technical report "Navy Forward Presence Coverage and Response Times" the authors, Brown, Lawphongpanich and Schrady, model deployment scheduling as a two-commodity network flow problem with side constraints. As the title suggests, they address the problem of AOR coverage and crisis response time. The foundation of their model, Coverage and Response Estimation (CORE), rests upon the following tenets:

- Individual carriers are optimally scheduled for deployments over a ten-year frame, 1997 to 2006, so as to maximize European Command (EUCOM) and Central Command (CENTCOM) coverage. [Brown, 1997]
- The model is a deterministic, time indexed, weekly resolution model.
- Carriers must be in one of three states: maintenance, workup or deployment.
- Scheduling is done globally: LANT and PAC carriers are not scheduled separately but rather all carriers are considered within the single scheduling problem. [Brown, 1997]

The model ultimately measures the percentage of coverage and response times as a function of the number of carriers in the Navy force structure. "The model was run with the number of carriers ranging from 7 to 16. The upper value of 16 was selected to calibrate the model with the (then) present OPNAV Force Presence Model, which calculates that 14 to 16 carriers are necessary for 100% coverage."[Brown, 1997]

A similar study by Ayik, analyzes the U.S. Navy's ability to maximize coverage in the Areas of Responsibility (AORs) by shifting existing scheduled maintenance periods within allowable limits as directed by the Chief of Naval Operations (CNO). It investigates the effects of maintenance shifting on the following measures:

- Crisis response time: the expected time to send the closest carrier to a crisis location;
- AOR coverage: the percentage of time a carrier is available in a specific AOR;
- Economic costs and implications. [Ayik, 1998]

Ayik's study builds on the CORE model and introduces a Generalized Coverage and Response Estimation (GENCoRE) model to investigate the effect of one-month shifts on simultaneous deployment planning and maintenance scheduling.

Further research by Ayik models carrier deployment planning as a set-partitioning problem (SPP). In his SPP formulation "all possible schedules that provide the period-by-period status of each carrier for the planning horizon" are generated, subject to operations and maintenance constraints. [Ayik, 2000] Furthermore, the formulation "maximizes coverage in the areas of responsibility (AORs) subject to the constraints that exactly one alternate schedule is chosen for each carrier and each AOR should be covered in each period." [Ayik, 2000]

B. CONCEPTUAL FRAMEWORK

In this analysis we explore the FRP and FRTP under four independent, steady-state, training schedules: *"6 to 18" 12-month employable (D)* state schedule, *"3 to 15" 12-month employable (D)* state schedule, *"6 to 21" 15-month employable (D)* state schedule and the "*3 to 18" 15-month employable (D)* state schedule. The first two schedules follow a *notional*, 24-month training cycle while the last two schedules follow a *suggested*, 27-month training cycle.

Under each of these schedules, three unique scenarios are modeled. The scenarios are as follows: (1) *baseline* FRP (12 CSGs); (2) *loss* of an Atlantic Fleet (LANTFLT)

CSG; and (3) *gain* a LANTFLT CSG. The scenarios begin in August 2004, end in July 2013, and follow the aggregate carrier maintenance schedule of 12 May 2004 provided by the NAVSEA maintenance office. Table 9 summarizes the scenarios used to inspect the FRP and FRTP.

Training Plan	Training Schedule	Scenario	Model Description
Notional (24-month training cycle)	"6 to 18"	Gain Baseline Loss	A 24-month training cycle is modeled over 120 months. The "employable" state in each training cylce is allowed to vary between 6 and 18 months.
	"3 to 15"	Gain Baseline Loss	A 24-month training cycle is modeled over 120 months. The "employable" state in the first two training cylces is allowed to vary between 3 and 15 months — the remaining "employable" states vary between 6 and 18 months.
Suggested (27-month training cycle)	"6 to 21"	Gain Baseline Loss	A 27-month training cycle is modeled over 120 months. The "employable" state in each training cylce is allowed to vary between 6 and 21 months.
	"3 to 18"	Gain Baseline Loss	A 27-month training cycle is modeled over 120 months. The "employable" state in the first two training cylces is allowed to vary between 3 and 18 months — the remaining "employable" states vary between 6 and 21 months.

Table 9. FRP Scenarios. Changing the durations of the “employable” periods and shifting them earlier, or later in the cycle, relaxes the optimization problem and permits optimal planning under the FRP/FRTP construct.

1. Notional Training Plan vs. Suggested Training Plan

The notional training plan adheres to the representative intervals, durations, maintenance cycles and repair mandays for depot-level maintenance availabilities of U.S. Navy ships as set forth in OPNAV Notice 4700. [OPNAV, 2003b] The standard training cycles under the *notional* training plan last 24 months and have a 12-month *employable (D)* state—that is, 12 months are spent in the *surge ready, deployable,* or *sustainment* states. The remaining 12 months are spent in the *maintenance*, *post-maintenance “shake-down,”* or *emergency surge* states.

Conversely, the training cycles under the *suggested* training plan last 27 months and have a 15-month *employable (D)* state. Under this plan, the three months that are gained in the *employable (D)* state relax the optimization problem, increase scheduling options and improve our ability to satisfy the "6+2" FRP requirement.

2. Steady-State FRP

The four independent training schedules we investigate are run through the model in the steady-state. Steady-state FRP represents peacetime operations where the constraints placed on the model come specifically from FRP guidelines, i.e. "6+2" capability and irrefutable depot level maintenance constraints. The ability to meet these guidelines answers the supply side question of FRP – "Is it possible to have six Aircraft Carrier Strike Groups available within 30 days of a crisis and an additional two CSGs available within 90 days of a crisis?" It does not propose the manner in which the CSGs should be deployed or when they should surge. It does, however, provide "windows" for employment. Whereas past deployment schedules were driven primarily by AOR presence requirements, this model's employment windows are primarily driven by the need to maintain "6+2" surge ready force.

3. Maintenance Inputs

Table 10 represents a suggested 27-month maintenance schedule covering seven full training cycles for each respective aircraft carrier. The schedule in its entirety is used as data input to the model.

	Cycle	E	Dmin	Dmax	M^{WD}	M^{WP}	M^{ED}	M^{EP}	P	
k2	1	0	**1**	**1**	0	0	0	9	3	LANTFLT
CVN 65	2	3	6	21	0	0	0	6	3	
Enterprise	3	3	6	21	0	0	7	4	5	
	4	3	6	21	0	0	0	6	3	
	5	3	6	21	0	0	0	6	3	
	6	3	6	21	0	0	7	4	5	
	7	3	6	21	0	0	0	6	3	
k3	1	0	9	9	0	0	8	8	5	LANTFLT
CV 67	2	3	6	21	0	0	0	3	3	
JFK	3	3	6	21	0	0	0	3	3	
	4	3	6	21	0	0	8	4	5	
	5	3	6	21	0	0	0	3	3	
	6	3	6	21	0	0	0	3	3	
	7	3	6	21	0	0	8	4	5	
k4	1	0	0	0	0	**1**	0	0	3	PACFLT
CVN 68	2	3	6	21	0	6	0	0	3	
Nimitz	3	3	6	21	7	4	0	0	5	
	4	3	6	21	0	6	0	0	3	
	5	3	6	21	0	6	0	0	3	
	6	3	6	21	7	4	0	0	5	
	7	3	6	21	0	6	0	0	3	

Table 10. Suggested 27-month Maintenance Schedule. A "cycle" consists of an Emergency Surge window (E), an Employable window (D), a Maintenance period (M^{XX}: M^{WD}=Maintenance / West Coast / DPIA) and a Proficiency / "Shake Down" Training window (P).

The individual cycles in Table 10 vary slightly depending upon the respective position of the carriers in their maintenance schedules. For instance, CVN 65 begins the scenario with one month remaining in her *employable (D)* state (D_{min} to D_{max}) whereas CVN 68 begins the scenario with one month remaining in the *maintenance* state—West Coast, PIA type maintenance (M^{WP}).

4. Varying the Employable (D) State Duration

Holding the material and personnel preparedness constraints constant, the remaining factor available for scrutiny is the *employable (D)* state – that state which falls after *depot-level maintenance*, *post-maintenance "shake down"* and the *emergency surge* state and consists of the *surge ready*, *deployable*, and *sustainment* states. For purposes of the calculations which follow, key state durations are labeled in Figure 5. The *employable*

(D) state duration is labeled "A," the *depot-level maintenance*, *post-maintenance "shake down"* and the *emergency surge* state durations are labeled "B," and the entire training cycle duration is labeled "C."

A												B											
2004												2005											
J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Surge Ready				Deployable						Sustainment		PIA Maintenance						Post-Maintenance "Shake Down"			Emergency Surge		
Employable (D)												Depot Level Maintenance (M)						Proficiency Training (P)			E-Surge (E)		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
C																							

Figure 5. Notional FRP Training Cycle displayed for purposes of the above calculation.

The notation "6 to 18" indicates a minimum *employable (D)* length of six months and a maximum *employable (D)* length of 18 months, the "3 to 15" notation states the minimum *employable (D)* length is three months and the maximum *employable (D)* length is 15 months. The significant difference between the two is the duration of time available to train and achieve the readiness state required to undertake the ensuing deployment. For instance, under the "6 to 18" training schedule, a CSG has six months after completion of the *emergency surge* state to meet the minimum *surge ready* and *deployable* state requirements as previously listed in Table 3. In the "3 to 18" case, a CSG has three months to meet these same requirements.

When we look at the fraction of time a CSG is available for employment we can quantify the policy impact of varying the *employable (D)* state duration under the different training schedules. The formula for calculating the percentage of time a CSG is available for employment is

$$\%\ of\ \ time\ available\ for\ employment\ \ =\ \ \frac{Employable\ (D)\ duration}{Total\ time\ in\ the\ training\ cycle}$$

$$A = employable\ (D)\ state\ duration\ (months)$$

$$B = (depot\text{-}level\ maintenance\ +\ \text{"}shake\ down\text{"}\ +\ emergency\ surge)$$
$$state\ durations\ (months)$$

$$C = entire\ training\ cycle\ duration\ (months)$$

$$\%\ of\ \ time\ available\ for\ employment\ \ =\ \ \frac{A}{A+B} = \frac{A}{C}\ where\ (C\ =\ A\ +\ B)$$

In the case of the *notional* FRP training cycle displayed in Figure 5, the percentage of time the CSG is available for employment is

$$\%\ of\ \ time\ available\ for\ employment\ \ =\ \ \frac{12\ months}{24\ months} = 50\%.$$

In the case of the *suggested* FRP training cycle the percentage of time the CSG is available for employment is

$$\%\ of\ \ time\ available\ for\ employment\ \ =\ \ \frac{15\ months}{27\ months} = 56\%.$$

Our analysis shows that this extra 6% does make a difference.

5. Employable (D) State Duration Output

Table 11, shown below, displays a portion of the output received after each run of the model. The optimal column chosen is presented and the associated durations of the *employable (D)* state are shown to the right. For example, for aircraft carrier k2, column 65 provided the optimal *employable (D)* state durations. Under this column the *employable (D)* state in the first training cycle lasts one month; in the second training cycle the *employable (D)* state lasts 21 months, and so on. Because the durations of the first two cycles are dependent upon a carrier's location in the training cycle at the beginning of the scenario, some durations may not fall within the "6 to 21" month window.

Aircraft Carrier	Column	Training Cycle (Months)						
		1st Cycle	2nd Cycle	3rd Cycle	4th Cycle	5th Cycle	6th Cycle	7th Cycle
k2	c65	1	21	17	21	21	21	21
k3	c100	9	18	15	21	21	21	21
k4	c257	0	21	21	20	21	21	21
k5	c520	0	14	21	19	21	21	21
k6	c337	21	16	20	21	21	21	21
k7	c22	0	3	16	20	21	21	21
k8	c1	21	21	21	21	21	21	21
k9	c273	5	21	20	20	21	21	21
k10	c61	9	18	21	21	21	21	21
k11	c869	16	21	18	21	21	21	21
k12	c9	13	21	21	21	21	21	21

Table 11. Employable (D) state durations from the *baseline* "6 to 21" 15-month Employable (D) State Training Schedule.

C. MODEL FORMULATION

The number of possible employment schedules in this problem is very large and, consequently, we use column generation to make the analysis more convenient—we generate a large, but manageable, number of potential schedules for each carrier. Each of these schedules becomes a column in a set partitioning formulation, which formulates the problem of choosing a set of schedules, one per carrier, that is, in some sense "best" for the overall maintenance schedule for all carriers. Even after a column generation, the data set is still very large—there are 5,760,000 rows (12 carriers*4,000 columns*120 time periods) of input data. For the purpose of this analysis, we generate 4,000 columns for each carrier and each column is indexed over 120 time periods.

The model we use to explore aircraft carrier maintenance scheduling is a time indexed, monthly resolution optimization model. This model is formulated upon the Representative Intervals, Durations, Maintenance Cycles and Repair Mandays for Depot Level Maintenance Availabilities over a ten-year (120-month) timeframe. It is important to note that each aircraft carrier is scheduled according to its respective ship class maintenance strategy: CV 63 Kitty Hawk Class - Forward-Deployed Naval Forces

(FDNF) - Progressive maintenance (PROG); CVN 65 Enterprise - Engineering Operating Cycle (EOC); CV 67 John F. Kennedy - Engineering Operating Cycle (EOC); and CVN 68 Nimitz Class - the Incremental Maintenance Program (IMP). The strategies are further defined in Appendix A.

We divided the Carrier Strike Group FRP maintenance and training schedule into four distinct states: *Emergency surge (E), employable (D), maintenance (M) and proficiency Training (P)*. The *emergency surge (E)* state lasts for three months and immediately follows the *proficiency training (P)* state. Though the *employable (D)* state is represented by one variable, three states are captured within the duration of this state timeframe: *surge-ready, deployable,* and *sustainment*. The *maintenance (M)* state has four independent sub-states determined by: homeport, (LANTFLT or PACFLT), and type of maintenance, (PIA or DPIA). The duration of the *proficiency training (P)* state varies with the type of maintenance conducted. Following a Planned Incremental Availability (PIA), three months are required; following a Docking Planned Incremental Availability (DPIA), five months are required; following a Reactor Complex Overhaul (RCOH), seven months are required; and following the new construction of an aircraft carrier, nine months are required until the unit is considered "emergency surge-able." [OPNAV, 2003c]

For each carrier, we generate a fixed number of employment schedules (currently 4,000) from which we will ultimately choose one. Each schedule is completely determined by the length of each *employable (D)* state interval. Over 120 months, a carrier may have up to seven such *employable (D)* intervals. Once the lengths of these are determined for one schedule, we can determine in which state the carrier will be for all time periods.

Given the 4,000 schedules for each carrier, we develop an optimization model that chooses one schedule for each carrier so that the overall demands on maintenance facilities is feasible and so that we come as close as possibly to meeting the FRP "6+2" coverage requirements. Each schedule for a CSG is completely specified by a set of time indexed parameters for each state that indicate whether or not the CSG is in that state in each time period.

The optimization model is formulated as follows:

1. Optimization Model

Indices:

k Carrier Strike Groups $k \in \{1,2,3,...K\}$

s States of the Carrier Strike Group
$s \in S = \{E =$ e-surge, $D =$ deployable,
$M^{WD} =$ PACFLT carrier in DPIA maintenance,
$M^{WP} =$ PACFLT carrier in PIA maintenance,
$M^{ED} =$ LANTFLT carrier in DPIA maintenance,
$M^{EP} =$ LANTFLT carrier in PIA maintenance,
$P =$ proficiency training$\}$

t Time Index (months) $t \in \{1,2,3...T\}$

c Column Index $c \in \{1,2,3...3000\}$

Data:

a CSG Employment Requirement at time t

b CSG Surge-Ready Requirement at time t

pa_t Penalty for not meeting employment requirement a at time t

pb_t Penalty for not meeting surge-ready requirement b at time t

pd_t Penalty for not meeting dry-dock requirements at time t

$E_{k,c,t}$ CSG k is in state "E" at time t in schedule c

$D_{k,c,t}$ CSG k is in state "D" at time t in schedule c

$M^{WP}_{k,c,t}$ PACFLT CSG k is in state "M" conducting PIA maintenance, at time t in schedule c

$M^{WD}_{k,c,t}$ PACFLT CSG k is in state "M" conducting DPIA maintenance, at time t in schedule c

$M^{EP}_{k,c,t}$ LANTFLT CSG k is in state "M" conducting PIA maintenance, at time t in schedule c

$M^{ED}_{k,c,t}$ LANTFLT CSG k is in state "M" conducting DPIA maintenance, at time t in schedule c

$P_{k,c,t}$ CSG k is in state "P" at time t in schedule c

$maint^{WD}$ Max Number of PACFLT CSGs in drydock DPIA maintenance at any time

$maint^{WP}$ Max Number of PACFLT CSGs in PIA maintenance at any time

$maint^{ED}$ Max Number of LANTFLT CSGs in drydock DPIA maintenance at any time

$maint^{EP}$ Max Number of LANTFLT CSGs in PIA maintenance at any time

$discount_t$ Time indexed, discount factor for the penalty functions

$rate$ Rate of exponential decay of the penalty functions

Decision Variables:

ZA_t Slack employment variable

ZB_t Slack emergency surge-ready variable (within 90 days of PIA maintenance)

$Ddock_t$ Slack dry-dock variable

$X_{k,c}$ Binary variable:

$$\begin{cases} 1 & \text{if CSG } k \text{ follows schedule in column } c \\ 0 & \text{otherwise} \end{cases}$$

Objective Function and Constraints:

$$\text{Min } \sum_t discount(t) * \left(ZA_t * pa_t + ZB_t * pb_t + Ddock_t * pd_t \right) \qquad (4.0)$$

Subject to:

$$\sum_{c} X_{k,c} = 1 \qquad \forall\ k \qquad (4.1)$$

$$\sum_{k,c}\left[\left(D_{k,c,t}\right)\left(X_{k,c}\right)\right] + \mathrm{ZA}_t \geq a \qquad \forall\ t \qquad (4.2)$$

$$\sum_{k,c}\left[\left(D_{k,c,t} + E_{k,c,t}\right)\left(X_{k,c}\right)\right] + ZB_t \geq \left(a+b\right) \qquad \forall t \qquad (4.3)$$

$$\sum_{k,c}\left[\left(M^{WD}\right)\left(X_{k,c}\right)\right] \leq maint^{WD} \qquad \forall t \qquad (4.4)$$

$$\sum_{k,c}\left[\left(M^{WP}\right)\left(X_{k,c}\right)\right] \leq maint^{WP} \qquad \forall t \qquad (4.5)$$

$$\sum_{k,c}\left[\left(M^{ED}\right)\left(X_{k,c}\right)\right] - Ddock_t \leq maint^{ED} \qquad \forall t \qquad (4.6)$$

$$\sum_{k,c}\left[\left(M^{EP}\right)\left(X_{k,c}\right)\right] \leq maint^{EP} \qquad \forall t \qquad (4.7)$$

$$ZA_t \geq 0 \qquad \forall\ t \qquad (4.8)$$

$$ZB_t \geq 0 \qquad \forall\ t \qquad (4.9)$$

$$X_{k,c} \in \{0,1\} \qquad \forall\ k,c \qquad (4.10)$$

In the above formulation, the objective is to minimize the penalty for failing to reach the “6+2” CSG surge requirements over the ten-year period.

- The objective (4.0) enforces penalties for missing the presence requirements, and applies an optional discount to emphasize certain time periods over others.
- Constraint (4.1) states that only one column, that is one schedule, can be chosen out of the total number of columns generated for each CSG;
- (4.2) counts the number of *employable* carriers in each time period, t, and assesses the “shortfall” in coverage, ZA_t, from *a*;
- (4.3) counts the number of *employable* and *emergency surge* ready carriers in each time period, t, and calculates the “shortfall” in coverage, ZB_t, from *(a+b)* ;
- (4.4) provides an upper bound on the number of PACFLT aircraft carriers that can conduct dry-dock DPIA maintenance at any one time;

- (4.5) provides an upper bound on the number of PACFLT aircraft carriers that can conduct PIA maintenance at any one time;
- (4.6) provides an upper bound on the number of LANTFLT aircraft carriers that can conduct dry-dock DPIA maintenance at any one time;
- (4.7) provides an upper bound on the number of LANTFLT aircraft carriers that can conduct PIA maintenance at any one time;
- (4.8 and 4.9) non-negativity constraints;
- (4.10) binary variable.

2. Software

The General Algebraic Modeling System (GAMS) was used to formulate the model, and the CPLEX MIP solver was used to solve the model. The model was solved using an Intel(R) Pentium (R) 4 CPU 2.00 GHz based personal computer. The size of the model under each training schedule and for each scenario is displayed in Table 12. The relative optimality criterion for a MIP problem was set to one percent. The model arrives at a solution between seven and ten minutes.

Columns are generated by the program defined in gencols.c, in Appendix D. This program takes, as input, a data file specifying the minimum and maximum duration of each *employable (D)* interval, and the length of every other interval, for seven cycles, for each carrier. It then enumerates as many columns as needed (here, 4,000) starting with the column resulting from making all *employable (D)* intervals as long as possible, and then generating successive columns by shortening one employable interval at a time. The first *employable (D)* interval is shortened by one month at a time, until it hits its minimum length at which point it is raised back to its maximum length, and then the second *employable (D)* interval is shortened by one month. This proceeds, with the first cycle's *employment (D)* interval length changing most frequently, and the last cycle usually not ever changing, but certainly changing most slowly. Each of these column sets values for the parameters $E_{k,c,t}$, $D_{k,c,t}$, etc., and therefore determines the bulk of the parameters for the model. The file generated by gencols.c is input directly into the GAMS model. We could generate any 4,000 columns for each carrier, and the model will choose the best combination of the columns presented to it. In the next section we summarize some of these results for various scenarios. In each, we generated an appropriate set of columns to represent the options available in the scenario.

Training Plan	Training Schedule	Scenario	Model Description
Notional (24-month training cycle)	"6 to 18"	Baseline Loss Gain	A 24-month training cycle is modeled over 120 months. The "employable" state in each training cylce is allowed to vary between 6 and 18 months.
	"3 to 15"	Baseline Loss Gain	A 24-month training cycle is modeled over 120 months. The "employable" state in the first two training cylces is allowed to vary between 3 and 15 months — the remaining "employable" states vary between 6 and 18 months.
Suggested (27-month training cycle)	"6 to 21"	Baseline Loss Gain	A 27-month training cycle is modeled over 120 months. The "employable" state in each training cylce is allowed to vary between 6 and 21 months.
	"3 to 18"	Baseline Loss Gain	A 27-month training cycle is modeled over 120 months. The "employable" state in the first two training cylces is allowed to vary between 3 and 18 months — the remaining "employable" states vary between 6 and 21 months.

Table 12. Model Sizes for Each Training Plan, Training Schedule and Scenario

IV. MODEL RESULTS

This chapter presents the results from each of the four independent, steady-state, training schedules that we ran through our scheduling optimization model. As a reminder, the model attempts to minimize deviation from the "6+2" FRP construct and maximize asset availability and assured readiness while adhering to established Navy force guidelines.

Figure 6 displays a sample of output from the "6 to 21" *baseline* scenario run with a 15-month *employable (D)* state. In the first three time periods, this scenario "fails-to-meet" (FTM) the "6" CSG requirement by two CSGs, i.e. only four CSGs are available at time t = 1, 2 and 3 months. At time t = 18 months the scenario FTM "6" by one CSG and FTM "+2" by two CSGs.

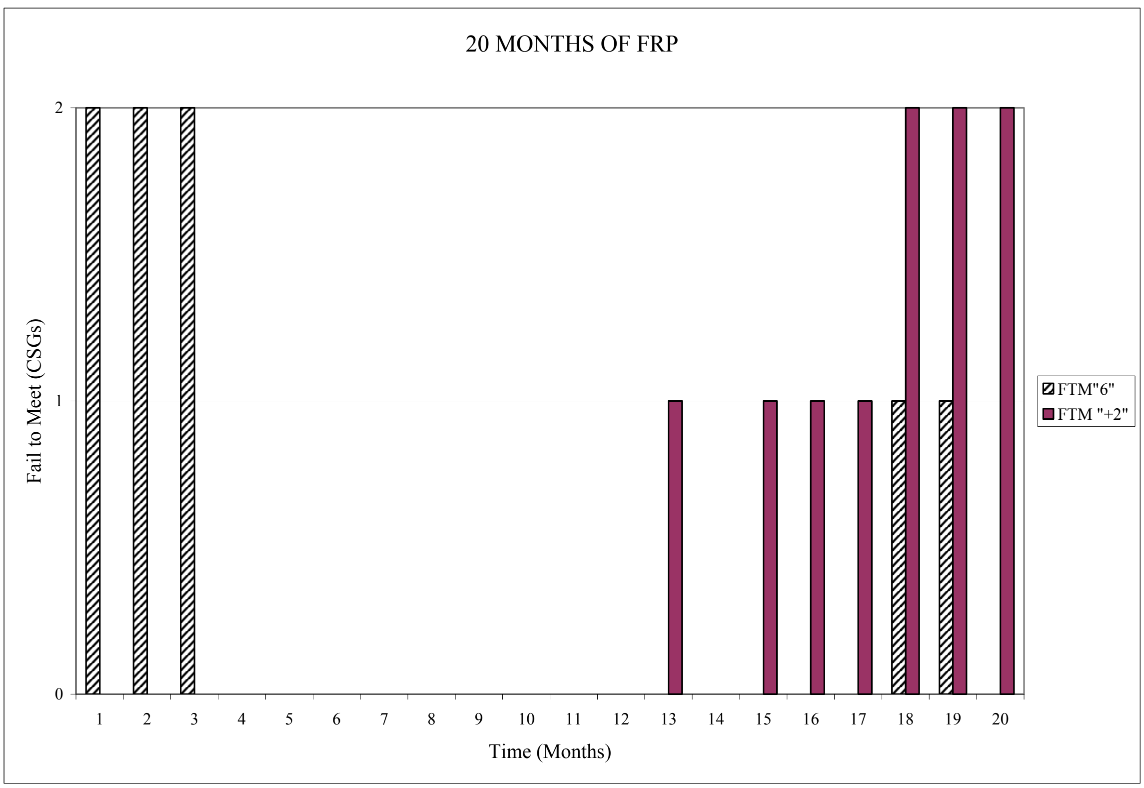

Figure 6. 20 Months of FRP. The results shown above are taken from the "6 to 21" *baseline* scenario run with a 15-month *employable (D)* state. Although the entire 120-month time frame is not shown, all of the discrepancies occur in the first 62 months. (FTM "6" corresponds to the variable ZA_t, and FTM "+2" corresponds to the variable ZB_t.)

The result presented in Figure 6 is fairly intuitive as the maintenance system has not had sufficient time to absorb the impact of this new scheduling construct. It is also optimistic in the sense that after the first 62 months, under this training schedule, FRP is feasible. The primary conclusion to be drawn from this result is the FRP "6+2" requirement, under the "6 to 21" 15-month *employable (D)* state training plan, can be met, undeniably, by October 2009.

A. MEETING THE FRP "6+2" CSG REQUIREMENT

In the results that follow the abilities of the different training schedules to meet the "6+2" requirement are shown. The first column in the table displays the percentage of time, out of 120 months, that the given scenario is able to meet the "6," or the "+2" requirement. The remaining columns represent the percentage of time the schedules "fail to meet" (FTM) the "6," or "+2" requirement.

For example, below in Table 13, the *baseline* scenario meets the "6" requirement 93% of the time, fails to meet the "6" requirement by one CSG 4% of the time and fails to meet the "6" requirement by two CSGs 3% of the time. Conversely, the *baseline* scenario meets the "+2" requirement 60% of the time, fails to meet the "+2" requirement by one CSG 31% of the time and fails to meet the "+2" requirement by two CSGs 9% of the time. In Table 13, as in Tables 14, 15 and 16, the *loss* scenario produces obvious deterioration of coverage in each of the categories.

1. “6 to 18” 12-Month Employable (D) State Training Schedule

"6 to 18" 12-Month Employable (D) State - Meet "6"

	"6"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	91%	5%	4%	---	---
Baseline:	**93%**	**4%**	**3%**	**---**	**---**
Loss:	83%	8%	7%	2%	---

"6 to 18" 12-Month Employable (D) State - Meet "+2"

	"+2"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	73%	18%	9%	---	---
Baseline:	**60%**	**31%**	**9%**	**---**	**---**
Loss:	28%	46%	22%	3%	1%

Table 13. Ability to meet the “6+2” requirement under the “6 to 18” 12-Month Employable (D) State Training Schedule.

The results in Table 14, below, are similar to those shown in Table 13. The *gain* scenario does not produce a significant increase in meeting the “6” CSGs requirement but does show improvement in its ability to meet the “+2” requirement.

2. “3 to 15” 12-Month Employable (D) State Training Schedule

"3 to 15" 12-Month Employable (D) State - Meet "6"

	"6"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	84%	12%	3%	1%	---
Baseline:	**84%**	**10%**	**5%**	**1%**	**---**
Loss:	68%	20%	9%	2%	1%

"3 to 15" 12-Month Employable State (D) - Meet "+2"

	"+2"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	68%	14%	17%	1%	---
Baseline:	**49%**	**35%**	**13%**	**3%**	**---**
Loss:	25%	39%	28%	5%	3%

Table 14. Ability to meet the “6+2” requirement under the “3 to 15” 12-Month Employable (D) State Training Schedule.

In Table 15, once again, the behavior of the *gain* scenario mimics the results from the previous two model runs. The *baseline* scenario's ability to meet "6", 96% of the time, is the highest percentage under each of the four training schedules.

3. "6 to 21" 15-Month Employable (D) State Training Schedule

"6 to 21" 15-Month Employable (D) State - Meet "6"

	"6"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	94%	3%	3%	---	---
Baseline:	**96%**	**2%**	**2%**	**---**	**---**
Loss:	82%	14%	3%	1%	---

"6 to 21" 15-Month Employable (D) State - Meet "+2"

	"+2"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	87%	7%	6%	---	---
Baseline:	**79%**	**15%**	**6%**	**---**	**---**
Loss:	51%	31%	14%	4%	---

Table 15. Ability to meet the "6+2" requirement under the "6 to 21" 15-Month Employable (D) State Training Schedule.

In Table 16, shown below, the difference (3%) between the *baseline* and *gain* scenario's ability to meet "6" is greatest under the "3-18" 15 month *employable (D)* State Training Schedule.

4. "3 to 18" 15-Month Employable (D) State Training Schedule

"3 to 18" 15-Month Employable State (D) - Meet "6"

	"6"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	90%	6%	4%	---	---
Baseline:	**93%**	**3%**	**3%**	**---**	**---**
Loss:	77%	17%	5%	1%	---

"3 to 18" 15-Month Employable (D) State - Meet "+2"

	"+2"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	73%	19%	8%	---	---
Baseline:	**67%**	**24%**	**9%**	**---**	**---**
Loss:	35%	41%	19%	5%	---

Table 16. Ability to meet the "6+2" requirement under the "3 to 18" 15-Month Employable (D) State Training Schedule.

The result of interest under each of these four training schedules is counter-intuitive yet crucial to understanding the complexity of the maintenance scheduling problem. The addition of one carrier to the force structure, as modeled in the *gain* scenario, does not significantly increase the ability of the training schedule to meet FRP requirements. In fact, the ability of this training schedule to meet "6" CSGs decreases from the *baseline* scenario. The ability of the schedule to meet the "+2" requirement, however, improves in each case. The implication being, an additional carrier in the force structure does not necessarily increase the ability of the fleet to meet the FRP "6+2" requirement. This again, points to the complexity of the problem in the first place.

B. MAINTENANCE IMPLICATIONS

Cost ineffectiveness along with wasted human and material resources are among the more serious consequences of poor scheduling. In the case of scheduling aircraft carriers for depot-level maintenance, poor scheduling may mean maintenance facilities are under used or forward-presence requirements are not met.

Of all the runs that were conducted with one West Coast dry-dock and two East Coast dry-dock facilities, with the exception of the training schedules that use the "6 to

21” *employable (D)* state, each solution is driven to infeasibility at time t = 10 and t = 11. The cause of these infeasibilities is the East Coast dry-dock maintenance facilities. Although these schedules are, technically, infeasible for one two-month period, we anticipate the measured use of overtime and/or additional maintenance personnel will keep operations running close enough to schedule so as not to cause further problems. In any scenario in which this 'infeasibility' occurs, maintenance schedulers should be made aware of the potential problem in advance so that appropriate corrective measures can be taken. In the tables that follow, the percentages of time that dry-dock maintenance facilities are utilized over the 120 month timeframe are shown.

1. "6 to 18" 12-Month Employable (D) State Training Schedule

Gain Scenario - "6 to 18" 12-Month Employable (D) State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	52%	0	77%
1	27%	1	23%
2	21%	---	---

Baseline Scenarioe - "6 to 18" 12-Month Employable (D) State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	50%	0	77%
1	30%	1	23%
2	20%	---	---

Loss Scenario - "6 to 18" 12-Month Employable (D) State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	56%	0	77%
1	24%	1	23%
2	20%	---	---

Table 17. Percentage of time dry-dock maintenance facilities are in use under the "6 to 18" 12-Month Employable (D) State Training Schedule.

In the *baseline* scenario shown in Table 17, two of the East Coast dry-dock facilities are in use 20% (24 months) of the time and one dry-dock is in use 30% (36 months) of the time for carrier maintenance. The remaining 50% (60 months) of the time the dry-dock facilities are not in use for CVN maintenance. While the maintenance percentages associated with the East Coast dry-docks vary slightly among the three scenarios, the maintenance percentages associated with the West Coast dry-docks remain constant throughout each scenario. This suggests that maintenance is not a constraint on the West Coast.

2. “3 to 15” 12-Month Employable (D) State Training Schedule

Gain Scenario - "3 to 15" 12-Month Employable (D) State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	47%	0	77%
1	31%	1	23%
2	22%	---	---

Baseline Scenario - "3 to 15" 12-Month Employable (D) State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	53%	0	77%
1	25%	1	23%
2	22%	---	---

Loss Scenario - "3 to 15" 12-Month Employable (D) State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	58%	0	77%
1	21%	1	23%
2	21%	---	---

Table 18. Percentage of time dry-dock maintenance facilities are in use under the “3 to 15” 12-Month Employable (D) State Training Schedule.

The results in Table 18 are fairly consistent with those received under the previous training schedule. As can be expected, the greater the number of aircraft carriers in the model, the greater the total time spent in maintenance. Under the *loss* scenario, 42% of the time is spent in maintenance; under the *baseline* scenario, 47% of the time is spent in depot-level maintenance; and under the *gain* scenario, 53% of the time is spent in maintenance. Once again, the West Coast maintenance percentages remain the same in each of the scenarios.

3. “6 to 21” 15-Month Employable (D) State Training Schedule

Gain Scenario - "6 to 21" 15-Month Employable State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	47%	0	77%
1	29%	1	23%
2	24%	---	---

Baseline Scenario - "6 to 21" 15-Month Employable State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	52%	0	77%
1	31%	1	23%
2	17%	---	---

Loss Scenario - "6 to 21" 15-Month Employable State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	60%	0	77%
1	22%	1	23%
2	18%	---	---

Table 19. Percentage of time dry-dock maintenance facilities are in use under the “6 to 21” 15-Month Employable (D) State Training Schedule.

The *loss* scenario in Table 19 yields the highest percentage (60%) of time when zero dry-docks are occupied and the training schedule as a whole produces consistent figures for the West Coast dry-dock throughout.

4. “3 to 18” 15-Month Employable (D) State Training Schedule

Gain Scenario - "3 to 18" 15-Month Employable State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	43%	0	77%
1	38%	1	23%
2	19%	---	---

Baseline Scenario - "3 to 18" 15-Month Employable State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	50%	0	77%
1	30%	1	23%
2	20%	---	---

Loss Scenario - "3 to 18" 15-Month Employable State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	55%	0	77%
1	26%	1	23%
2	19%	---	---

Table 20. Percentage of time dry-dock maintenance facilities are in use under the “3 to 18” 15-Month Employable (D) State Training Schedule.

The interesting result in Table 20 is the *baseline* scenario results are exactly the same as the *baseline* scenario results in Table 17, under the “6-18” 12-month *employable (D)* state training schedule. This suggests that lengthening the *employable (D)* state from 12 to 15 months does not significantly affect the optimal schedule of depot-level maintenance availabilities.

C. ADDING AN EAST COAST DRY-DOCK FACILITY

Up to this point, the four scenarios were run through the model with one dry-dock facility available on the West Coast and two dry-dock facilities available on the East Coast. The results presented below represent the ability to meet the FRP "6+2" requirements with a third LANTFLT dry-dock facility added to the model. As the 15-month training scenarios have been providing the most optimistic results, we have limited our analysis in this section to only the 15-month *employable (D)* state training schedules.

Generally speaking, the results in Table 21 do not differ significantly from the results received under the same training schedule, shown in Table 15, which was constrained by the availability of two East Coast dry-dock facilities. This initial insight suggests that in the absence of a well-planned long-range maintenance schedule, the addition of one dry-dock facility does not affect the Fleet's ability to meet FRP "6+2."

1. "6 to 21" 15-Month Employable (D) State Training Schedule

"6 to 21" 15-Month Employable State (D) - Meet "6"

	"6"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	94%	3%	3%	---	---
Baseline:	**95%**	**3%**	**2%**	**---**	**---**
Loss:	86%	12%	1%	1%	---

"6 to 21" 15-Month Employable State (D) - Meet "+2"

	"+2"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	88%	8%	4%	---	--
Baseline:	**84%**	**8%**	**8%**	**---**	**---**
Loss:	48%	38%	12%	2%	---

Table 21. Ability to meet the "6+2" requirement under the "6 to 21" 15-Month Employable (D) State Training Schedule.

In Table 22, below, the previous "trade-off" we saw between the meet "6" and meet "+2" requirement when an additional CSG was added to the force structure is no longer evident—both scenarios yield a 93% success rate. The effect we saw earlier seems to have been countered by the addition of one dry-dock facility.

2. “3 to 18” 15-Month Employable (D) State Training Schedule

"3 to 18" 15-Month Employable State (D) - Meet "6"

	"6"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	93%	5%	2%	---	---
Baseline:	**93%**	**5%**	**2%**	**---**	**---**
Loss:	81%	13%	5%	1%	---

"3 to 18" 15-Month Employable State (D) - Meet "+2"

	"+2"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	78%	13%	9%	---	---
Baseline:	**73%**	**19%**	**8%**	**---**	**---**
Loss:	38%	42%	15%	5%	---

Table 22. Ability to meet the “6+2” requirement under the “3 to 18” 15-Month Employable (D) State Training Schedule.

Tables 23 and 24 display the maintenance implications of adding an additional East Coast dry-dock facility to the model. In Table 23, the percentage of time the third dry-dock is in use, under each of the three scenarios is 3% or approximately four of 120 months. Once again, as expected, the greater the number of CSGs in the force structure, the more time the maintenance facilities are utilized—in the *loss* scenario, 40% of the time the facilities are occupied; in the *baseline* scenario, 45% of the time facilities are occupied; and in the *gain* scenario 52% of the time the dry-dock facilities remain occupied.

3. "6 to 21" Maintenance Implications of an Additional East Coast Dry-dock

Gain Scenario - "6 to 21" 15-Month Employable State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	48%	0	77%
1	31%	1	23%
2	18%	---	---
3	3%	---	---

Baseline Scenario - "6 to 21" 15-Month Employable State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	55%	0	77%
1	29%	1	23%
2	13%	---	---
3	3%	---	---

Loss Scenario - "6 to 21" 15-Month Employable State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	60%	0	77%
1	25%	1	23%
2	12%	---	---
3	3%	---	---

Table 23. Percentage of time dry-dock maintenance facilities are in use under the "6 to 21" 15-Month Employable (D) State Training Schedule.

In Table 24, the relative percentages of time spent in zero or one dry-docks under each training plan, in each scenario, remains approximately the same as the scenarios run with two dry-docks. The primary difference is observed between the distribution of time spent in two and three dry-docks.

4. "3 to 18" Maintenance Implications of an Additional East Coast Dry-dock

Gain Scenario - "3 to 18" 15-Month Employable State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	54%	0	77%
1	25%	1	23%
2	11%	---	---
3	10%	---	---

Baseline Scenario - "3 to 18" 15-Month Employable State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	51%	0	77%
1	38%	1	23%
2	5%	---	---
3	6%	---	---

Loss Scenario - "3 to 18" 15-Month Employable State

East Coast		West Coast	
# of Dry Docks Occupied	% of Time	# of Dry Docks Occupied	% of Time
0	62%	0	77%
1	22%	1	23%
2	10%	---	---
3	6%	---	---

Table 24. Percentage of time dry-dock maintenance facilities are in use under the "3 to 18" 15-Month Employable (D) State Training Schedule.

D. MEETING "5+2" FRP

We have demonstrated that the *baseline* "6 to 21" 15-month *employable (D)* state training plan meets the "6" requirement 96% of the time and the "+2" requirement 79% of the time. If we change the FRP requirement to "5+2" and maintain one dry-dock facility on the West Coast and two dry-dock facilities on the East Coast does our ability to meet this requirement change significantly? The results in Tables 25 and 26 were produced in the model running under the "5+2" requirement.

The results received from increasing the *employable (D)* state duration to 15 months are shown in Table 25. In this case, in the *baseline* scenario, we meet the "5" requirement 98% of the time and the "+2" requirement 97% of the time.

1. "6 to 21" 15-Month Employable (D) State Training Schedule

"6 to 21" 15-Month Employable (D) State - Meet "5"

	"5"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	98%	2%	---	---	---
Baseline:	**98%**	**2%**	**---**	**---**	**---**
Loss:	96%	3%	1%	---	---

"6 to 21" 15-Month Employable (D) State - Meet "+2"

	"+2"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	97%	3%	---	---	---
Baseline:	**97%**	**3%**	**---**	**---**	**---**
Loss:	86%	11%	3%	---	---

Table 25. Ability to meet the "5+2" requirement under the "6 to 21" 15-Month Employable (D) State Training Schedule.

The results for the "6 to 18" 12-month *employable (D)* state training schedule scenario under the "6+2" requirement were 93% and 60%, respectively. As shown in Table 26, when the requirement was lowered to "5+2", the ability to meet "6" increases slightly but the ability to meet "+2" jumps substantially. In fact, the ability to meet "+2" increases by 34%—generating approximately 41 additional months of "+2" force capability.

2. "6 to 18" 12-Month Employable (D) State Training Schedule

"6 to 18" 12-Month Employable (D) State - Meet "5"

	"5"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	96%	4%	---	---	---
Baseline:	**96%**	**4%**	**---**	**---**	**---**
Loss:	95%	4%	1%	---	---

"6 to 18" 12-Month Employable (D) State - Meet "+2"

	"+2"	FTM "1"	FTM "2"	FTM "3"	FTM "4"
Gain:	94%	6%	---	---	---
Baseline:	**94%**	**6%**	**---**	**---**	**---**
Loss:	78%	16%	6%	---	---

Table 26. Ability to meet the "5+2" requirement under the "6 to 18" 12-Month Employable (D) State Training Schedule.

When we increase the *employable (D)* state duration to 15 months and drop the surge requirement to "5+2" both respective percentages increase. The most significant result that stems from this portion of the analysis is displayed in Figure 7 below. The 2% of the time—approximately 3 out of 120 months— that we fail to meet "5" CSGs occurs at time t = 1 (Aug 04), t = 2 (Sep 04), and t = 3 (Oct 04). In other words, beginning in November, 2004, we are able to meet the "5" CSG requirement indisputably. We are able to meet the "5+2" requirement indisputably at time t = 31, i.e., February 2007.

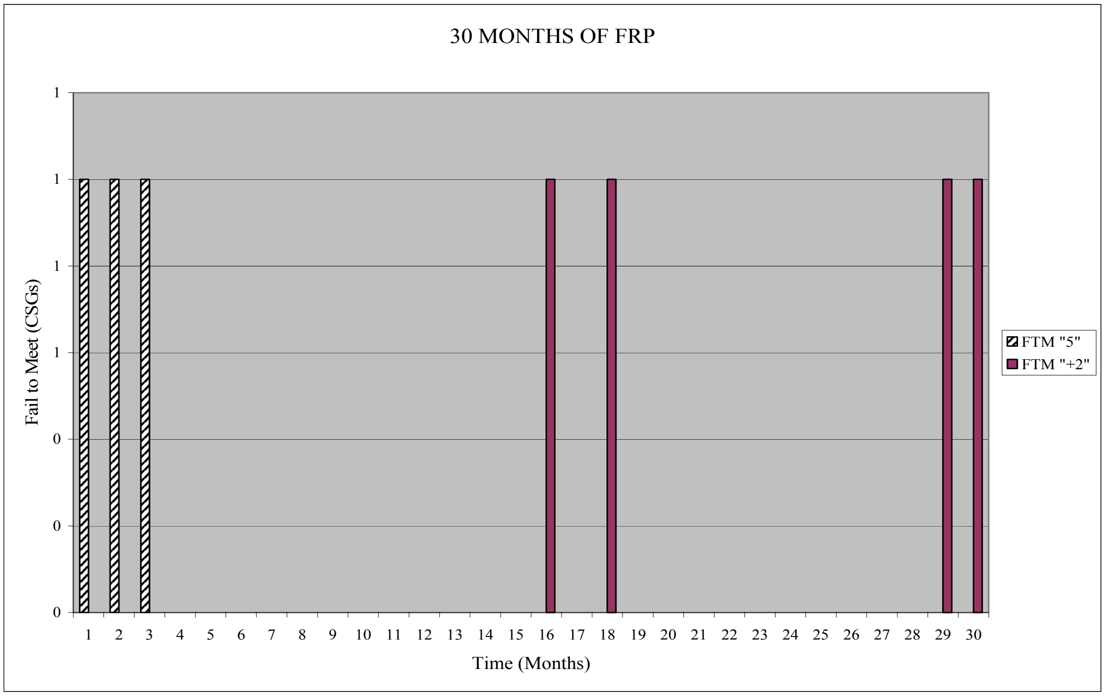

Figure 7. 30 Months of FRP—how well do we meet "5+2"? The results above were produced running the "6 to 21" 15-Month Employable (D) State Training Plan. This figure presents all of the "5+2" violations throughout the entire 120-month scenario.

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V. CONCLUSIONS AND RECOMMENDATIONS

Optimally scheduling ships' long-term maintenance and training cycles is a complex decision making process that involves the allocation of a scarce resource, in this case Carrier Strike Groups (CSGs), in a manner that maximizes their employment availability. This process is essential to providing U.S. Naval Force capabilities as required under the 2003 Fleet Readiness Plan (FRP) and Fleet Readiness Training Plan (FRTP) construct. Manual enumeration of such schedules is tedious, time-consuming, and severely limited in its ability to explore the long-term affects of policy change. This work quantifies the ability to meet FRP and increase the percentage of time an Aircraft Carrier Strike Group (CSG) is available for employment. It demonstrates that over the long-term, with current maintenance plans and restrictions, we cannot meet the FRP "6+2" requirement 100% of the time. If one lengthens the *employable (D)* state to 15 months, the percentage of time one can meet the "6+2" requirement increases. Under the "6 to 21" 15-month *employable (D)* state training plan, "6+2"can be met, undeniably, by October 2009.

If one increases the *employable (D)* state to 15 months and in addition, decreases the FRP requirement to "5+2," these forces are available, unquestionably, by February 2007. The benefit of this analysis is that we propose alternative solutions to meeting the FRP "6+2" requirement and can quantify the affects of the associated policy changes.

Even though this research concentrated on maintenance scheduling of aircraft carriers, similar research conducted on the maintenance scheduling of the carrier air wing (CVW) promises to hold significant insight. A close look at the CVW maintenance cycle may provide additional insights that affect the employability of the CSG force. Additionally, a similar look into the training and maintenance cycles for Expeditionary Strike Groups (ESGs) may provide insights into the flexibility and constraints upon these forces.

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APPENDIX A. MAINTENANCE TERMS AND DEFINITIONS

The following definitions are quoted from Enclosure (2) of OPNAV NOTICE 4700, Representative Intervals, Durations, Maintenance Cycles, and Repair Mandays for Depot Level Maintenance Availabilities of U.S. Navy Ships.

1. **Docking Planned Incremental Availability (DPIA)**. A labor-intensive availability, of less than a year duration, for aircraft carriers in an Incremental Maintenance Program. Maintenance and modernization are accomplished. Aircraft carriers assigned to Incremental Maintenance Programs are maintained through PIAs and DPIAs in lieu of overhauls.
2. **Docking Selected Restricted Availabilities (DSRA)**. An SRA expanded in scope to include maintenance and modernization that require dry-docking.
3. **Duration**. The period from the start of an availability to its completion.
4. **Engineering Operating Cycle (EOC)**. This maintenance philosophy keeps ships in an acceptable material condition while sustaining or increasing the operational availability of the ship. Earmarked by a structured engineered approach for ship maintenance while minimizing the time spent in depot-level availabilities. Major elements of the maintenance strategy include:
    - Periodic inspections of selected systems and equipment to identify and document necessary repair requirements and material condition trends.
    - Periodic maintenance tasks to be accomplished at specified times during the ship's life cycle.
    - Scheduled intra-cycle Intermediate Maintenance Availabilities (IMAVs), Drydocking SRAs (DSRAs), SRAs, and ROHs to accomplish the maintenance and modernizations required to sustain or improve the material condition of the ship.
    - Extensive modernization to maintain and upgrade the ship class war fighting capability.
5. **Extended Docking Selected Restricted Availability (EDSRA)**. A DSRA expanded in scope to include maintenance and modernization that cannot be accomplished in a DSRA.
6. **Inactivation Availability (INAC)**. An availability assigned to prepare a ship for inactivation or disposal. The scope of work depends on the planned disposition of the ship.
7. **(Incremental Maintenance Program IMP)**. A maintenance philosophy that keeps aircraft carriers in an acceptable material condition through a

series of incremental depot maintenance actions. Types of availabilities under this maintenance philosophy include PIAs and DPIAs.

8. **Incremental Selected Restricted Availability (ISRA)**. An availability for continuous accomplishment of industrial maintenance and selected modernization. A nearly continuous availability period assigned to forward deployed aircraft carriers, mine warfare ships and AFG 3.

9. **Interval**. The period from the completion of the prior scheduled depot availability to the start of the next scheduled depot availability.

10. **Maintenance Cycle**. The period of time, which starts after the completion of a ship's overhaul (or docking availability, when no overhaul availabilities are included in the maintenance plan) and ends after completion of the next overhaul or docking availability. For new construction or conversion ships, the maintenance cycle starts after the completion of the post shakedown availability or as defined in the ship's class maintenance plan.

11. **Overhaul**. A major availability normally exceeding six months duration to accomplish maintenance and modernization. Program Managers frequently use terms such as:

    - Regular, Complex, or Engineered Overhaul availability (ROH, COH, or EOH) to describe or identify planning and execution differences among overhaul availabilities of different ship classes.
    - Refueling complex or engineered refueling overhaul availability (RFOH, RCOH or ERO) to describe or identify fundamental planning and execution differences among overhaul availabilities of different nuclear powered ship classes during which the reactor is also refueled.

12. **Planned Incremental Availability (PIA)**. A labor-intensive availability, of less than six months, for aircraft carriers in an Incremental Maintenance Program. Maintenance and modernization are accomplished. Aircraft carriers assigned to Incremental Maintenance Programs are maintained through PIAs and DPIAs in lieu of overhauls.

13. **Post Shakedown Availability (PSA)**. An availability assigned to newly built activated or converted ships upon completion of post-delivery shakedown. PSAs will be scheduled so they are completed no later than the end of the Shipbuilding and Conversion Navy (SCN) obligation work limiting date which is the date on which SCN funding and work authority terminates. Work performed shall normally include correction of defects noted during shakedown correction of deficiencies remaining from the acceptance trials and performance of class modifications remaining from the new construction activation or conversion period.

14. **Progressive Maintenance (PROG)**. This maintenance philosophy is designed to support ships with reduced manning, limited organizational

level maintenance, and operational tempos that limit availability periods. It is also designed to sustain a high level of readiness and increase the ship's availability for required operations. Ships with reduced manning are designed for major component removal and replacement. To compensate for the reduced manning and other shipboard maintenance off-ship component refurbishment is done by intermediate and depot level activities. This concept requires maintenance and logistic support systems significantly different from those required for conventionally manned surface ships. Major elements of the maintenance strategy include:

- Engineered maintenance planning,
- Progressive overhaul,
- Upgrading of maintenance tasks from ship's force to the Intermediate Maintenance Activity (IMA),
- Modular replacement,
- Dedicated material support and increased stock-level procurement.

15. **Repair Mandays**. Those type commander maintenance mandays typically accomplished by the executing activity to satisfactorily complete the type of availability indicated. Repair mandays include Title D and F alteration mandays normally accomplished during the availability. Repair mandays do not include mandays from concurrent intermediate level maintenance availabilities.

16. **Selected Restricted Availability (SRA)**. A short labor-intensive industrial period assigned to ships in Progressive or Engineered Operating Cycle Maintenance Programs for the accomplishment of maintenance and selected modernization. Ships assigned to Progressive Maintenance Programs are maintained through SRAs in lieu of overhauls.

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APPENDIX B. REPRESENTATIVE INTERVALS, DURATIONS, MAINTENANCE CYCLES, AND REPAIR MANDAYS FOR DEPOT LEVEL MAINTENANCE AVAILABILITIES

SHIP CLASS	MAINT STRATEGY	TYPE AVAIL	REP DURATION (MOS)	REP INTERVAL (MOS)	MAINT CYCLE (MOS)	REP MANDAYS (000)	TIME LINE NUMBERS INDICATE MONTHS						
CV 63	PROG	IDSRA	5	57	61	129.3	IDSRA	--------	ISRA	--------	ISRA	--------	ISRA
(FDNF)		ISRA	4	8		71	0		8 - 12		20 - 24		32 - 36
NOTE A							--------	ISRA	--------	IDSRA			
								44 - 48		56 - 61			

SHIP CLASS	MAINT STRATEGY	TYPE AVAIL	REP DURATION (MOS)	REP INTERVAL (MOS)	MAINT CYCLE (MOS)	REP MANDAYS (000)	TIME LINE NUMBERS INDICATE MONTHS						
CV 67	EOC	COH	12	60	72	401.3	COH	--------	SRA	--------	SRA	--------	COH
		SRA	3	18		49.7	0		18 -21		39 - 42		60 - 72
		DSRA	4			60.4							

SHIP CLASS	MAINT STRATEGY	TYPE AVAIL	REP DURATION (MOS)	REP INTERVAL (MOS)	MAINT CYCLE (MOS)	REP MANDAYS (000)	TIME LINE NUMBERS INDICATE MONTHS						
CV 65	EOC	ESRA1	6	18	76.5	190.2	PSA	--------	ESRA1	--------	EDSRA1		
NOTE B		ESRA2	6	18		226.3	0		18 - 24		42 - 52.5		
		ESRA3	6	18		261.3	--------	ESRA2	--------	ESRA2	--------	EDSRA2	
		EDSRA1	10.5	66		401.2		70.5 - 76.5		94.5 - 100.5		118.5 - 129	
		EDSRA2	10.5	66		401.2	--------	ESRA3	--------	ESRA3	--------	EDSRA3	
		EDSRA3	10.5	67		462.8		147 - 153		171 - 177		195 - 205.5	

SHIP CLASS	MAINT STRATEGY	TYPE AVAIL	REP DURATION (MOS)	REP INTERVAL (MOS)	MAINT CYCLE (MOS)	REP MANDAYS (000)	TIME LINE NUMBERS INDICATE MONTHS						
CVN 68	IMP	RCOH	33			3200	PSA-SRA	--------	PIA1	--------	PIA1	--------	DPIA1
NOTE C		DPIA1	10.5	66	76.5	255.8	0		18 - 24		42 - 48		66 - 76.5
		DPIA2	10.5	66		308.9	--------	PIA2	--------	PIA2	--------	DPIA2	--------
		DPIA3	10.5	66		356.6		94.5 - 100.5		118.5 - 124.5		142.5 - 153	
		PIA1	6	18		146.2	PIA3	--------	PIA3	--------	DPIA3	--------	PIA3
		PIA2	6	18		173.8	171 - 177		195 - 201		219 - 229.5		247.5 - 253.5
		PIA3	6	18		201.4	--------	PIA3	--------	RCOH	--------	PSA-SRA	--------
		PSA-SRA	4			71		271.5 - 277.5	295.5	0		4 - 8	
							PIA2	--------	PIA2	--------	DPIA2	--------	PIA3
							26 - 32		50 -56		74 - 84.5		102.5 - 108.5
							--------	PIA3	--------	DPIA3	--------	PIA3	--------
								126.5 - 132.5		150.5 - 161		179 - 185	
							PIA3	--------	DPIA3	--------	PIA3	--------	PIA3
							203 - 209		227 - 237.5		255.5 - 261.5		279.5 - 285.5
							INAC						
							303.5						

SHIP CLASS	MAINT STRATEGY	TYPE AVAIL	REP DURATION (MOS)	REP INTERVAL (MOS)	MAINT CYCLE (MOS)	REP MANDAYS (000)	TIME LINE NUMBERS INDICATE MONTHS						
CVN 68	IMP	RCOH	33				PSA-SRA	--------	PIA1	--------	PIA1	--------	DPIA1
		DPIA1	10.5	66			0		18 - 24		42 - 48		66 - 76.5
									+/- 3		+/- 4		+/- 6
		DPIA2	10.5	66			--------	PIA2	--------	PIA2	--------	DPIA2	--------
		DPIA3	10.5	66				94.5 - 100.5		118.5 - 124.5		142.5 - 153	
								+/- 7		+/- 7		+/- 7	
		PIA1	6	18			PIA3	--------	PIA3	--------	DPIA3	--------	PIA3
		PIA2	6	18			171 - 177		195 - 201		219 - 229.5		247.5 - 253.5
							+/- 7		+/- 7		+/- 7		+/- 7
		PIA3	6	18			--------	PIA3	--------	RCOH	--------	PSA-SRA	--------
		PSA-SRA	4					271.5 - 277.5	295.5	0		4 - 8	
								+/- 7					

[OPNAVNOTE 4700]

A. NOTES

A. KITTY HAWK (CV 63) is a one-of-a kind forward-deployed carrier. For ISRA availabilities from FY 04 to INACT the maintenance requirement will decrease in a stepped function, as follows: FY 04: 90K MDs, FY 05: 80K MDs, FY 06: 70K MDs, FY 07: 60K MDs, FY08: 25K MDs.

B. CVN 65 has its own specifically designed Incremental Maintenance Program (IMP). It closely follows the IMP for the CVN 68 Class but uses different names for the availabilities; e.g., ESRA and EDSRA. This naming convention will continue until the end of CVN 65's service life.

C. NIMITZ Class CVNs have transitioned to the Incremental Maintenance Program. The RCOH will normally coincide with the fourth DPIA depending on the operational tempo and the actual duration of earlier depot level availabilities, which directly affect the rate of fuel depletion. A material condition assessment is required four years in advance of RCOH to delay any requirements further.

APPENDIX C. AGGREGATE CARRIER MAINTENANCE SCHEDULE AS OF 12 MAY 2004

Title	Hull Type	Hull ID	Avail	Start Date	Comp Date	Curve	Ovhlyard	Homeport	CFcst	TDL EST
CONNIE	CV	64	IA	9/29/2003	8/31/2004	PU0229	PUGET	SD	38500	45347
USS JOHN F. KENNEDY	CV	67	SRA	1/6/2003	11/13/2003	PU0B63	PUGET	MAYPT	103665	102000
USS JOHN F. KENNEDY	CV	67	ESRA	1/6/2003	11/15/2003		SJACK		0	217000
USS JOHN F. KENNEDY	CV	67	RAV	5/2/2005	6/24/2005	000548	SJACK		50000	50000
USS JOHN F. KENNEDY	CV	67	COH	6/23/2005	8/18/2006	NO0222	NORVA	MAYPT	369108	374513
USS JOHN F. KENNEDY	CV	67	ROH	7/1/2005	8/16/2006	000427	SPORT		49948	50000
USS JOHN F. KENNEDY	CV	67	SRA	1/14/2008	7/11/2008		SJACK		49700	49700
USS JOHN F. KENNEDY	CV	67	SRA	3/31/2010	9/30/2010		SJACK		49700	49700
USS ENTERPRISE	CVN	65	ESRA	9/8/2004	6/7/2005		SNEWS		239405	241300
USS ENTERPRISE	CVN	65	RA	10/4/2004	2/25/2005	NO0B47	NORVA	NORVA	15000	11024
USS ENTERPRISE	CVN	65	ESRA	2/12/2007	8/10/2007		SNEWS		241300	241300
USS ENTERPRISE	CVN	65	EDSR	7/12/2008	7/12/2009		SNEWS		416200	416200
USS NIMITZ	CVN	68	RA	2/23/2004	6/23/2004	NO0B36	NORVA	SD	11000	10986
USS NIMITZ	CVN	68	PIA	2/23/2004	8/23/2004	PU0240	PUGET	SD	131835	128800
USS NIMITZ	CVN	68	PIA	2/23/2004	8/23/2004		SSD		65176	77600
USS NIMITZ	CVN	68	PIA	3/1/2006	9/1/2006	PU0240	PUGET	SD	128860	126000
USS NIMITZ	CVN	68	PIA	3/1/2006	9/1/2006		SSD		74000	74000
USS NIMITZ	CVN	68	DPIA	6/16/2008	5/1/2009	PU0B78	PUGET	SD	325794	263900
USS NIMITZ	CVN	68	DPIA	6/16/2008	5/1/2009		SPUGT		44919	45000
USS NIMITZ	CVN	68	PIA	8/2/2010	2/4/2011	PU0B42	PUGET	SD	145241	123500
USS NIMITZ	CVN	68	PIA	8/2/2010	2/4/2011		SSD		89082	90000
USS DWIGHT D. EISENHOWER	CVN	69	RFOH	4/7/2004	8/21/2004	000521	SNEWS		0	67063
USS DWIGHT D. EISENHOWER	CVN	69	RFOH	8/7/2004	10/29/2004	000522	SNEWS		0	37231
USS DWIGHT D. EISENHOWER	CVN	69	PSA	3/1/2005	7/1/2005		SNEWS		24000	24000
USS DWIGHT D. EISENHOWER	CVN	69	SRA	3/1/2005	7/1/2005		SNEWS		77900	77900
USS DWIGHT D. EISENHOWER	CVN	69	PIA	7/12/2007	1/11/2008	NO0240	NORVA	NORVA	157361	158744
USS DWIGHT D. EISENHOWER	CVN	69	PIA	10/6/2009	4/4/2010	NO0240	NORVA	NORVA	149568	173800
USS CARL VINSON	CVN	70	RFOH	11/14/2005	11/14/2008		SNEWS		0	252600
USS CARL VINSON	CVN	70	SRA	2/16/2009	6/19/2009		SNEWS		81000	81000
USS CARL VINSON	CVN	70	PSA	2/16/2009	6/19/2009		SNEWS		15000	15000
USS CARL VINSON	CVN	70	PIA	2/28/2011	9/2/2011	PU0B42	PUGET	BREM	182898	99300
USS CARL VINSON	CVN	70	PIA	2/28/2011	9/2/2011		SPUGT		33000	33000
USS THEODORE ROOSEVELT	CVN	71	RAV	2/2/2004	12/17/2004	000685	SPORT		0	78000
USS THEODORE ROOSEVELT	CVN	71	DPIA	2/3/2004	12/17/2004	NO0004	NORVA	NORVA	316800	252606
USS THEODORE ROOSEVELT	CVN	71	RFOH	10/1/2005	8/2/2012	000524	SNEWS		2960000	2960000
USS THEODORE ROOSEVELT	CVN	71	PIA	2/13/2007	8/10/2007	NO0240	NORVA	NORVA	174826	191163
USS ABRAHAM LINCOLN	CVN	72	DPIA	6/23/2003	5/7/2004	PU0004	PUGET	EVRT	373185	308500
USS ABRAHAM LINCOLN	CVN	72	DPIA	6/23/2003	5/7/2004		SPUGT		8431	95000
USS ABRAHAM LINCOLN	CVN	72	PIA	9/4/2006	3/2/2007	PU0240	PUGET	EVRT	215605	176925
USS ABRAHAM LINCOLN	CVN	72	PIA	9/4/2006	3/2/2007		SPUGT		29590	30000
USS ABRAHAM LINCOLN	CVN	72	PIA	1/12/2009	7/17/2009	PU0240	PUGET	EVRT	198259	173000
USS ABRAHAM LINCOLN	CVN	72	PIA	1/12/2009	7/17/2009		SPUGT		30000	30000
USS ABRAHAM LINCOLN	CVN	72	DPIA	1/10/2011	12/23/2011	PU0B17	PUGET	EVRT	358401	146200
USS ABRAHAM LINCOLN	CVN	72	DPIA	1/10/2011	12/23/2011	000544	SPUGT		50000	50000
USS ABRAHAM LINCOLN	CVN	72	RFOH	10/1/2012	11/18/2016		SNEWS		0	296000
USS GEORGE WASHINGTON	CVN	73	PIA	2/21/2003	8/15/2003	NO0A38	NORVA	NORVA	184164	182488
USS GEORGE WASHINGTON	CVN	73	DPIA	1/10/2005	11/22/2005	000428	SNEWS		342900	342900
USS GEORGE WASHINGTON	CVN	73	RAV	1/18/2005	7/15/2005		NORVA		5000	
USS GEORGE WASHINGTON	CVN	73	PIA	9/19/2007	3/21/2008	NO0240	NORVA	NORVA	184835	208786
USS GEORGE WASHINGTON	CVN	73	PIA	4/29/2010	10/29/2010	NO0240	NORVA	NORVA	184036	201400
USS JOHN C. STENNIS	CVN	74	DPIA	2/14/2005	12/20/2005	PU0004	PUGET	SD	248420	256315
USS JOHN C. STENNIS	CVN	74	DPIA	2/14/2005	12/20/2005		SPUGT		0	40000
USS JOHN C. STENNIS	CVN	74	PIA	10/29/2007	4/29/2008	PU0240	PUGET	SD	162420	140800
USS JOHN C. STENNIS	CVN	74	PIA	10/29/2007	4/29/2008		SPUGT		32921	33000
USS JOHN C. STENNIS	CVN	74	PIA	2/1/2010	8/6/2010	PU0B60	PUGET	SD	175785	140800
USS JOHN C. STENNIS	CVN	74	PIA	2/1/2010	8/6/2010		SPUGT		45000	45000
USS HARRY S. TRUMAN	CVN	75	PIA	8/20/2003	2/18/2004	NO0A45	NORVA	NORVA	145022	140264
USS HARRY S. TRUMAN	CVN	75	RAV	8/20/2003	2/16/2004		SPORT		0	36000
USS HARRY S. TRUMAN	CVN	75	DPIA	3/28/2006	2/15/2007	NO0004	NORVA	NORVA	233042	234824
USS HARRY S. TRUMAN	CVN	75	PIA	11/17/2008	5/19/2009	NO0240	NORVA	NORVA	155611	173800
USS HARRY S. TRUMAN	CVN	75	PIA	2/11/2011	8/13/2011	NO0240	NORVA	NORVA	163612	173800
USS RONALD REAGAN	CVN	76	PSA	12/1/2003	5/2/2004		SNEWS		0	18400
USS RONALD REAGAN	CVN	76	SRA	12/1/2003	5/2/2004		SNEWS		0	85000
USS RONALD REAGAN	CVN	76	PIA	4/2/2007	9/28/2007	PU0240	PUGET	SD	113975	112580
USS RONALD REAGAN	CVN	76	PIA	4/2/2007	9/28/2007		SSD		65000	65000
USS RONALD REAGAN	CVN	76	PIA	8/3/2009	2/5/2010	PU0240	PUGET	SD	114953	98130
USS RONALD REAGAN	CVN	76	PIA	8/3/2009	2/5/2010		SSD		61965	65000
TBD	CVN	77	PSA	10/20/2008	3/1/2009		SNEWS		35386	36500
TBD	CVN	77	SRA	10/20/2008	3/1/2009		SNEWS		78483	81000
TBD	CVN	77	PIA	2/1/2011	8/1/2011	PU0B42	PUGET	NORVA	116117	141000
TBD	CVN	77	PIA	2/1/2011	8/1/2011		SSD		65000	65000

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APPENDIX D. GENCOLS.C

The following code was written in C and generates a specified number of columns for the set-partition formulation of the aircraft carrier scheduling problem.

```
#include <stdio.h>
#include <math.h>
#include <stdlib.h>

#define CYCLES 7
#define STATES 7

/*Generate columns for set-partition formulation of
  carrier scheduling problem*/

/*Column coefficients for carrier k, column c, will be in .csv format
  in a file called cols.dat, with the following structure:

dummy,dummy,dummy,E,D,Mwp,Mwd,Mep,Med,P
k1,c1,t1,1,0,0,0,0,0,0
k1,c1,t2,0,1,0,0,0,0,0
...

representing the gams TABLE format:
 TABLE coefs(c,k,t,s)
            E     D     Mwp   Mwd   Mep   Med    P
  k1.c1.t1  1     0     0     0     0     0      0
  k1.c1.t2  0     1     0     0     0     0      0
  ...

Where a 1 indicates that carrier k is in state (E,D,Mwp,Mwd,Mep,Med,P)
in month t.

states 0-6
0=E=emergency surge, 1=D=deployed, 2-5 =Mxx =maintenance (w=west,
e=east, p=pierside, d=drydock),
6=P=prep (mandatory training)
*/

/*Also creates summary output file, summ.dat, which
  gives the deployment durations for each column, for each CSG.
  This allows us to look up the solutions and figure out the
  deployment and maintenance schedule for each CSG.*/


int main(int argc, char **argv) {
  int kk,cc,tt;
  int k,c,t,s,ss,i,ii;
  int *durS,*dlow,*dup;
  int sdur;

  FILE *infile;
  FILE *outfile;
```

```
  FILE *summfile;

  if(argc != 2){
    printf("Usage: %s <columns>\n",argv[0]);
    return 1;
  }

  cc=atoi(argv[1]);
  kk=12;
  tt=120;

  durS=(int *)malloc(STATES*CYCLES*sizeof(int));
  dlow=(int *)malloc(CYCLES*sizeof(int));
  dup =(int *)malloc(CYCLES*sizeof(int));
  /*durS[i*4+s] is duration of state s (0-6) in cycle i (0-6)*/
  infile=fopen("durations.csv","r");

 /*format of durations.csv is
   e1,dlow1,dup1,mwp1,mwd1,mep1,med1,p1
   e2,dlow2,dup2,mwp2,mwd2,mep2,med2,p2
   ...

   where dlow is min duration, dup is max duration of deployment in
each cycle
 */

  outfile=fopen("cols.dat","w");
  summfile=fopen("summ.dat","w");

  fprintf(outfile,"dummy,dummy,dummy,E,D,Mwp,Mwd,Mep,Med,P\n");
  for(k=2;k<=kk;k++){  /*skip k1=KHK*/
    for(i=0;i<CYCLES;i++){

fscanf(infile,"%d,%d,%d,%d,%d,%d,%d,%d\n",&durS[i*STATES],&dlow[i],&dup
[i],

&durS[i*STATES+2],&durS[i*STATES+3],&durS[i*STATES+4],&durS[i*STATES+5]
,&durS[i*STATES+6]);
      printf("%d,%d,%d,%d,%d,%d,%d,%d\n",durS[i*STATES],dlow[i],dup[i],

durS[i*STATES+2],durS[i*STATES+3],durS[i*STATES+4],durS[i*STATES+5],dur
S[i*STATES+6]);
      durS[i*STATES+1]=dup[i];
    }
    for(c=1;c<=cc;c++){
      i=0;
      s=0;
      while(durS[s]==0) /*find first nonzero state duration (guaranteed
to occur in cycle 0)*/
        s++;
      sdur=1;
      for(t=1;t<=tt;t++){
        fprintf(outfile,"k%d,c%d,t%d",k,c,t);
        for(ss=0;ss<STATES;ss++)
          if(s==ss)
            fprintf(outfile,",1");
          else
```

```
            fprintf(outfile,",0");
          fprintf(outfile,"\n");
          if(sdur==durS[i*STATES+s]) {
            if(s==STATES-1){
              i++;
              s=0;
            }
            else{
              s++;
              while(durS[i*STATES+s]==0)
                s++;
            }
            sdur=1;
          }
          else
            sdur++;
        }
        fprintf(summfile,"k%d,c%d",k,c);
        for(i=0;i<CYCLES;i++)
          fprintf(summfile,",%d",durS[i*STATES+1]);
        fprintf(summfile,"\n");
        /*next column: increment (or reset) deployment durations
appropriately*/
        /*find first deployment longer than min deployment for that
cycle*/
        for(i=0;durS[i*STATES+1]<=dlow[i] && i<CYCLES;i++)
          ;
        /*decrement that deployment*/
        if(i<CYCLES)
          durS[i*STATES+1]--;
        /*reset deployments in earlier cycles to maximum durations*/
        for(ii=0;ii<i;ii++)
          durS[ii*STATES+1]=dup[ii];
      }
    }
  fclose(infile);
  fclose(outfile);
  fclose(summfile);
  return 0;
}
```

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APPENDIX E. DURATIONS.CSV FILE

The following durations.comma-separated-values (CSV) file is used as input data to the scheduling model. This data corresponds exactly to the *suggested* maintenance schedule data shown in Table 10.

0	1	1	0	0	0	9	3
3	6	21	0	0	0	6	3
3	6	21	0	0	7	4	5
3	6	21	0	0	0	6	3
3	6	21	0	0	0	6	3
3	6	21	0	0	7	4	5
3	6	21	0	0	0	6	3
0	9	9	0	0	8	8	5
3	6	21	0	0	0	3	3
3	6	21	0	0	0	3	3
3	6	21	0	0	8	4	5
3	6	21	0	0	0	3	3
3	6	21	0	0	0	3	3
3	6	21	0	0	8	4	5
0	0	0	0	1	0	0	3
3	6	21	0	6	0	0	3
3	6	21	7	4	0	0	5
3	6	21	0	6	0	0	3
3	6	21	0	6	0	0	3
3	6	21	7	4	0	0	5
3	6	21	0	6	0	0	3

Table 27. Durations.CSV file for the *Suggested* 27-Month Maintenance Schedule Found in Table 10.

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