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MBA PROFESSIONAL REPORT

Analysis and Forecasting of Operating and Support costs for F-16 C/D

By: Aurel Cobianu, and
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June 2006

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The primary objective was to understand the methodological specifics of estimating Operating and Support (O&S) costs for the F-16 fighter aircraft. To facilitate this, the report identifies and analyzes the top cost drivers over the F-16C/D lifecycle. The cost drivers are a major consideration in identifying Reduction of Total Ownership Costs (R-TOC) opportunities. This research also explores forecasting techniques to estimate the Cost per Flying Hour (CPFH). Holt's method appears to have promise as an estimator of future CPFHs.

Finally, this report concludes that TOC should be a priority consideration when acquiring a multi-role fighter aircraft such as F-16 and recommends that the Polish Air Force (recent F-16 user) and the Romanian Air Force (potential future user) should establish databases to record O&S costs and should implement R-TOC best practices.

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ANALYSIS AND FORECASTING OF OPERATING AND SUPPORT COSTS FOR F-16 C/D

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
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LIST OF ACRONYMS

AFROCC	- Air Force Requirements for Operational Capabilities Council
AFTOC	- Air Force Total Ownership Cost
AG	- Aerodynamic Center
AMRAAM	- Advanced Medium Range Air to Air Missile
ANG	- Air National Guard
AoA	- Analysis of Alternatives
BVR	- Beyond Visual Range
CAIV	- Cost As an Independent Variable
CBS	- Cost Breakdown Structure
CCE/ECP	- Contract and Engineering Change Proposals
CCIP	- Common Configuration Implementation Program
CDD	- Capability Development Document
CER	- Cost Estimating Relationship
CG	- Center of Gravity
CLTS	- Combined Life Time Support
COA	- Course of Action
COARS	- Command On-line Accounting & Reporting System
CPD	- Capability Production Document
CPFH	- Cost Per Flight Hour
CRIPT	- Cost Reduction Integrated Product Team
DAB	- Defense Acquisition Board

DAU	- Defense Acquisition University
DLR	- Depot Level Reparable
DMS	- Diminishing Manufacturing Sources
DoD	- Department of Defense
DoDD 5000.1	- Department of Defense Directive 5000.1
DoDI 5000.2	- Department of Defense Instruction 5000.2
DRR	- Design Readiness Review
DSMC	- Defense Systems Management College
DTC	- Design-To-Cost
EA	- Evolutionary Acquisition
FAA	- Federal Aviation Administration
FOC	- Full Operational Capability
FOT&E	- Follow-on Operational Test and Evaluation
FRP	- Full Rate Production
GAFS	- General Accounting & Finance System
GAO	- United States General Accounting Office
GPS	- Global Positioning System
HIS	- Human System Integration
HMCS	- Helmet-Mounted Cueing System
HQ	- Headquarter
HSD	- Horizontal Situation Display
HUD	- Head-Up Display
ICD	- Initial Capabilities Document

IFF	- Identification Friend or Foe
IOC	- Initial Operational Capability
IOT&E	- Initial Operational Test and Evaluation
IPT	- Integrated Process Teams
ISP	- Information Support Plan
ITT	- Integrated Test Team
JCIDS	- Joint Capabilities Integration and Development Systems
JDAM	- Joint Direct Attack Munition
JORC	- Join Requirements Oversight Council
KPP	- Key Performance Parameter
LCCA	- Life-Cycle Cost Analysis
LCL	- Life-Cycle Logistics
LCMP	- Life Cycle Management Plan
LMI	- Logistic Management Institute
LRIP	- Low Rate Initial Production
LSBF	- Least Squares Best Fit
MA	- Maintenance Action
MA	- Moving Average
MAE	- Mean Absolute Error
MAPE	- Mean Absolute Percentage Error
MC&ER	- Main Characteristics and Engineering Specifications
MDA	- Milestone Decision Authority
MDAP	- Major Defense Acquisition Program

ME	- Mean Error
MLDT	- Mean Logistics Down Time
MLU	- Mid Life Upgrade
MMT	- Mean Maintenance Time
MPE	- Mean Percentage Error
MTBF	- Mean Time Between Failure
MTTR	- Mean-Time-to-Recovery
NATO	- North Atlantic Treaty Organization
O&M	- Operation and Maintenance
O&S	- Operating and Support
OA	- Operational Assessment
OBOGS	- On-Board Oxygen Generating System
OH	- Operating Hour
OO-ALC	- Ogden Air Logistics Center
OSD	- Office of Secretary of Defense
OSMIS	- Operating and Support Management Information System
OT&E	- Operational Test and Evaluation
P&D	- Production and Deployment
PBL	- Performance Base Logistics
PEISC	- Parametric Estimating Initiative Steering Committee
PGM	- Precision Guided Munition
PM	- Program Manager
PMD	- Program Management Directive

PoAF	- Polish Air Forces
PPBE	- Planning, Programming, Budgeting and Execution
PRF	- Pulse Repetition Frequency
PSP	- Programmable Single Processor
REMIS	- Reliability and Maintainability Information System
RLGINS	- Ring Laser Gyro Inertial Navigation System
RoAF	- Romanian Air Forces
RSR	- Requirement Strategy Review
R-TOC	- Reduction of Total Ownership Cost
RWR	- Radar Warning Receiver
SAR	- Synthetic Aperture Radar
SCEA	- Society of Cost Estimating and Analysis
SCM	- Supply Chain Manager
SDD	- System Demonstration and Development
SE	- System Engineering
SES	- Single Exponential Smoothing
SOE	- System Operational Effectiveness
SPO	- System Program Office
TDS	- Technology Development Strategy
TLCSM	- Total Life Cycle System Management
TOC	- Total Ownership Cost
USAF	- United States Air Force
USD	- United States Dollars

VAMOSC	- Visibility and Management of Support Costs
WBS	- Work Breakdown Structure

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Major Aurel Cobianu
Romanian Air Force

Captain Konrad Madej
Polish Air Forces

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Polish Air Forces

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Major Cobianu
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I. INTRODUCTION

A. PROBLEM DESCRIPTION

The F-16 is the first American fighter to be concurrently deployed domestically and abroad. United States Air Force introduced F-16 into service in 1979. The total number of employed aircraft in the United States Air Force (USAF) as well as in the allied forces is currently 4,426.[1] Superior aerodynamic characteristics, variety of carried weapon systems, modern electronic equipment and huge potential for modernization make the F-16 one of the most popular and desired multi-role aircraft.

Rapidly aging post-Soviet air fleets of many Eastern European countries forced them to look for a new, modern solution for their air forces – multi-role aircraft. Because the F-16 has proven its effectiveness and reliability during many conflicts, and the fact that the F-16 is used in most NATO Air Forces, means that the aircraft is still a preferred option for potential users to modernize their air fleet. Recently, the Polish Air Force (PoAF) acquired 48 F-16s C/D Block 50/52+ (2004). It provides the PoAF with great operational capability and strengthens air power of the NATO in Europe. At the same time, the Romanian Air Force (RoAF) is facing an aging air fleet problem and is looking to acquire a new multi-role aircraft. Current military requirements and political situations point out that the F-16 aircraft may be the right choice for Romania.

But a new and modern weapon system is very often accompanied by significant costs. Acquisition of a weapon system is only the beginning of a long life cycle. The Operating and Support (O&S) costs, associated with servicing a weapon system, increase the Total Ownership Costs (TOC). O&S costs are responsible for 78 percent of TOC of the modern weapon system.[2] Therefore, this report provides an analysis of the O&S costs of the F-16 C/D Block 50/52+. The report will examine O&S costs of F-16 in the USAF. Based on information gathered from analysis of the United States Air Force (USAF) F-16

[1] Global Security, "F-16 Fighting Falcon," http://www.globalsecurity.org/military/systems/aircraft/f-16-history.htm/ (accessed April 27, 2006).

[2] Office of the Secretary of Defense, "Operating and Support Cost-Estimating Guide," (Washington, DC: Cost Analysis Improvement Group, May 1992), 2-3, http://www.dtic.mil/pae/ (accessed March 27, 2006).

Life Cycle Management (LCM) and Department of Defense Acquisition System, we will provide recommendations for the PoAF to reduce O&S of the F-16 C/D Block 50/52+. Our project will try to capture the best experience in managing O&S costs in the USAF, and to formulate recommendations for the PoAF F-16 and RoAF.

To create recommendations for the PoAF and the RoAF, the theoretical basis of O&S costs will be explained, and the basic cost drivers will be identified. Furthermore, the O&S costs of the F-16 C/D data from the Air Force Total Ownership Cost (AFTOC) database will be examined and used to build forecasting models of O&S costs.

Poland and Romania have not had any influence on the initial phases of the LCM of the F-16 (Program Initiation, Concept Exploration and Definition, Concept Demonstration and Validation, Engineering and Manufacturing Development). Therefore, this report will emphasize the O&S phase of the LCM.

B. SCOPE

The intention of this report is to provide a general guideline for air forces which have acquired or are in the ongoing acquisition process of the F-16C/D. The report focuses on O&S costs and Total Life Cycle System Management (TLCSM) of a fighter aircraft in general and the F-16C/D in particular.

C. RESEARCH QUESTIONS

This report raises the questions:

- How can O&S costs of the modern multi-role aircraft be approached to minimize their impact on the TOC?
- What are the objectives and elements of the USAF F-16 C/D Life Cycle Management and Acquisition Process?
- What are the structure and estimating methods of the O&S costs in the USAF?
- What are best practices of reducing O&S costs in the USAF?
- What is the AFTOC database?
- What recommendations can be drawn for foreign users of the F-16 C/D by analyzing O&S costs incurred by the USAF?
- How have O&S cost of the F-16C/D been forecasted in the USAF?
- What recommendations may be formulated for the PoAF and RoAF?

D. REPORT ORGANIZATION

First, this MBA professional report presents background information on the F-16 weapon system. It first considers the development of the F-16 weapon system followed by the main characteristics and description of the F-16. Chapter II describes the PoAF acquisition process and the governmental Offset Agreement signed between the Polish and US Governments. The last part of Chapter II presents the F-16 as a possible solution for the RoAF.

Chapter III describes the acquisition process of the weapon system according to DoD best practices and doctrines. It also examines the TLCSM.

Chapter IV deals with the O&S costs. It presents cost structure and the theoretical foundation for the O&S costs. It provides background information about R-TOC practices as well.

Chapter V examines data from the AFTOC database. In the first section, the AFTOC database is presented, then the O&S cost of the F-16C/D are examined in context. The last part of Chapter V presents approaches to forecasting future O&S costs based on data from the AFTOC.

Finally, this report will provide recommendations and conclusions for future operators of the F-16 weapon system.

E. METHODOLOGY

The methodology used in this MBA report consists of the following steps:

- A summary of the DoD acquisition rules and regulations regarding TLCSM and O&S costs.
- A review of the theoretical foundations of the O&S costs based DoD instructions and publications, governmental and Congressional reports and scholarly articles.
- A review of the literature available in the Dudley Knox Library, USAF magazines, and Internet resources regarding the evolution of the F-16.
- An analysis of the F-16 C/D O&S costs data from the AFTOC database and development forecasting method for O&S costs.
- A development of recommendations based upon findings and data analysis.

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II. LOCKHEED MARTIN F-16 MULTI-ROLE AIRCRAFT

The purpose of this chapter is to provide a brief history of F-16 Fighting Falcon development with primary focus on the F-16C/D version. In addition, the main characteristics of the aircraft are presented in the context of its development. Republic of Poland has been involved in the F-16 acquisition process since 2002, when the F-16C/D won the fighter competition organized by PoAF. The second part of this chapter presents the acquisition process for the PoAF. The RoAF will withdraw its MiG-21 Lancer fighters from 2008 to 2010, and is seeking the best replacement for them with a multi-role aircraft. The F-16C/D represents a possible solution. Some implications of the future multi-role fighter acquisition process for RoAF are presented in the last part of the chapter.

A. F-16 FIGHTING FALCON - BRIEF HISTORY AND MAIN CHARACTERISTICS

1. History

The F-16 program traces its beginnings to the Vietnam War. During that conflict, American combat aircraft suffered a lack of maneuverability at transonic speeds in close contact with enemy aircraft. This was the stimulus for the Lightweight Fighter Program. The main point of that program was to combine maximum maneuverability with great load qualities. Lightweight Fighter candidates were provided by several American manufacturers in 1972. Two of them, General Dynamics and Northrop, built prototypes: Northrop's twin engine YF-17, and the single engine YF-16 from General Dynamics.

The competition was completed in 1975. Both planes proved their maneuverability and high performance at both transonic and slow speeds. The YF-16 was selected by the Air Force on January 13, 1975. The General Dynamics' YF-16 showed superior performance over its Northrop rival in several aspects, such as:

- Lower production cost (initial procurement cost and life cycle cost)
- Lower O&S cost
- Great results with a new fly-by-wire technology application
- New concept of reclined seat backs

- Transparent Heads-up Display (HUD) and panels as a design to face high-g maneuvers
- High profile canopy with expanded visibility from the cockpit[3]

2. Design

A number of subsystems were adapted from other aircraft already in service (F-15, F-111). Parts and detail assemblies were designed for simplifying the manufacturing process and for using low cost materials. The main purpose was to minimize purchase price and life cycle cost. Structural simplicity and weight reduction were taken into consideration as well. The light weight of the airframe was achieved without reduction of high-g performance capability; the F-16 Fighting Falcon can withstand up to nine g's.

Figure 1. An F-16 Fighting Falcon Flies a Mission in the Skies near Iraq (From: Air Force Link, U.S. Air Force photo by Staff Sgt. Cherie A. Thurlby, http://www.af.mil/library/raptor/photos.asp?galleryID=3&page=2).

3 Global Security, "F-16 Fighting Falcon."

The aerodynamic configuration is a synthesis of the high overall performance achieved by the configuration of the airframe: cropped delta wings, single vertical tail supported by a small fixed ventral fin located under the bottom of the fuselage, moving horizontal tail, and the fixed geometry inlet which supplies air to the single Pratt & Whitney F100-PW-200 turbofan engine. Good performance of the engine during the flight with a huge range of angle of attack is achieved by inlet location at the bottom of the fuselage.

Cropped delta wings are supported by the strakes, which extend from the wings' edges. That allows generation of vortexes which prevent wing stall at high angles of attack. The trailing edge of the wing is equipped with flaperons, which serves two purposes: flaps for high lift and ailerons for lateral control. The leading edge of the wing is equipped with automatically deployed maneuvering flaps to improve aerodynamic performance.

The F-16 utilizes an advanced fly-by-wire system for its aerodynamic control surfaces. The pilot's intentions are transmitted to the control surfaces by electrical signals that activate hydraulic systems to move aerodynamic control surfaces. That system, compared to the older mechanical control systems, is lighter, more precise, and simpler.

Another novel element in the F-16 design is "relaxed static stability." The traditional longitudinal stability, which is necessary for the airframe to be stable, was reduced to a level unacceptable for traditional airframes. It was achieved by moving the center of gravity (CG) to a point very near to the aerodynamic center (AC) of the plane. As a result the tail load and trim drag was reduced. That "uncomfortable environment" for the pilot is compensated for by the electronic-hydraulic augmentation system, which injects correction signals into the flight control system during flight.[4]

The cockpit is bubble-shaped, giving the pilot a high degree of unobstructed forward and upward vision. Additionally, the seat-back angle of 30 degrees increases G-force tolerance and comfort for the pilot. The traditional stick was replaced by the side arm controller, located on the right arm console of the cockpit.

[4] Global Security, "F-16 Fighting Falcon."

The avionic system is built of highly accurate inertial navigation system. The computer provides the pilot with all necessary information during the flight. It also enables the F-16 to carry a variety of weapons.

3. F-16 Versions and Customers

The F-16 is one of the most popular fighters worldwide. As the largest weapon systems program in the contemporary Western world, 4,426 aircraft have been built with production still continuing.[5] F-16s, in different versions, serve in the air forces of 24 countries: Royal Bahraini Air Force, Belgian Air Force, Chilean Air Force, Royal Danish Air Force, Egyptian Air Force, Indonesian Air Force, Israeli Air Force, Italian Air Force, Royal Jordanian Air Force, Royal Norwegian Air Force, Royal Air Force of Oman, Pakistani Air Force, Polish Air Force, Portuguese Air Force, Republic of China Air Force (Taiwan), Republic of Singapore Air Force, Republic of Korea Air Force, Royal Thai Air Force, Royal Netherlands Air Force, Turkish Air Force, United Arab Emirates Air Force, United States Armed Forces (Air Combat Command, United States Air Force in Europe, Pacific Air Forces, United States Navy, NASA, Air Force Reserve Command, Air National Guard), and Venezuelan Air Force.

Because of the variety of customers and upgrades of the F-16 weapon system, many versions of the airplane entered operational service:

- F-16 A/B Block 1/5/10/15/10OCU/20
- F-16 C/D Block 25
- F-16 C/D Block 30/32
- F-16 C/D Block 40/42
- F-16 C/D Block 50/52
- F-16 E/F Block 60
- F-16 MLU

[5] Global Security, "F-16 Fighting Falcon."

Another three versions F-16/101, F-16/79, and F-16XL were built as prototypes.

4. Specifications

a. Structure

The aircraft structure consists of 80 percent aluminum alloy. Less than eight percent of the structure is made from steel. Composites account for three percent, while titanium alloy is used in only 1.5 percent. 60 percent of the structural parts are manufactured from sheet metal, less than two percent require chemical milling. Advanced technology enabled significant weight reduction. During the design phase, General Dynamics assumed the cost of the airframe would be USD 60 per pound. That reduction therefore reduced airframe cost by USD 80,000.[6]

The F-16 fuselage is manufactured in three major sections: nose/cockpit, center, and aft. The forward section break point is aft of the cockpit. The second section is located forward of the vertical fin. The advanced aerodynamics and airframe gives the F-16 great range performance. For the F-16, 31 percent of the weight of loaded aircraft is fuel (for comparison, the equivalent figure for the F-14 is 28 percent).

Wing/body blending was carried out in three dimensions. Viewed from both front and rear, it is almost impossible to define where the wings end and the fuselage begins. The wings' leading edges also blend with the fuselage tanks. Gradually increase of wing thickness at its root results in the very stiff wing. The leading edge maneuvering flaps and trailing edge flaperons can be moved up to 35 degrees per second to fit Mach number and angle of attack.

The vertical stabilizer has a multi-spar and multi-rip structure, made from aluminum alloy. The two ventral fins beneath the fuselage section are made from fiberglass.

The intake location is unconventional. The ventral location means minimal airflow disturbance during the different conditions in flight. For example, at angle of attack 25 degrees, the airflow into the intake is at an angle of only 10 degrees.

[6] Douglas Richardson, *Modern Fighting Aircraft - F-16*, (New York, NY: Arco Publishing Inc., 1983), 18.

To reduce the number of spare parts, some components are designed to be interchangeable between port and starboard. Reduction of number of spare parts and modular construction of the plane reduced O&S cost compared to older fighter planes in the USAF (Figure 2). Total O&S costs for the F-4 squadron equal USD 21,400,000 in 1976 USD. For the F-16 squadron the O&S costs equal USD 14,600,000 in 1976 USD. Applications of new technology and new procedures decreased annual O&S costs by USD 6,500,000 in USD 1976.

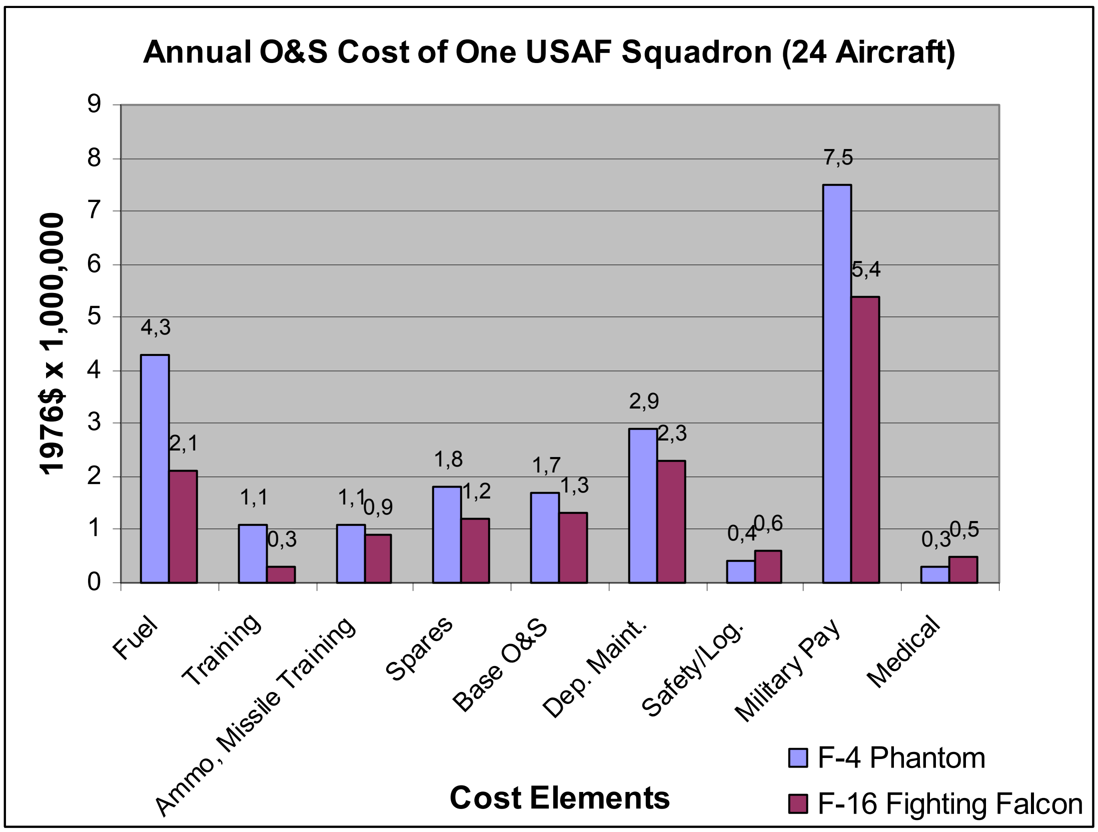

Figure 2. Comparison of Annual O&S Costs of One USAF Squadron (From: Douglas Richardson, *Modern Fighting Aircraft - F-16*).

The F-16 is equipped with the McDonnell Douglas ACES II ejection seat. That ejection seat was also used on the F-15 Eagle. It is rocket powered with a vectored thrust pitch control system. ACES II offers zero-zero performance; from an aircraft, which does not move, the ejection seat will move the pilot up to 100 feet (30 meters) forward and rearwards up to 50 feet (15 meters). ACES II also has built-in survival equipment: emergency oxygen, URT-33C radio beacon, life raft, and rucksack.[7]

The F-16C/D Block 50/52+, offered to Poland, is one of the latest versions of the plane. It has special provisions for adverse weather delivery of the McDonnell Douglas JDAM (Joint Direct Attack Munitions). In addition, the 50/52+ version has an add-on tail unit containing a synthetic aperture radar, providing guidance to 1,000 pounds Mk.83, 2,000 pounds Mk.84 and the 2,000 pounds BLU-109 warhead. Other features include passive missile warning, terrain-referenced navigation and on-board oxygen generating system (OBOGS). The airframe is modified to incorporate 600 US gallons (2,271 liters) external fuel tanks and conformal fuel tanks.[8]

b. Power Plant

Pratt & Whitney started to develop the F100 turbofan engine in 1968, designed originally to power the F-15. Because of the new concept of fighter aircraft with high thrust-to-weight ratios, the engine had to meet high stringent requirements. It pushed the technology of that time to the limits.

The F-100 is an axial flow turbo fan engine with a bypass ratio 0.7:1. The engine has two shafts. One of them carries a three-stage fan driven by the two-stage turbine. The second one carries a ten-stage compressor and a two-stage turbine. Normal dry (without afterburner) rating is 12,420 pounds (5,634 kilograms); maximum rating is 14,670 pounds (6,654 kilograms). Specific fuel consumption is 0.69 at normal rating and 0.71 at maximum rating. At afterburner deployment, the engine has thrust equal to 23,830 pounds (10,809 kilograms) with specific fuel consumption of 2.17. At that rating the engine burns 860 pounds (390 kilograms) of fuel per minute.[9]

The General Electric F110 is similar in size to the Pratt & Whitney F100. The F110 has a three-stage fan leading to a nine-stage compressor, the first three stages of which are variable. The bypass ratio is 0.87 to 1. The annular combustion chamber is

[7] Richardson, *Modern Fighting Aircraft - F-16*, 21.

[8] Carl Krittenden, “F-16C/D Block 50/52,” F-16.net, http://www.f-16.net/f-16_versions_article9.html (accessed April 29, 2006).

[9] Richardson, *Modern Fighting Aircraft - F-16*, 24.

designed for smokeless operation, and has 20 dual-cone fuel injectors and swirling-cup vaporizers. The single-stage HP turbine is designed to cope with inlet temperatures as high as 2500 degrees F (1370 C). Blades are individually replaceable without rotor disassembly. An uncooled two-stage turbine leads to a fully-modulated afterburner. When afterburning is demanded, fuel is injected into both the fan and core flows, which mix prior to combustion.[10]

Pratt & Whitney developed the F100-PW-229 in the 1990s to compete with the GE F110 engine. It has about 22 percent more thrust than the previous F100 model. It is also the power plant for the F-16C/D Block 50/52+. The F100-PW-229 engine has following main characteristics:

- Maximum Thrust (Full Augmentation) - 29,100 pound-force (129.4 kilo Newton)
- Intermediate Thrust (Non-augmented) - 17,800 pound-force (79.2 kilo Newton)
- Weight (Specification Maximum) - 3,740 pounds (1,681 kilograms)
- Length - 191 inch (4.85 meters)
- Inlet Diameter - 34.8 inch (0.88 meters)
- Maximum Diameter - 46.5 inch (1.18 meters)
- Bypass Ratio - 0.36
- Overall Pressure Ratio - 32 to 1.[11]

c. Avionics

The F-16C/D Block 50/52 version carries a comprehensive suite of avionics:

- Honeywell H-423 Ring Laser Gyro Inertial Navigation System (RLG INS) for rapid in-flight alignment
- Global Positioning System (GPS) receiver
- Data Transfer Cartridge with a large capacity (128 KB) to accommodate planned avionic upgrades

[10] Joseph Baugher, "Engines for the General Dynamics F-16 Fighting Falcon," AirToAirCombat.com, March 19, 2000, http://www.airtoaircombat.com/background.asp?id=8&bg=40 (accessed April 29, 2006).

[11] Aeronautics Learning Laboratory for Science, Technology, and Research, "Pratt & Whitney Engines: F100-PW-229 Turbofan Engine," http://www.allstar.fiu.edu/AERO/P&WEngines03.html (accessed April 29, 2006).

- Improved Data Modem for faster data transmission
- AN/ALR-56M advanced Radar Warning Receiver (RWR)
- AN/ALE-47 threat adaptive countermeasure system
- Digital terrain system data transfer cartridge
- Night vision system compatibility
- IFF interrogator
- MIL-STD-1760 data bus for programming new-generation Precision Guided Munitions (PGMs)
- Upgraded Programmable Display Generator
- Horizontal Situation Display (HSD) for increased situational awareness and tactical flexibility on all missions.[12]

Figure 3. F-16C/D Block 50/52+ Cockpit (From: Defense Update International Online Defense Magazine, "Advanced F-16 Block 50/52/60," http://www.defense-update.com/features/du-1-04/feature-advanced-f-16.htm).

The configuration of an F-16C/D Block 50/52+ cockpit (Figure 3) features a helmet-mounted cueing system. It allows the pilot to direct sensors or weapons to his

[12] Krittenden, "F-16C/D Block 50/52."

line of sight or to help him find a designated target. Heads-Up Display, several color multifunction displays, and advanced recording and data-transfer equipment is used to reduce pilot workload in every phase of the mission. The cockpit is also compatible with a night vision system.

One of the key elements of the modern fighter plane is the radar system. The development of the F-16 as a weapon system was always related to its ability to find and engage targets from a distance and to detect targets even during their low altitude profile flights. In the 1970s and early 1980s, the primary detection sensor of the F-16A/B version was the Westinghouse AN/APG-66 radar, medium-PRF (Pulse Repetition Frequency) radar (10 to 15 Megahertz). It operates in I/J band and features a flat-plate array antenna. It provides the pilot with 16 operating frequencies. The pilot can chose among any four. Total weight of the APG-66 is 296 pounds (134 kilograms). Mean Time between Failure (MTBF) is 97 hours.[13]

Primary air-combat mode is look-down. In that mode, the AN/APG-66 can detect a fighter-size plane at a range of 34.5 Nautical miles (55.6 kilometers). Four modes are available in air-to-air combat. In dogfight mode, the radar scans a 20 degrees x 20 degrees field. In high-g maneuvers, it scans a 40 degrees x10 degrees pattern.[14]

The version of the F-16C/D offered to Poland, Block 50/52+, has several additional modifications of the avionics. The IFF system was upgraded to the AN/APX-113 advanced electronic interrogator/transponder IFF system. Also the Helmet-Mounted Cueing System (HMCS) was added. The new, upgraded radar system significantly improves performance of the F-16C/D Block 50/52+. Modifications to the AN/APG-68 radar system and to the Northrop Grumman AN/APG-68(V)9 improved detection range and resolution. Application of advanced electronics enhances the radar's ability to operate in a dense electronic environment and to better resist jamming.

13 Richardson, *Modern Fighting Aircraft - F-16*, 31.

14 Ibid., 32.

The AN/APG-68(V)9 radar system improves air-to-air capabilities as well as air-to-ground capabilities by:

- 30 percent increase in detecting range
- Improvement in false alarm rate and mutual interference
- Increase in maximum tracked targets to four
- Improved track performance in the Track While Scan mode
- Improved track performance in Single-Target-Track mode
- Two-foot resolution in the new Synthetic Aperture Radar (SAR) mode for autonomous and precision weapon delivery
- Improvement in target detection and map quality in Ground Moving Target Indication mode.[15]

This new radar is five times faster in processing in information mode and it offers ten times more memory than that of the AN/APG-68 radar system.

d. Armament

Ordnance carried by F-16 ranges from simple unguided rockets to PGMs, JDAM and nuclear weapons. This section will present the main ordnance of the F-16 with short descriptions.

20 mm Gatling Gun System M61A1 Vulcan, a six-barrel 20 mm cannon. It can fire standard M50 ammunition at 6,000 rounds per minute. In some F-16 versions, the rate of firing is selectable. The gun is fed through linked belts of ammunition and driven by a hydraulic system. The ammo drum of the F-16 has a 511-round capacity. The M61A1 Vulcan may use the following types of ammo:

- M55A1/A2 Target Practice Round (M220 TP Tracer Round)
- M53 Armor-Piercing Incendiary Round
- M56 High Explosive Incendiary Round (XM242 HEI Tracer)
- PGU-28 ammo available in the Block50/52 version and higher.[16]

AIM-9 Sidewinder, a supersonic, heat-seeking, air-to-air missile, with a high-explosive warhead. Sidewinder is guided by a passive infrared guidance system.

[15] Krittenden, "F-16C/D Block 50/52."

[16] Ibid.

Unit cost ranges from USD 56,000 to USD 84,000. The missile is built of an infrared homing guidance section, an active optical target detector, a high explosive warhead and a rocket motor. It can accelerate from 0 to 2.5 Mach in 2.2 seconds. Early models of the Sidewinder were considered to have 70 percent single shot kill probability in ideal conditions. The following Sidewinder versions are available for F-16: AIM-9, AIM-9A, AIM-9B, AIM-9C, AIM-9D, AIM-9E, AIM-9E2, AIM-9G/H, AIM-9J, AIM-9J-1, AIM-9J-3, AIM-9N, Rb 24, AIM-9L/M, AIM-9M-7, Rb 74, AIM-9P, AIM-9P-1, AIM-9P-2, AIM-9P-3, AIM-9P-4, AIM-9Q, AIM-9R, AIM-9S, AIM-9X.[17]

AIM-120 AMRAAM. The Advanced Medium Range Air to Air Missile is a high-supersonic, day/night/all weather Beyond Visual Range (BVR) weapon. It has fire-and-forget air-to-air capability. It consists of a high-explosive warhead, an active radar homing sensor for the final stages of flight, and a rocket motor. It is launched with inertial mid-course guidance without the need for the fighter to keep the target illuminated. Its capabilities include look-down, shoot-down, multiple launches against multiple targets, and intercepts at very short range in dogfight situations. The unit cost of the AIM-120 is USD 386,000. There are four versions of the AMRAAM: AIM-120A, AIM-120B, Rb-99, AIM-120C. It is capable to of flying with speeds up to 4 Mach, and it can engage targets 30+ Nautical miles (48+kilometers).[18]

AGM-65 Maverick, a tactical, air-to-surface, infra-red or electro-optically guided missile. The Maverick is primarily employed in Close Air Support missions, but it is equally effective in anti-armor, SEAD and interdiction roles. Unit costs vary due to the many versions of the AGM-65 (e.g., USD 48,000 for the A-model and USD 269,000 for the G-model).[19] During the history of conflicts, Maverick has demonstrated an 86 percent hit rate in combat. Average miss distance during tests was 3 feet (0.91 meters).[20] The AIM-65 is available in 7 variants: A, B, C, D, E, F, G.

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17 Krittenden, “F-16C/D Block 50/52.”

18 Ibid.

19 Ibid.

20 Richardson, *Modern Fighting Aircraft - F-16*, 42.

Other Armament. The F-16 can also carry the JDAM, guided by a GPS system, and dropped up to 15 NM standoff distance. To ensure high performance in flight and attack, the F-16 can carry navigation and targeting pods: AN/AAQ-13 and AN/AAQ-14 LANTIRN. The LANTIRN system consists of two pods, which allows the plane to fly in all weather conditions, day and night. It provides the crew with a Terrain-Following Radar (TFR), a Forward-Looking Infra-Red (FLIR), targeting information for the on-board fire control system, and target laser illumination. The following armament may be also carried by the F-16:

- Durandal anti-runway weapon
- Cluster munitions
- Penguin MK-3 anti-ship missile
- Nuclear bombs
- ALQ-131 pod
- LAU rocket launcher
- Paveway laser guided bombs
- Mk82 500 pounds (227 kilograms)
- Mk83 1000 pounds (454 kilograms)
- Mk84 2000 pounds (907 kilograms)
- Mk117 750 pounds (340 kilograms)
- Mk82 Snakeye
- AGM-78 anti-radar missile
- AGM-88 HARM
- AGM-45 Shrike[21]

5. Summary

The F-16 is one of the most widely deployed fighter planes. There are currently 4,426 F-16s in service throughout the world. Despite its 1970s origins, there are still opportunities to modernize it. Since the 1970s, the only common part of the many versions is its famous name – "Viper." Engines, avionics, control systems and ordnance have been developed and modified to meet the demands of its many users. International

[21] Richardson, *Modern Fighting Aircraft - F-16*, 46.

air forces still want to acquire F-16s and put them in service as a major combat weapon system. Even though there are available airframes ranked as 4.5th and 5th generation fighters on the military market, the F-16 – a 4th generation fighter - still meets the requirement of the contemporary battlefield.

In the next part of this chapter, we will discuss the F-16 acquisition process in Poland. We will point out main turning points in that process, and we will show how a modern weapon system may affect the country's economy. We will also discuss the F-16 as a possible solution for the Romanian Air Force – which has yet to decide about its future combat aircraft.

B. ACQUISITION OF F-16 C/D BLOCK 50/52+ BY POLISH AIR FORCE

1. Polish Decision

The contract for the acquisition of 48 F-16C/D Block50/52+ traces its beginning to 1992. Then, the Commander of the Polish Air Force Gen. Jerzy Gotowala suggested during an official visit in the United States of America that the Polish Air Force consider leasing 12 fighter planes from the USAF (F-16C or F-18). The F-18 option was declined in later considerations due to the high cost of acquisition. That idea was the beginning of the acquisition process of a new multi-role fighter aircraft. On June 22, 2001, the Polish Government approved the modernization plan for the Polish armed forces. One of the main points of that plan was to acquire 48 new fighter planes. The offset program, explained in greater detail below, was considered to be one of the most important elements of the acquisition process. As it turned out, the size of the offset offered was the decisive element in the Polish decision.

On July 8, 2001, the specific requirements of the new fighter planes for the Polish Air Forces were sent to the French, American, British, and Swedish Embassies. With this decision, the Polish government confirmed its possible future options: F-16, Mirage, and Gripen.

Requirements were specified in 266 pages, and they defined Polish expectations regarding:

- Characteristics of the plane
- Possible financial options
- Offset program.[22]

On November 12, 2002, the proposed offers from the contractors were submitted. Evaluation of propositions was then carried out by Polish authorities and the Acquisition and Offset Committee. The whole process took 657 days with 93 specialists engaged.[23]

2. Evaluation Standards and Requirements for the Multi-Role Aircraft Proposals

The evaluation standards consisted of four elements: price of aircraft, combat and operational capabilities of the aircraft, main characteristics and engineering specifications of the airplane (MC&ER), and the offset program.

Evaluation Standards and Requirements Structure used by Polish Ministry of Economy and Offset Program Committee during multi-role aircraft selection process for the Polish Air Force are presented in Figure 4. The structure consisted of: Price (maximum 45 points), Combat Requirements (maximum 20 points), Main Characteristics and Engineering Requirements (maximum 15 points) and Offset Program (maximum 15 points).

Combat and operational capabilities had to meet Polish Air Force and Defense Policy needs. The PoAF had an aging fleet problem since the 1980s. Soviet aircraft delivery ended just after 1989, when Polish society overthrew the communist regime. The existing aircraft fleet did not allow the PoAF to accomplish defense tasks at modern warfare levels.

[22] Zdzislaw Wydra, "Zwyciężyl F-16," [in Polish] *Wiraże*, no. 2 (2003), http://www.czasopismawlop.mil.pl/wiraze/w_numerzew/archiwumw/2-2003/zwyc.htm (accessed March 28, 2006).

[23] Ibid.

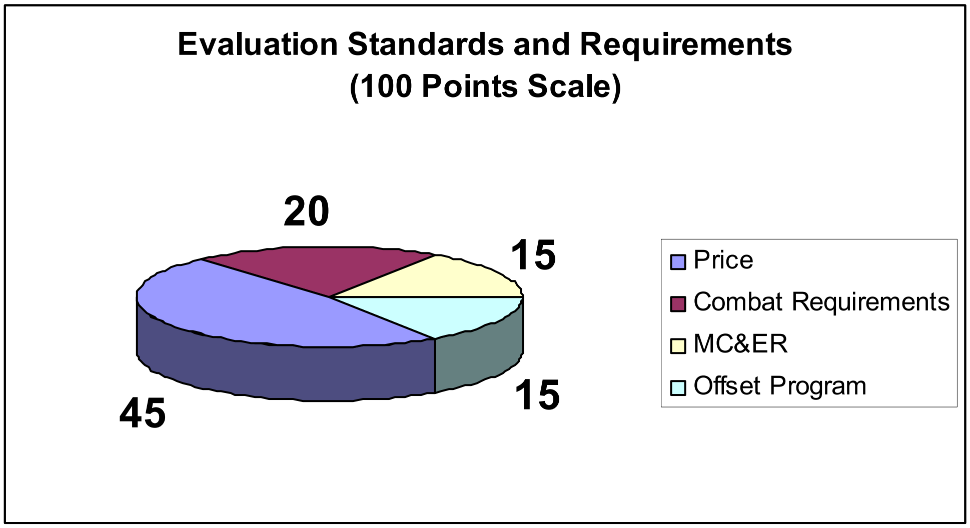

Figure 4. Evaluation Standards and Requirements Structure (From: Zdzislaw Wydra, "Zwyciężyl F-16," [in Polish] *Wiraże,* no. 2, (2003)).

There were 53 Combat and operational requirements. The new planes for Poland had to have air refueling capability, and carry a large amount of various armaments. One requirement considered armament compatibility with NATO standards and be able to operate with NATO partners.

In addition, the engineering and technical specifications of the plane played a major role during the selection process. Polish authorities evaluated 430 elements, including the following aspects: speed, maneuverability, take-off and landing distance, case of maintenance, durability, and O&S cost profile. In addition, the Polish specialists evaluated the airframe, hydraulic system, electrical system, fuel system, and engine system. The armament configuration, weapons carriages, cockpit configuration, avionics systems, and life support systems were also evaluated. Survivability of the aircraft on the modern battlefield, training, flying and maintenance personnel, possibility of acquiring simulators to train personnel, spare parts procurement, and technical support from the contractor also constituted important elements in the selection process.[24]

[24] Wydra, "Zwyciężyl F-16."

3. Offset Program

Every country pays special attention to the development of its national defense sector, including research activity, because of the great importance of defense for each country. However, national industry is not always able to meet requirements of national defense policy. Similarly to other countries, the Polish defense industry must support its efforts from foreign resources, and must import armaments. In this case an offset is a kind of obligatory cooperation between national contractors and foreign suppliers. Offsets are compensation instruments required when a contract for supplying armaments is awarded to a foreign contractor.

Offsets mean compensation for the country spending money on purchases in the public sector. This is one method for promoting economic growth.[25]

All offset agreements between the Polish government and foreign companies are based on Polish law (see offset process structure in Figure 5). The main law concerning offset is the Act on Offset Agreements of September 10, 1999, for compensation agreements concluded to cover defense and security contracts.

The Act sets forth the rules as well as the rights and liabilities for parties making an offset agreement related to armament and weapon system delivery into the Republic of Poland for the purposes of defense and security of State.[26] The Act also establishes general provisions, rules of execution of the offset agreement, the composition and tasks for the Committee for the Offset Agreements as well as the supervision of the performance of the offset agreements.

[25] Republic of Poland, Ministry of Economy, "Offset in Poland," http://www.mgip.gov.pl/English/ECONOMY/Offset+Programmes/Basic+information/ (accessed April 28, 2006).

[26] Republic of Poland, Ministry of Economy, "Act of 10 September 1999, on certain compensation agreements concluded in connection with contracts for deliveries for the needs of defense and security," http://www.mgip.gov.pl/English/ECONOMY/Offset+Programmes/Basic+information/ (accessed April 28, 2006).

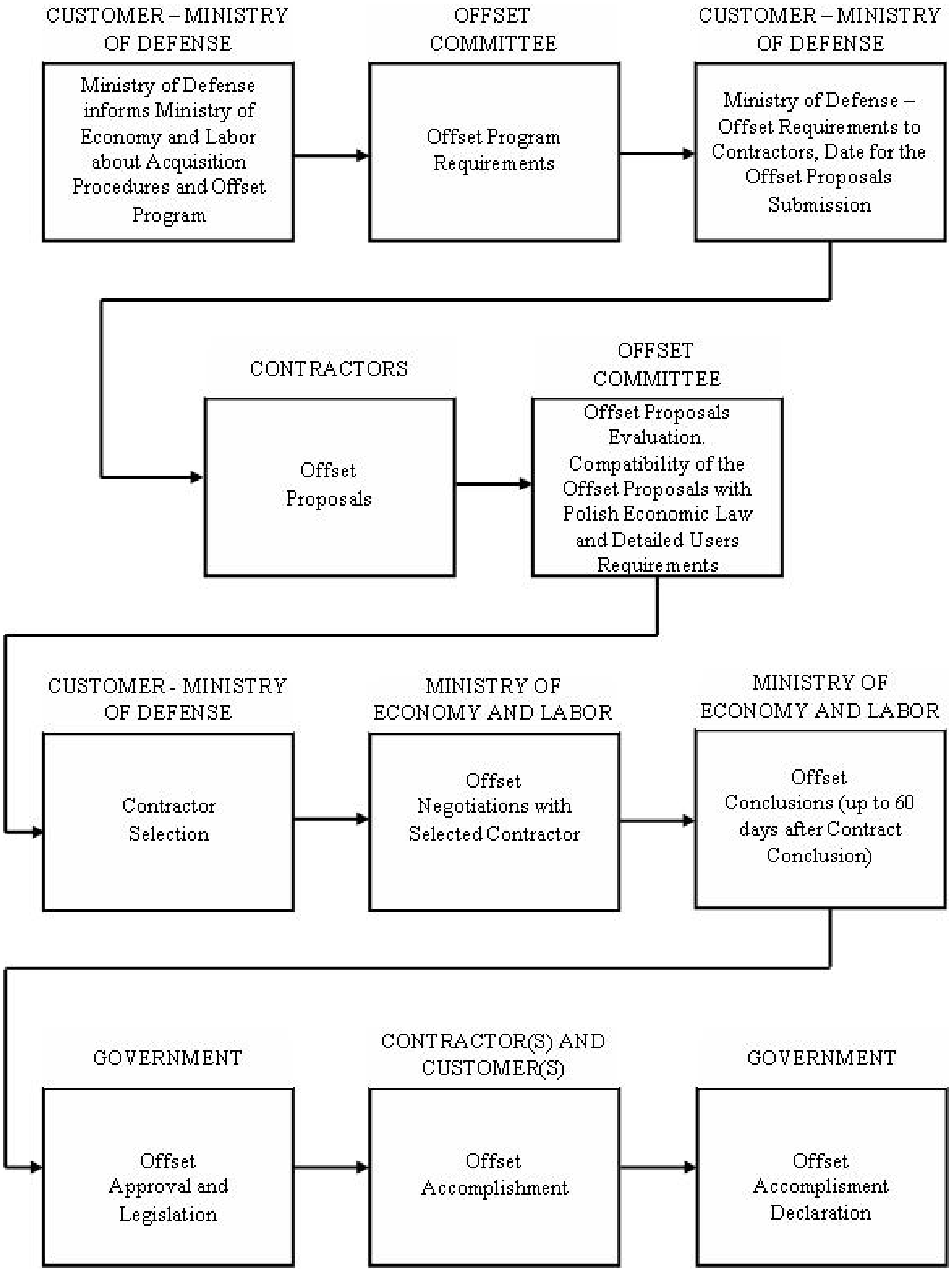

Figure 5. Offset Procedure in the Republic of Poland.

The main objectives of the offset programs in Poland are:

- Development of Polish industry
- Access to the new exports market
- Increasing current export potential
- Transfer of new technologies
- Development of research work
- Development of Polish universities and R&D centers
- Creation of new jobs in the Republic of Poland.[27]

Because of the factors listed above, the Polish Government paid great attention to the offset program incorporated in the new multi-role aircraft contractors' offers. The size of the possible contract (USD 3.5 billion) also underlined the significance of the Offset Program. Additionally, one of the main principles of the offset agreement in Polish Law states: "The total value shall not be lower than the equivalent of the supply contract."[28] That means that the offset could be as high as USD 7 billion.

The combat, operational and engineering specifications of all the offers were closed to one another. That is why the points (maximum 15) for the offset program had been considered to be crucial. Two of the three offset offers exceeded 100 percent of the contract value (Lockheed Martin and Saab-BAE Systems). The French proposal did not reach 100 percent; after verification and offset multipliers application it turned out the French proposal was equal to 60 percent of the total contract value.[29]

According the Polish Offset Law, offset multipliers were used to evaluate the attractiveness of the offset program proposals. It helps to draw foreign contractors' attention to Poland's offset needs and to state which of them are of special significance for the economy:

$$\text{Offset Value} = \text{Nominal Value} \times \text{Multiplier}$$

[27] Republic of Poland, Ministry of Economy, "Offset in Poland."

[28] Ibid.

[29] Zdzislaw Wydra, "F-16 Oferta Offsetowa," [in Polish] *Wiraże*, no. 3 (2003), http://www.czasopismawlop.mil.pl/wiraze/w_numerzew/archiwumw/3-2003/f16o.htm (accessed March 28, 2006).

There are different types of the multipliers and they depend on the nature of the offset. Polish offset law distinguishes two offsets: direct and indirect. A direct offset is an offset commitment performed by defense industry companies (listed in the relevant regulation), whose objectives are production, repairs, servicing, research and development and trading in armaments. Indirect offsets concern other companies registered in Poland.[30] Multipliers for direct and indirect offset are presented in Appendix A, Appendix B, and Appendix C.

The amount of money transferred to the Polish economy, as an effect of proposed offset programs for the Multi-Role Aircraft Acquisition before and after offset multiplier application, is presented in Figure 6.

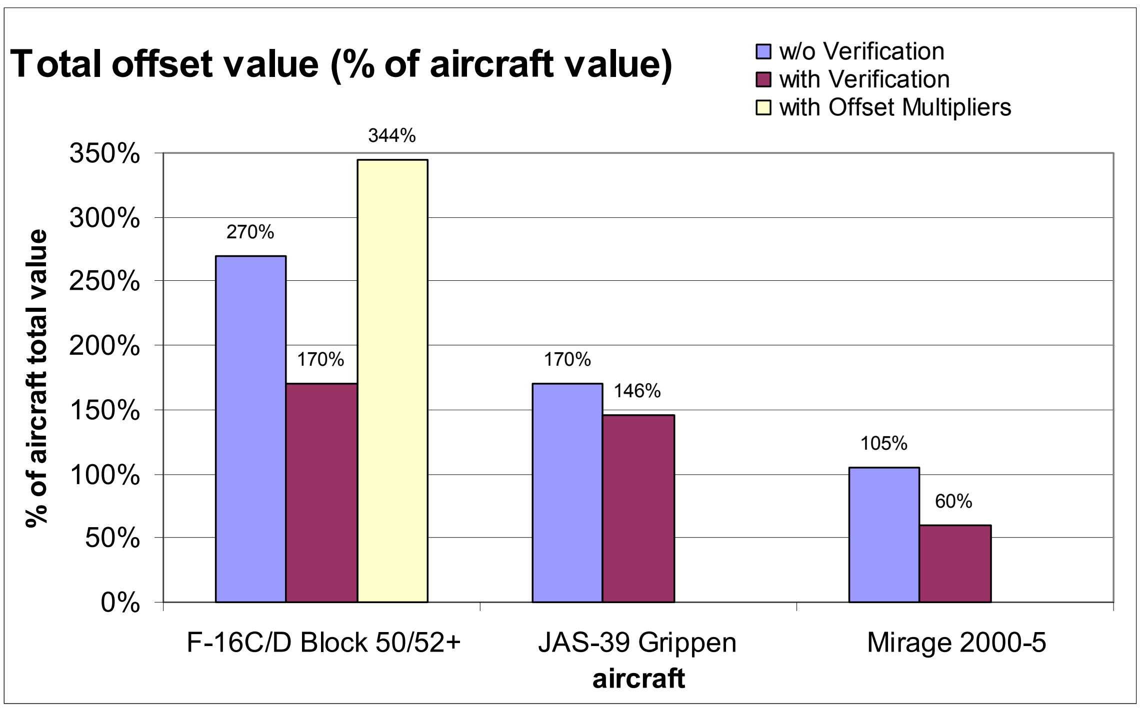

Figure 6. Total Offset Value Depends on Applied Multipliers. In the two cases (U.S. and U.K.-Sweden) total offset value was larger than contract value. (From: Zdzislaw Wydra," F-16 Oferta Offsetowa," [in Polish] *Wiraże*, no. 3 (2003)).

30 Republic of Poland, Ministry of Economy, "Offset in Poland."

The United States' offer was originally estimated to be USD 9.8 billion. After the verification process, the American offer was still the biggest and equal to USD 6.3 billion. The offset proposal consisted of 104 commitments. The United States' offer claimed to meet the offset commitments by investing in 55 programs in the defense sector (direct offset) and in 49 programs in the other branches of Polish economy (indirect offset).[31] The complete list of the United States offset commitments is attached in the Appendix D and Appendix E.

The total offset value, after an offset multiplier application, is equal today to USD 12,547 million with its nominal value of USD 7,751 million.[32] This contributes significantly to the Polish economy. As models, offset programs were boosters for the economy in Brazil (Embraer airline transport), for the Finnish economy (the electronic and wood industries), for Spain (military forces and airline industry), and for Israel (electronics sector). The Polish offset program has following structure:

- Export and purchase – 70%
- Investment in economy – 20%
- Technology transfer – 10%.[33]

There is one more very important issue about the "Contract of the Century" (as referenced in Polish and European newspapers). The United States government decided to give Poland a loan for that purchase. Poland will pay the USD 3.5 billion after 2010. Until that time the only financial obligation to the United States will be interest. Poland will pay approximately a total amount of USD 4.7 billion to the US corporations for the 48 planes.[34]

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31 Wydra, "F-16 Oferta Offsetowa."

32 Republic of Poland, Ministry of Economy, "The List of Lockheed Martin's Offset Commitments," http://www.mgip.gov.pl/NR/rdonlyres/D388B4F0-F028-4D79-A15F-B5EFD29BDC8F/0/zestawienie_zbiorcze.doc/ (accessed March 30, 2006).

33 wprost Online, "Miliardy Dolarów na Skrzydlach F-16," [in Polish] (2003), http://www.wprost.pl/ar/?O=43338/ (accessed March 30, 2006).

34 Ibid.

To stress the significance and size of the offset commitments of the United States, it should be compared with the rest of the major offset programs in Poland (Figure 7 and Appendix F). The rest of the total offset programs in Poland equal USD 1.718 billion (1 March 2006).[35] The US offset commitment is equal to USD 6.028 billion nominal value.[36]

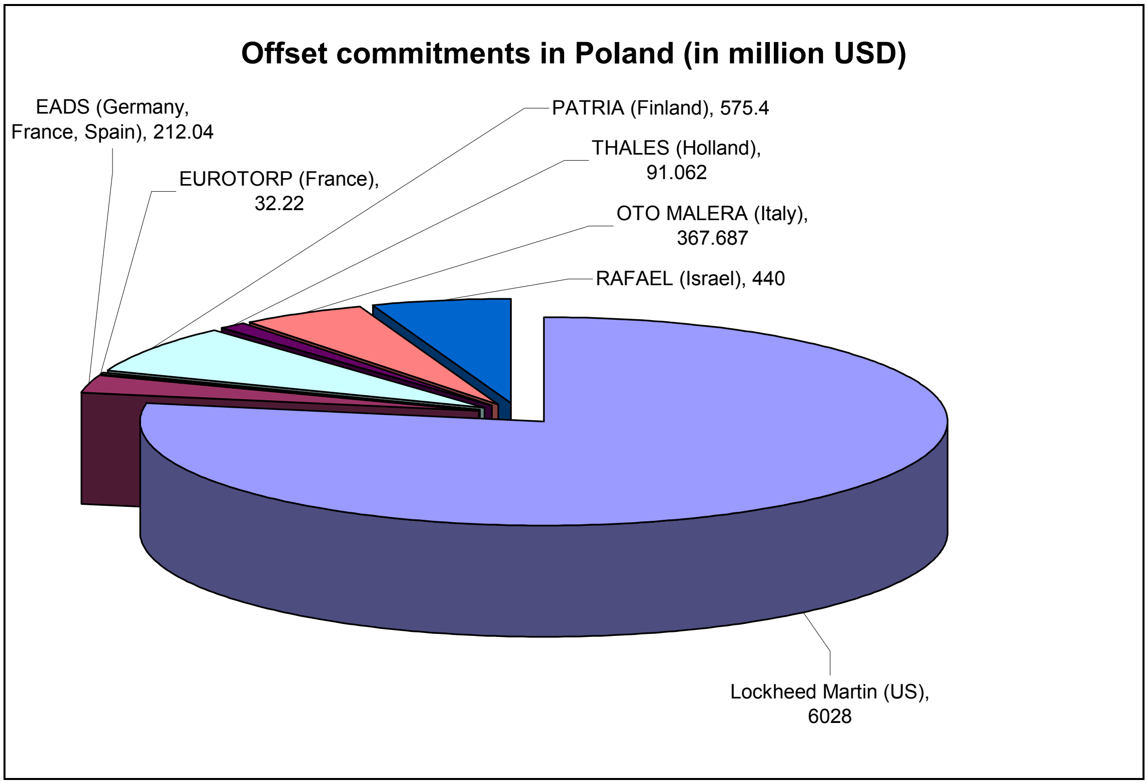

Figure 7. Offset Commitment in Poland as of March 1, 2006 (From: Republic of Poland, Ministry of Economy, "List of Offset Agreements in Poland (as of January 1, 2005)" [in Polish]).

The Polish F-16C/D Block50/52+ will be in service in October 2006 (the first 5 planes). Delivery is scheduled to end in 2008. After that time, three squadrons of F-16s from the Polish Air Force should achieve combat readiness for world wide deployment in

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35 Republic of Poland, Ministry of Economy, "List of offset agreements in Poland (as of 1 January 2005)" [in Polish], http://www.mgip.gov.pl/NR/rdonlyres/3627A141-DBD7-4010-950A-6A8C08AA5ABA/17858/offset_umowy_060302.pdf/ (accessed March 30, 2006).

36 The amount of offset commitment was transferred from the EURO to US Dollars using the rate of exchange €1 = $1.1935. Rate of exchange from March 1, 2006 from the National Bank of Poland, http://www.nbp.pl/ (accessed March 30, 2006).

NATO missions. Polish F-16C/D Block50/52+ will be the most advanced version among F-16 aircraft in NATO forces. This is important, because Polish F-16s are meant to stay in service for up to 30 years. In addition, they have huge potential to be modernized. Selection of the F-16 by the Polish government is also a selection of a course of policy. Given the key ally role for the United States, Poland will also have the opportunity to be one of the first countries for consideration for the new generation fighter F-35. There is a good chance that Romania will follow a similar strategy.

C. ROMANIA – POTENTIAL F-16 CUSTOMER

Poland and Romania share common values and have similar characteristics regarding their positions in Central Europe and South East Europe (respectively) and their relations with the United States. First, Poland is the largest and most important country in Central Europe, while Romania benefits from a key geo-strategic position in the South-Eastern part of the continent. Second, both countries are part of the "New Europe" as State Secretary Rumsfeld called them, and enjoy special partnerships with the United States.

Regarding its security, Romania has largely followed Poland's path. Admittedly, Romania was the first country to sign the Partnership for Peace Program which, in the beginning, was thought to be the anteroom for NATO accession. Poland became a NATO member in 1999 after the Washington summit. Five years later, in 2004, Romania joined the North-Atlantic club. A similar pattern was followed by Poland and Romania for European Union membership.

NATO membership was not only a culmination, but also a milestone along the way toward military restructuring. Given the security guarantees gained once Romania became a full member of the NATO Alliance, the number of fighting squadrons of the Romanian Air Force was diminished by two squadrons. Despite programs for upgrading the MiG-29, Romania decided to withdraw the MiG-29 from service and focus on the MiG-21 Lancer (the modernized version of the MiG-21M/MF) as its prime combat aircraft. This decision has been explained by Mr. Matache, a former State Secretary for the Department of Armament, who stated that ”after a deep analysis, the air force considered that the financial investment in the overhaul and upgrading [of the MiG-29] too big an effort for a small number of aircraft.”[37]

The MiG-21 upgrading program has been a major element in the regeneration of the RoAF and the Romanian aerospace industry following the dissolution of the Soviet Union and Warsaw Pact. It has allowed the RoAF to jump a generation of combat aircraft. Despite an over-30 year-old airframe, the MiG-21 Lancer is a fighter equipped with current sensors, avionics technology and modern weaponry. It has been modernized in two versions: the Lancer-A ground-attack version and the Lancer-C air-superiority version.[38] In addition, 14 MiG-21 UM two-seaters were modernized to the Lancer-B standard for training purposes.

The MiG-21 Lancer was accepted as an interoperable aircraft that may participate in missions alongside the NATO Air Forces. Starting in 2004, MiG-21 Lancer pilots are in fact executing air sovereignty missions over Romanian airspace. Based on this experience, NATO has accepted Romania’s proposal to take on responsibility of the air policing over the Baltic States as a part of regular NATO rotations in the region.

In current circumstances, the RoAF has to execute high-complexity and high-risk missions which require, as a necessity, a modern, multi-role fighting aircraft, belonging to the fourth or fifth generation. Among requirements, the following have priority: maximum efficacy in the battlespace environment, flexibility in executing missions with the capability to change assignment during mission, larger number of take-offs per time period, reduced times of flight recovery capacity, low operations and maintenance costs, higher flight autonomy, open system design to allow further upgrading, and excellent flight and maneuvering capabilities.

The MiG-21 will be in service until they run out of technical resources. Until 2010, 50 percent of them will be unsupportable, while the rest of them will remain in

[37] Michael J. Gething, “Lancer upgrade leads Romania’s leap into the 21st Century,” *Jane’s International Defence Review* 036, no. 006 (2003).

[38] For full details, see *Jane's Defence Systems Modernisation* IX, no.7, (1996).

service for another four years. Overall, the MiG-21 Lancer program has not been tremendously successful. The MiG-21 remains a useful aircraft for some missions, and its low-radar cross section and agility potentially make it a difficult opponent even for front-line fighters. However, its small, aging airframe and limited radar and avionics upgrade options have been a drag on modernization efforts. Consequently, Romania is interested in replacing the MiG-21 Lancer fleet with new aircraft. Therefore, an evaluation of available alternatives is being carried out.

During 2005, the following companies briefed the Romanian Air Force HQ about their offers of multi-role aircraft: Boeing with the F/A-18, a joint venture with Elbit Systems, Lockheed Martin with the F-16, and Gripen International with the JAS 39 Gripen. Given Romania's future membership in the European Union, the Eurofighter might also become a potential competitor.

According to Jane's, in February 2006, the National Supreme Defense Council approved the "conception on major procurement programs for Romanian Armed Forces 2006-2025" document. Romania's NATO status requires a fourth-generation, multi-role fighter aircraft. To carry out domestic missions and meet NATO commitments, the RoAF needs 48 multi-role fighters to be operational by 2010.[39]

At the end of October 2005, the Israeli media announced that Romania signed a new contract with Elbit Systems, worth 150 million dollars, to buy F-16A and F-16B jet-fighters. Other sources reported an even higher price, some 400 million dollars. This would also include additional costs such as Mid Life Upgrade (MLU), also known as Falcon Up (which is about 3 million dollars per aircraft), operating and maintenance costs, the cost for training pilots and technicians, and the new armament systems.

However, Romanian authorities denied that a decision has been made. As Defense Minister Atanasiu emphasized, for the time being Romania is evaluating and researching

[39] Radu Tudor, "Romania opens talks on fighter procurement," *Jane's International Defence Review* 39, no. 003 (2006).

the offers, but no firm decision has been made regarding the type of the aircraft to be purchased.[40] In addition, he mentioned that purchasing new aircraft are preferable to used ones:

"Our aspiration, which coincides with the desire of the Romanian Armed Forces, is to purchase new multi-role aircraft. We do not know if the budget, the Finance Minister and the government would agree with our request, or we would get much limited funding and we would be forced to purchase second-hand aircraft."[41]

A decision regarding the acquisition of a multi-role aircraft is scheduled to be made by the end of 2006, meaning that in 2007 negotiations would start with aircraft entering the RoAF service in 2010, and all units equipped and fully operational by 2014.

The final decision about the purchase of fighter aircraft will influence the structure and effectiveness of the RoAF for the next 20 years. Irrespective of the aircraft chosen, the RoAF would pay not only for the acquisition price, but also for operating and support costs.

In the wake of the Cold War, defense budgets have continually decreased. This results in a general decrease of numbers of military aircraft purchased since early 1990s, associated with dramatic increase in aircraft acquisition cost. Taking into account the above-mentioned, financial aspects have outweighed military reasoning in choosing among alternatives. Also, cost is clearly a significant driver when choosing an acquisition strategy.

Financial acquisition strategy includes four categories: budget financing, fund financing, debt financing, and leasing. During the Cold War, budget financing was the preferred method. However, "the Navy has a long history of leasing ships to augment military capability in times of war."[42] An extended debate was generated by the USAF

40 Arieh Egozi, "Israel, Romania seal F-16 sale deal," *Jane's International Defence Review* 38, no. 010 (2005).

41 Teodor Atanasiu, cited by Mihai Diac, "Bucharest would like to spend millions of dollars on fighter aircraft," [in Romanian] (Bucharest: Gandul, March 10, 2006).

42 Joseph G. San Miguel, John K. Shank and Donald E. Summers, "Navy Acquisition via Leasing: Policy, Politics, and Polemics with the Maritime Prepositioned Ships," NPS Acquisition Research, April 2005, 3.

proposal to lease new refueling tankers from Boeing. The Hungarian experience, which includes a 12-year lease of 14 JAS-39 Gripen multi-role fighters, has been more successful.

In the Hungarian case[43] as well as in the Polish case, the offset agreement was a key element in the acquisition process. A major part of the offset agreement is the participation of the aeronautical industry along with the contractor the modernization process.

Romania has a long history of producing high quality aircraft and helicopters. Numerous links with Western Europe's industries have been established since 1970s. During the 1990s, Romanian aeronautical industries started an extended collaboration with the Israeli defense industry. The modernization process of MiG-21 is only one of numerous examples. However, the current defense trade sector is still struggling with its legacy of state control, which includes inefficient production methods and obsolete management practices. Therefore, the involvement of Romanian industry in the procurement and ownership of the multi-role aircraft will be an essential element in the decision-making.

In conclusion, the acquisition process of the multi-role aircraft for RoAF must begin soon. As part of that process, the experience of Poland, as well as the Hungarian case will be analyzed by the decision-makers, and lessons learned will be applied. Undoubtedly some aspects of the acquisition process, as accomplished by DoD, would constitute a model for Romania's approach. Particularly important in this respect is the estimation of operatings and support costs. In the following chapters, the acquisition process in DoD will be addressed, and based on the above, it is expected that Romania will decide on the most appropriate and affordable path to be followed.

[43] Neil Barnett, "Hungary requests enhanced Gripen deal," *Jane's Defence Weekly*, September 11, 2002.

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III. DOD'S APPROACH TO WEAPON SYSTEM MANAGEMENT

The last fifteen years have brought significant changes to the structure and task of the U.S. Military Forces. Those changes were caused by shifting political and military requirements in the post Cold War Era. In addition, the development of modern technology has created a new battlefield environment. Modern technology is enormously expensive and needs large appropriations allocated from shrinking budgets. Almost every country has problems with fulfilling the needs of its military forces. In order to meet the requirements of the U.S. Military Forces in the 21st Century, the DoD fundamentally reengineered the way it does business, and a new Defense Acquisition System was established. "The Defense Acquisition System is the management process by which the DoD provides effective, affordable, and timely systems to the users."[44]

The effectiveness of modern weapon systems, such as the F-16 Multi-Role Aircraft, and their affordability, as well as the time needed to field them are determined by the way they are acquired. Moreover, the Total Ownership Cost (TOC) will also be affected by decisions during the acquisitions phases. In order to better understand the basics of the acquisition process and its effect on ownership costs, we present the new Defense Acquisition System developed by the DoD in this chapter. We also elaborate each phase of the acquisition process of the modern weapon system. Next, we concentrate on the Total Life Cycle Management System (TLCMS). TLCMS and acquisition system have direct impacts on TOC, particularly on operating and support costs.

The Defense Acquisition System was established to manage investment in modern technologies, programs and product support necessary to meet the requirements of the National Security Strategy and to support the U.S. Armed Forces. The national investment in technologies, conducted within the Defense Acquisition System, must

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44 Department of Defense, "DoD Directive no. 5000.1 – The Defense Acquisition System," (Washington, D.C.: Office of the Under Secretary of Defense for Acquisition Technology, and Logistics, 2003), para. 3.1, http://hfetag.dtic.mil/docs/DoD_5000-1.doc (accessed April 27, 2006).

support not only today's armed forces but also future armed forces. This provides U.S. military forces with a unique opportunity to be the leading armed forces all over the world.

The primary objective of the Defense Acquisition System is to provide users with quality products plus measurable improvements to mission capability and operational support. According to the DoDD 5000.1, the following policies should govern the Defense Acquisition System:

- Flexibility – there is no one way to satisfy users and accomplish objectives of the Defense Acquisition System. Milestone Decision Authorities (MDAs) and Program Managers (PMs) should tailor the program strategies and oversight to meet the particular condition of the program.
- Responsiveness – advanced technologies should be integrated with production and they should enter service in the shortest possible time. Evolutionary acquisition strategy is the preferred approach to satisfy operational needs.
- Innovation – acquisition professionals should continuously develop and implement strategies to improve the Defense Acquisition System. The main objective of the innovation capabilities of the acquisition system should be to reduce cycle time, cost and encourage teamwork.
- Discipline – every PM should establish program objectives with optimum cost, schedule and performance parameters that describe the program over its life cycle.
- Streamlined and Effective Management – responsibility for system acquisition should be decentralized to the maximum extent possible. Responsible individuals should be provided[45] by the MDA with sufficient authority to accomplish the Defense Acquisition System's objectives.

A. PROCESS OF ACQUISITION BASED ON THE DOD SYSTEM LIFE-CYCLE PHASES

The DoD acquisition process is extremely complex, involving hundreds of thousands of people and many years of engagement. The process also involves assimilation of information and management within many areas, often overlapping one another, which are difficult to predict and measure. The main objective of that structure is, however, to ensure the best possible expenditure of public funds. To accomplish that

[45] DoD, "DoD Directive 5000.1," para. 3 – "Policy."

task, DoD has developed its acquisition system over many years of experience,. The system has also evolved within boundaries where many potentially competing interests are balanced with many resource constraints.

The management framework for the Defense System Acquisition is commonly referred to as the acquisition life cycle. The new DoDI 5000.2 presents the acquisition system and its elements. The new framework for the acquisition system is called the "New 5000 Model" (Figure 8).[46] The main objective of the "New 5000 Model" is to improve performance and lower costs. To meet that objective, the model considers following key focus areas:

- Delivery of advanced technology to warfighters faster by
    - Rapid acquisition with demonstrated technology
    - Full system demonstration before commitment to production
- Reducing Total Ownership Cost and improving affordability
    - Costs as requirement that drives design, procurement, and support
    - Increased competition
- Deploying interoperable and supportable systems
    - Interoperability presented before production phase
    - Integration of logistic and acquisition
    - Improvement of software management

[46] Charles B. Cochrane, "Introduction to Defense Acquisition Management," 6th ed., (Fort Belvoir, VA: Defense Acquisition University Press, 2003), 49, http://www.dau.mil/pubs/gdbks/idam.asp (accessed April 10, 2006).

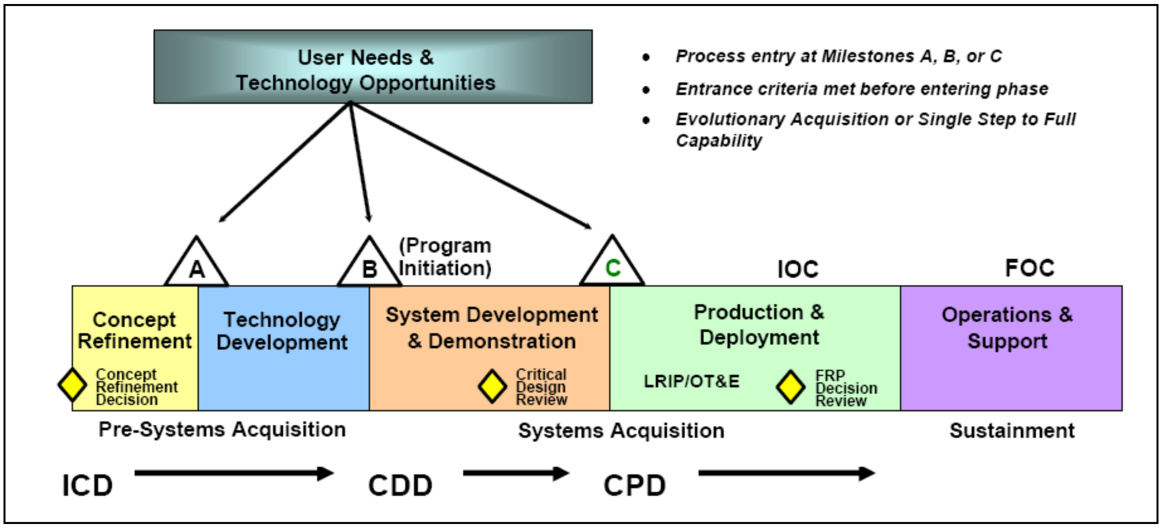

Figure 8. The New 5000 Model of the DoD Systems Acquisition Process (From: DoD Template for Application of TLCSM and PBL in the Weapon System Life Cycle, http://www.acq.osd.mil/log/lpp/tlcm/TLCSMGuidanceTemplate.pdf).

According to the New 5000 Model, technology opportunities and missions must be presented before entering the acquisition process. In the new model multiple systems acquisition strategies are possible, which the model encourages. The preferred approach is called evolutionary acquisition, based on the assumption that time-phased requirements will improve acquisition system performance. The success of this strategy depends on a consistent definition of operational capability requirements coupled with maturation of technologies. Evolutionary acquisition strategy also demands a robust system engineering approach focused on adding capabilities in future increments.[47]

Development of technology is separated from systems integration. As a result, technology is proved before beginning system-level work at Milestone B. The next important element of the new model is the requirement of meeting "entrance criteria" before moving to the next phase. It ensures the readiness of the system to be moved to the next phase of development without any delay. Moreover, it reduces the costs. In the New 5000 Model, the operation, support, and disposal phases have become integrated parts of the acquisition process. Thus, the process encompasses the entire system life cycle.

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[47] United States Air Force, "Air Force Instruction 63-101 - Operations of Capabilities Based Acquisition System," (Washington DC: Secretary of Air Force, 2005), para. 1.4, http://www.e-publishing.af.mil/pubfiles/af/63/afi63-101/afi63-101.pdf (accessed April 14, 2006).

1. Pre-Acquisition

a. Concept Refinement Phase and Milestone A

The pre-acquisition phase is composed of two elements: concept refinements and technology development.

The Concept Refinement Phase begins when the Concept Decision is approved by the Milestone A Decision Authority (MDA) (Figure 9 presents the framework of the Concept Refinements Phase prior to Milestone A). During that phase, the Technology Development Strategy (TDS) is developed. The main objective of the TDS is to set the foundations for the next phase – Technology Development. The MDA determines who will prepare the TDS.

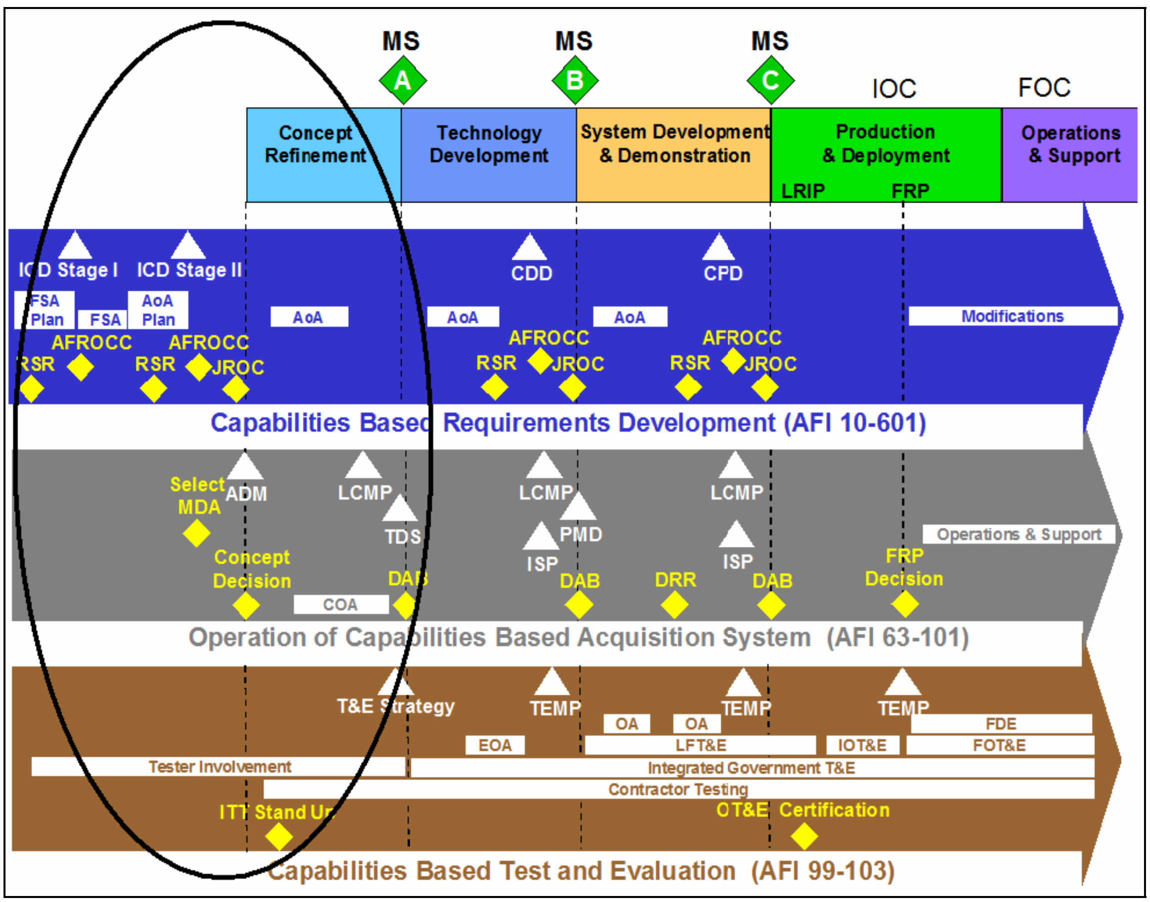

Figure 9. Integration of Acquisition, T&E and Requirements Events Prior to Milestone A (From: USAF, "*Air Force Instruction 63-101*," (2005)).

To support the Concept Refinement Phase, an Analysis of the Alternatives (AoA) is conducted. An AoA is an analytical comparison of the operational effectiveness and costs of proposed material solutions to shortfalls in operational capabilities, also called mission needs (Appendix G). The AoA presents the rationale for the preferred solutions to the mission needs.[48]

In order to achieve the best possible solutions, the Concept Refinement Phase emphasizes innovations and competitions. It also emphasizes existing commercial solutions. They are drawn from diverse specialties and from large and small businesses alike. The Concept Refinement Phase ends when the MDA approves the solution supported by the AoA and TBS, which form the guidelines for the next Phase – Technology Development.

b. Technology Development Phase

The Technology Development Phase should reduce technology risk (Figure 10 presents the Framework of the Technology Development Phase). It is also designed to determine suitable technologies which may be incorporated into the new weapon system. During that phase close cooperation of the following elements is required: operators, testers, and system development stakeholders. Elements which were developed in the Concept Refinement Phase, require updates during that phase as well.[49]

The Technology Development Phase begins after the Milestone A decision point, when the Milestone Decision Authority approves the TDS. The TDS, which was created in the prior phase, is the map for technology development during this phase. However, the favorable decision regarding TDS does not necessary mean that a new acquisition program has been initiated. During that phase a series of demonstrations of the new system may also be conducted to help the users and developers agree on appropriate technology to accomplish the acquisition program goals.

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[48] USAF, "AFI 63-101," para. 4.3.3.

[49] USAF, "AFI 63-101," para. 5.2.

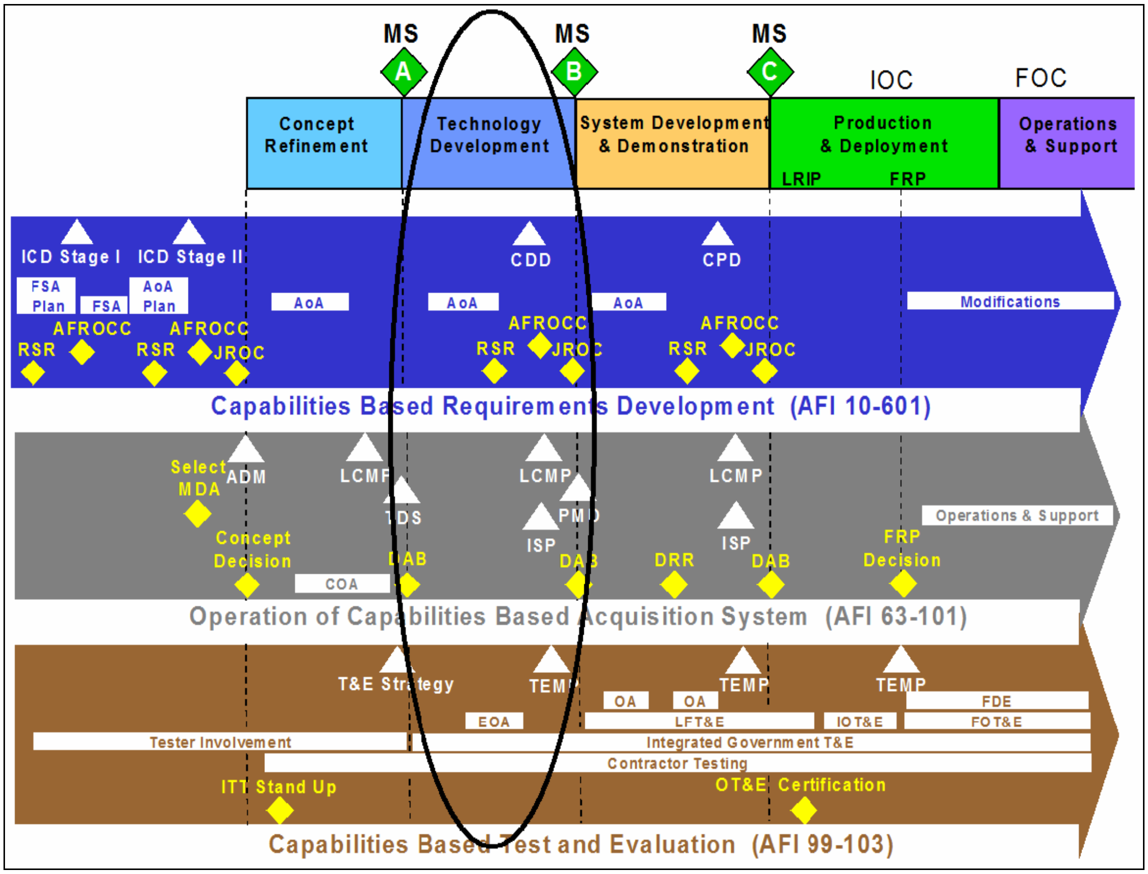

Figure 10. Integration of Acquisition, T&E, and Requirement Events Prior to Milestone B (From: USAF, "*Air Force Instruction 63-101*," (2005)).

"The project is ready to leave that phase when the technology for an affordable increment of a militarily useful capability has been demonstrated in a relevant environment."[50]

2. Systems Acquisition

a. Milestone B and System Development and Demonstration Phase

The objectives of the System and Development Demonstration phase are:

- Develop a system or increment of capability
- Reduce integration and manufacturing risk
- Ensure operational capability
- Implement human system integration

50 Cochrane, "Introduction to Defense Acquisition Management," 53.

- Ensure affordability and protection of critical program information using appropriate techniques (anti-tamper measures)
- Demonstrate system integration, interoperability, safety and utility.[51]

The decision point for the System Development and Demonstration phase is Milestone B, which is the acquisition program initiation. The decision is made by the Milestone Decision Authority (MDA) – a designated individual with overall responsibility for the program. The MDA has authority to approve entry into the next phase of the acquisition process. The MDA is also responsible for costs, scheduling and performance reporting to the higher authority (including Congressional reporting).

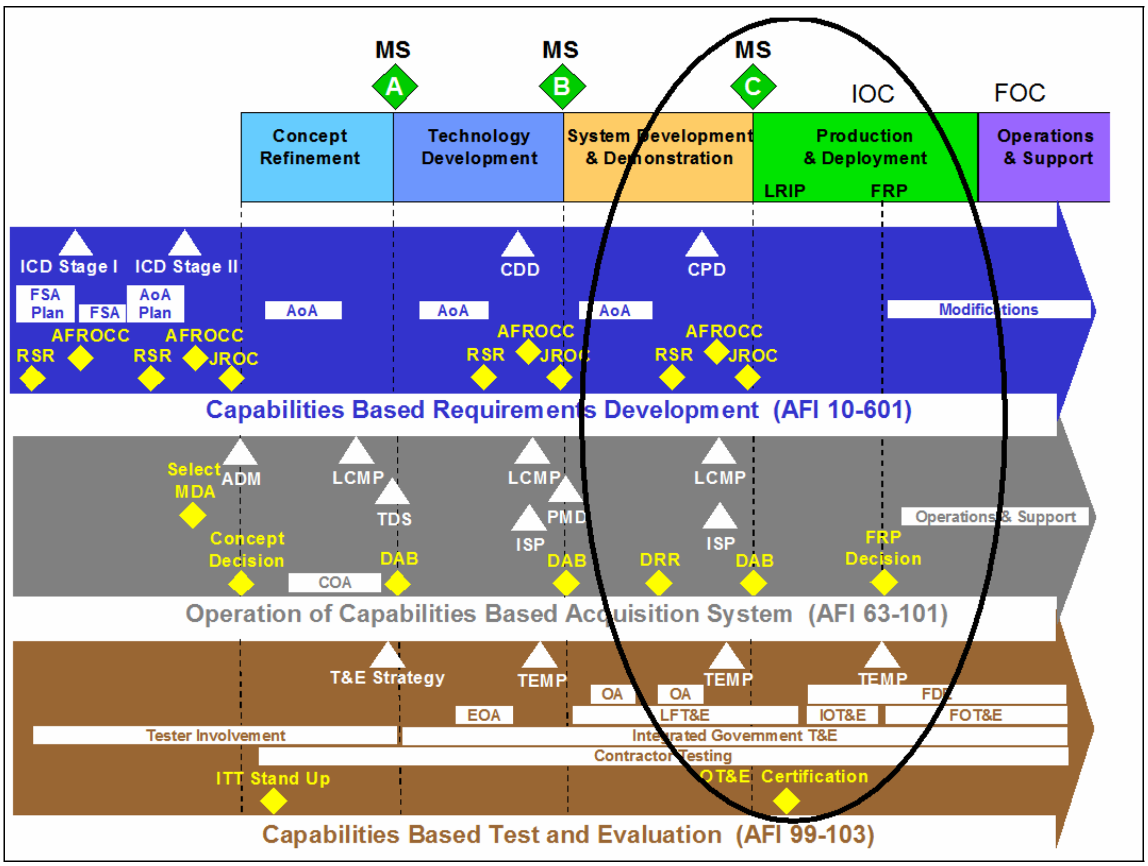

Figure 11. Integration of Acquisition, T&E, and Requirements Events Prior to Milestone C (From: USAF, "*Air Force Instruction 63-101*," (2005)).

51 Department of Defense, "Department of Defense Instruction 5000.2 - Operation of the Defense Acquisition System," (Washington, D.C.: Office of the Under Secretary of Defense for Acquisition Technology, and Logistics, 2003), para. 3.7.1.1., http://www.dtic.mil/whs/directives/corres/pdf2/i50002p.pdf (accessed April 14, 2006).

Before making any decision in the Milestone B decision point, the MDA confirms that technology is sufficiently mature for system-level development. The MDA also has responsibility to confirm that appropriate documents from the Joint Capabilities Integration and Development Systems (JCIDS) have been approved.[52] Additionally, the MDA ensures that funds are in the budget.

Taking into consideration these problems, the Milestone Decision Authority approves the acquisition strategy and program baseline. Entry into the System Demonstration and Development Phase is then approved (Figure 11).

Entrance criteria for the System Demonstration and Development phase are technology maturity, available funds and approved JCIDC document – Capability Development Document (CDD). Technical maturity determines the path to be taken by the program. A program entering that phase must have developed a systems and operational architecture (this is a condition to be met at the Milestone B Decision Point). That phase is driven by the Key Performance Parameters (KPP) found in the CDD. This Phase contains two main elements (Figure 12):

- System Integration – the main objective is to integrate subsystems, reduce system-level risk and complete detailed design. The acquisition program enters that part of the SDD when the PM has the technical solution for the program (technology maturity), but the program is not yet integrated into a complete and coherent system.[53]
- System Demonstration – the main objective is to prove that system can operate in a useful way consistent with the KPPs. This element of the SDD should be accomplished when the system proves that it can operate under requirements set by the future environment, using the selected prototype. The system should then meet (or exceed) exit criteria and entrance requirements for the Milestone C. Accomplishment of that phase requires a decision made by the MDA to continue the program in Milestone C or drop the program and search for another alternative.[54]

[52] JCIDS deals with the analysis of doctrines, organizations, training, materials, personnel, and facilities in an integrated process to define gaps in warfighting capabilities. JCIDC also proposes solutions to those problems.

[53] DoD, DoDI 5000.2, para. 3.7.3.

[54] Ibid., para. 3.7.5.

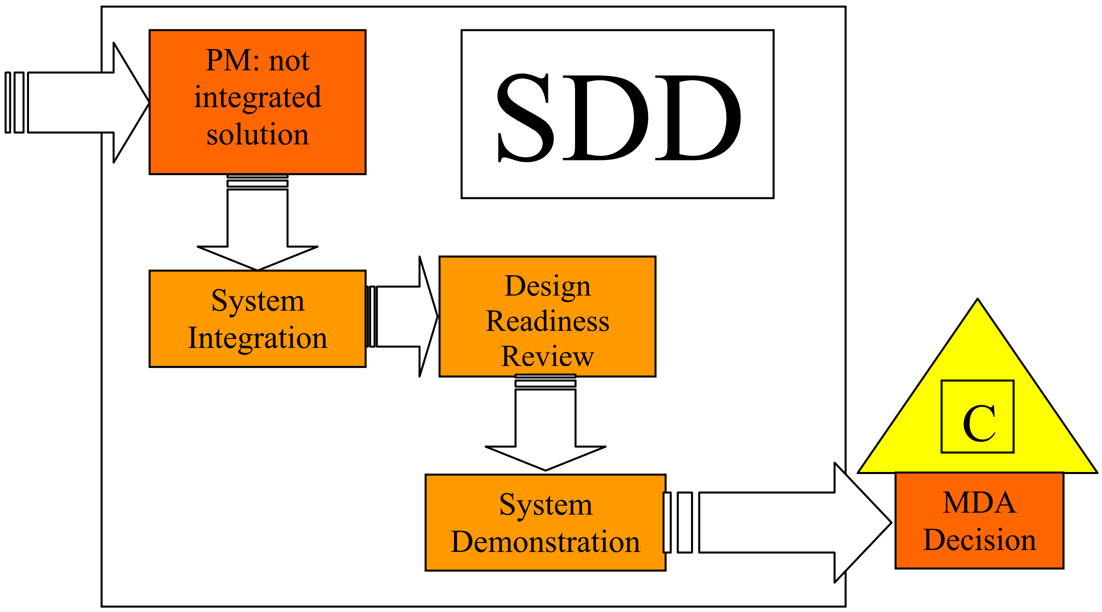

Figure 12. Elements of the System Development and Demonstration Phase (SDD).

The System Integration Phase is followed by the Design Readiness Review (DRR), which is an opportunity for mid-phase assessment. Successful completion of the DRR ends the System Integration Phase and begins the System Demonstration Phase.

b. Milestone C and Production and Deployment Phase

The decision regarding commitment to production of a new system is made by the MDA at the Milestone C Decision Point. A new system receives authorization to be produced at the Low Rate Initial Production (LRIP) level. The MDA will approve entry to the LRIP when a reasonable degree of confidence of system operational effectiveness is attained.

In some cases, Milestone C authorizes entry into full-scale production, bypassing the LRIP. Milestone C also authorizes a limited operational testing for the elements with no production components such as automated information systems or software systems.[55]

[55] Cochrane, "Introduction to Defense Acquisition Management," 55.

The main objective of the Production and Deployment phase (P&D) is to achieve the operational capability which meets the mission needs requirements. Entrance to P&D depends on the following factors:

- Acceptable performance in development, test and evaluation, operational assessment
- No significant manufacturing risk
- Mature software capability
- Manufacturing process under control
- Approved Initial Capabilities Document (ICD)
- Approved Capability Production Document (CPD)
- Acceptable interoperability
- Acceptable operational supportability
- Demonstration that the system is affordable through whole lifecycle.[56]

The P&D Phase consists of Low Rate Initial Production and Full Rate Production and Deployment. It also includes the Full Rate Production Decision Review.

The LRIP must result in completion of manufacturing development. Manufacturing development should be sufficient to produce a quantity necessary to provide production articles for Initial Operational Test and Evaluation (IOT&E). Manufacturing development should also establish an initial production base for the system and permit an increase to full rate production.[57]

LRIP quantities should be minimized and any production must be approved by the Milestone Decision Authority. Further, the MDA is responsible for assessment of the cost and benefits of a break in production versus annual buys, when the LRIP quantities are expected to be larger than predicted.

The MDA considers the initial operational tests, evaluation, and live fire test in the Full Rate Production Decision Review. A favorable review authorizes the program to be transferred into Full Rate Production and Deployment.

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[56] Cochrane, "Introduction to Defense Acquisition Management," 55.

[57] DoD, DoDI 5000.2, para. 3.8.3.1.

During the Full Rate Production and Deployment phase, the system is produced and delivered to units for operational use. The PM must ensure that the system is produced and deployed at an economical rate in accordance with the user's needs. Operation and Support begins as soon as the first systems are deployed. The Production and Deployment phase therefore overlaps the Operation and Support phase.

3. Operation and Support (O&S): Sustainment and Disposal

The most important goal of a successful strategy is to ensure that fielded systems are supportable. There are two main approaches to the O&S Phase: System Engineering (SE) (which includes all technical activity), and Performance Based Logistics (PBL) – (purchase of support as an integrated, affordable performance package).[58]

Weapon system costs and performance in the O&S phase is the ultimate measure of the success of the acquisition program. Measurement of outcomes is possible within the Total Life Cycle Systems Management (TLCSM). To meet that objective, TLCSM utilizes single point accountability tools and Performance Based Logistic.

During the O&S phase, full operational capability of the weapon system is achieved. Each element of logistics support is assessed, and operational readiness is also evaluated. These two concerns, logistics and readiness, dominate the O&S Phase. This phase is also divided in two main elements: Sustainment and Disposal.

a. Sustainment

Effective Sustainment begins with the design and development of a maintainable and reliable system, made possible by application of the system engineering methodology. Sustainment includes:

- Supply
- Maintenance
- Transportation
- Sustaining engineering
- Data management
- Configuration management

[58] USAF, "AFI 63-101," para. 6.5.

- Manpower and personnel
- Training
- Habitability and survivability
- Environmental concerns
- Safety
- Occupational health
- Protection of critical program information and information technology.

During this phase, weapon systems modifications are possible. They are done on a requirements basis, to improve systems performance and reduce ownership costs. System improvement programs are therefore initiated as a result of experience with the fielded system and may lead to life extension.

b. Disposal

Disposal of the fielded weapon system takes place at the end of useful life. The PM plans the disposal activities during the operational life. The PM is also accountable for minimizing the DoD's exposure to environmental safety, security, and health issues. The environmental safety is very important due to two reasons. First, most modern weapon systems may pose harm to the environment and influence it for many years. Second, the disposal very often must meet the requirements of international treaties or other legal considerations which would require intensive management of the system disposal.

B. TOTAL LIFE CYCLE SYSTEM MANAGEMENT (TLCSM)

"Total Life Cycle System Management is the implementation, management, and oversight by the Program Manager, of all activities associated with the acquisition, development, production, fielding, sustainment and disposal of a DoD weapon or material systems across its life cycle."[59] The PM is responsible and accountable for the accomplishment of program objectives throughout the life cycle. TLCSM mandates major system development decisions regarding operational effectiveness and logistic affordability. TLCSM includes the following elements:

[59] Defense Acquisition University, "Defense Acquisition Guidebook" (2004), para. 5.1.1. http://akss.dau.mil/dag/DoD5000.asp?view=document (accessed April 17, 2006).

- Single point of accountability (Program Manager)
- Evolutionary acquisition strategies
- Life Cycle Logistics (LCL) in the system engineering process
- Supportability as a major element of performance
- Reducing logistic footprint through increased reliability
- Performance based logistic strategies
- Sustainment strategy reviews.[60]

Under the TLCSM, Life-Cycle Logistics (LCL) is a major consideration during acquisition of the weapon system and its operational life cycle. LCL should ensure that supportability requirements are understood and consistent with costs, performance, and schedule through the entire life cycle of the weapon system.

Within LCL, Performance Based Logistics is the DoD's preferred approach to system support. The second dimension of the LCL is System Engineering (SE). SE must ensure that supportability requirements are met during the design, development, and sustainment of the weapon system (Figure 13).

1. System Engineering (SE)

The SE processes are system solutions. A major objective is to balance performance, risk, costs, and schedule outcomes.

SE plays an important role in the DoD's Acquisition Process. It is applied throughout the process from capability needs to an operational system. Accordingly, SE is applied very early in the concept definition and it is present through the entire life cycle.

60 Defense Acquisition University, "Defense Acquisition Guidebook" (2004), para. 4.1.3.

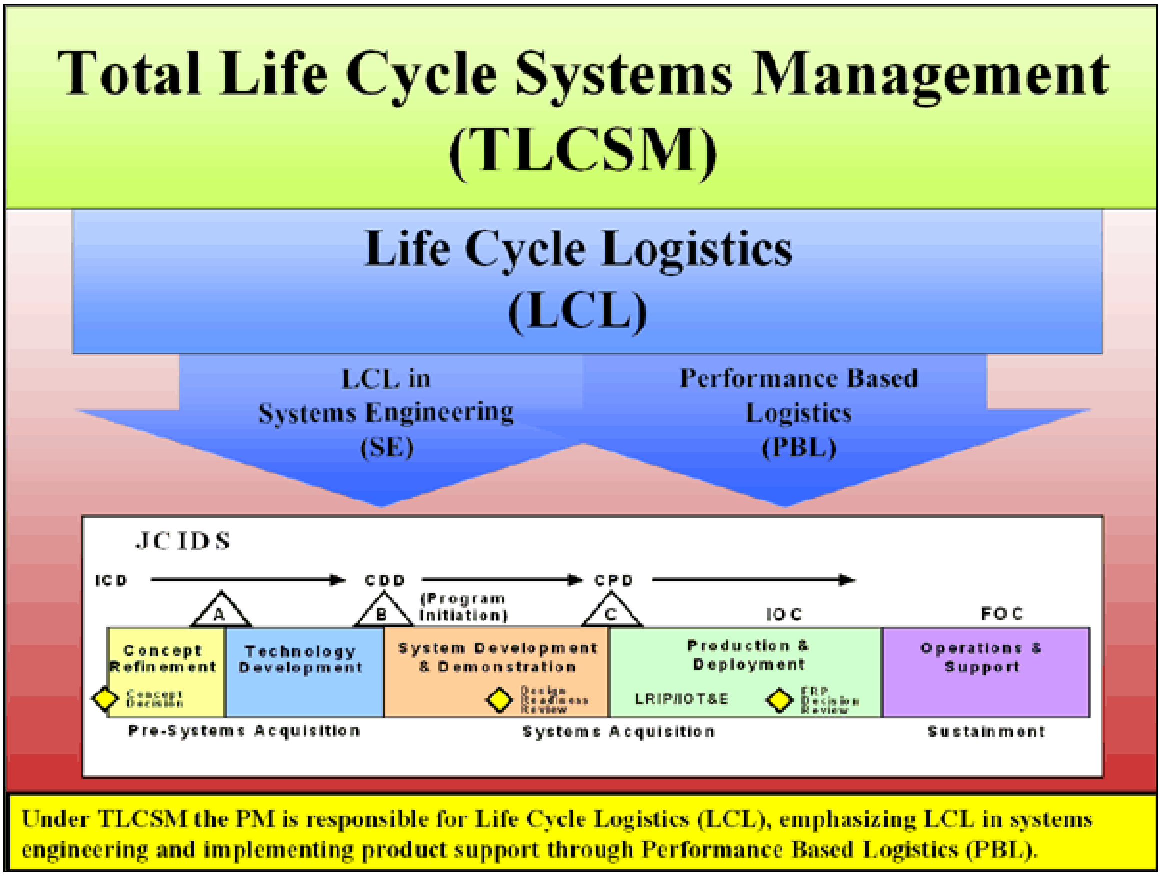

Figure 13. Conceptual Framework for the Total Life Cycle System Management (From: Defense Acquisition University, "Defense Acquisition Guidebook" (2004) para. 5.5.1.).

System Engineering provides a menu of processes which help coordinate and integrate activities throughout the life cycle. The main SE tool is the technical framework, which facilitates decision making by achieving balance between performance, cost, schedule, and risk. Successful implementation of SE will result in a total system solution which has the following characteristics:

- Responsive to changing technical, production, operating environment
- Adaptive to needs of the users
- Balanced among requirements, design consideration, constraints, and program budgets.[61]

[61] DAU, "Defense Acquisition Guidebook," para. 4.1.1.

The SE process is repeated in nature. It consists of four major elements: requirements analysis, functional analytical allocation, synthesis, and systems analysis and control. The feedback among these elements is essential to the overall process, as illustrated in Figure 14.

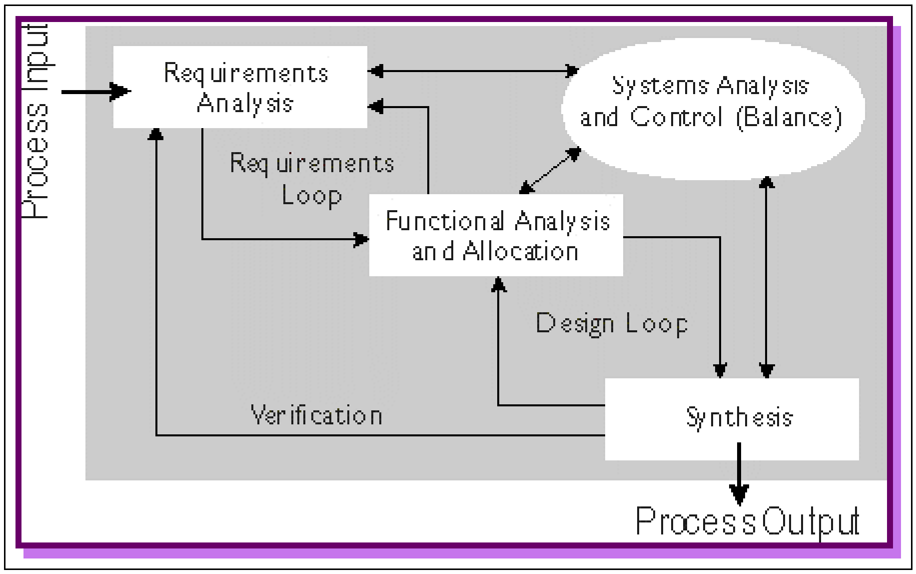

Figure 14. The System Engineering Process (From: Defense Systems Management College, "Acquisition Logistic Guide," 3rd ed., 1997).

SE is applied during the each phase of the acquisition process. During the development phase a progressive change in the central focus of SE is observed. In the early phases SE focuses on components. When the system develops, the focus is transferred to the subsystem level. Finally, when system maturity is achieved, SE focuses on system level considerations. Furthermore, logistic considerations are elements of SE and they must be integrated in the SE process from the very beginning. Supportability analysis must also be a vital part of the SE process.

a. Supportability Analysis

Supportability analysis is conducted by the PM through the entire life cycle of the weapon system (Appendix H). The initial analysis should focus on relations involving operational performance readiness and planned support structures. Supportability analysis can also include a numbers of tools, practices, or techniques. The results constitute the framework for design requirements regarding performance and logistics. The PM is responsible for the decisions either to continue a program or modify it based on supportability analysis. The Total Ownership Cost (TOC) plays a major role in the overall selection process. Support concepts for all systems provide cost effective, total lifecycle logistic support.[62] When considering alternative systems, the PM may use the following criteria:

- Life-cycle cost
- Diagnostic characteristics
- Energy characteristics
- Battle damage repair characteristics
- Transportability characteristics
- Facilities requirements.[63]

Supportability factors are also important elements of supportability analysis, and are integral to the program performance specification. The following items may be used when considering supportability issues:

- Operation and maintenance personnel constraints
- Personnel skill level constraints
- Life-cycle and O&S cost constraints
- Target percentages of systems failures correctable at each maintenance level
- Mean down time in the operational environment
- Turn-around time in the operational environment
- Standardization and interoperability requirements
- Built-infault isolation capability
- Transportability requirements.[64]

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62 DAU, "Defense Acquisition Guidebook," 2004, para. 4.4.9.2.

63 Defense Systems Management College, "Acquisition Logistic Guide," 3rd ed., 1997, para. 8.5.1. http://www.dau.mil/pubs/pdf/alg1.pdf (accessed May 4, 2006).

64 DSMC, "Acquisition Logistic Guide," para. 8.5.1.1.

b. Reliability, Maintainability, and Availability (R,M&A)

R,M&A issues must be considered from the very beginning of the lifecycle of the weapon system. They must meet operational requirements and contribute to the reduction of TOC.

(1) Reliability. It is the probability that weapon system will perform its functions in a satisfactory manner for a specific period of time, or during the duration of a mission under stated conditions. Reliability function may be expressed by the quotation:

$$R(t) = 1 - F(t),$$

where F(t) is the probability that system will fail by time t.[65]

The failure rate is defined as a number of failures per measure of unit life.

$$Failure\_rate = \frac{1}{MTBF},$$

where MTBF is Mean Time Between Failures.

Additionally we can distinguish two components of reliability:

- Mission Reliability is the probability that the weapon system will perform functions essential to accomplish a mission, under a certain period of time and under stated conditions.
- Logistic Reliability is the probability that no corrective maintenance will be performed until completing the scheduled mission profile.

(2) Maintainability. Maintainability is the probability that the weapon system will be retained in, or restored to an operational condition in a certain period of time if the prescribed procedures and resources are used. Maintainability is the characteristic of a weapon system which has been already fielded. It also indicates the maintenance required to keep that system in operational status. This characteristic is measured by Mean Time to Repair. A mathematic statement of that characteristic is expressed by the Mean Corrective Maintenance Time equation:

65 Benjamin S. Blanchard, *Logistic Engineering and Management*, 6th ed. (Upper Saddle River, NJ: Pearson Prentice Hall, 2004), 47.

$$\overline{Mct} = \frac{\sum_{i=1}^{n} Mct_i}{n}$$

where Mct_i is total active corrective maintenance cycle time for each maintenance action, and n is the sample size.

Maintainability is one of the factors which determine life cycle costs. Maintenance costs are affected by the decisions made during the early stages of the weapon system life cycle. Considering maintenance cost, the following criteria may be applied when developing a weapon system:

- Cost per maintenance action ($/MA)
- Maintenance cost per system operating hour ($/OH)
- Maintenance cost per month ($/month)
- Maintenance cost per mission or mission segment ($/mission)
- The ratio of maintenance cost to total life cycle cost.[66]

(3) Availability. Availability is defined as a probability that a weapon system is in operable state at a beginning of the mission when the mission is called at a random point in time. That parameter reflects the readiness of the system. [67] It is expressed by quotation:

$$Availability = \frac{Up\ time}{Up\ time + Down\ time}$$

Availability should be measured accordingly to the specific mission. The Operational Availability (Ao) is a very important indicator of system readiness. Ao is expressed by the following mathematical relationship:

$$A_o = \frac{MTBM}{MTBM + MMT + MLDT}$$

where

66 Blanchard, *Logistic Engineering and Management*, 72.

67 DSMC, "Acquisition Logistic Guide," para. 10.3.2.5.

- MTBM – Mean Time Between Maintenance – mean operating time plus mean standby time in operational conditions
- MMT – Mean Maintenance Time – includes mean time for corrective and preventive actions
- MLDT – Mean Logistics Down Time – combination of the logistics delays plus administrative delays

c. *Achieving Affordable System Operational Effectiveness (SOE)*

The SOE concept explores relationships between system performance, availability, process efficiency, and life cycle cost. That matrix provides the context for the PM to make "trades". The SOE requires involvement of every organization and individual engaged in the management of the weapon system. The SOE approach may be applied during the development of the new system as well as to modernization of a fielded system. The SOE concept is composed of the following elements (Figure 15):

- System Performance – designed system capabilities and functions
- Technical Effectiveness – a balance between system performance and system availability.
- System Availability – includes reliability, maintainability, supportability (discussed above), and productivity. Productivity is the degree to which the design of the weapon system facilitates timely, affordable, and high quality manufacture, assembly and delivery of the weapon system.
- Process Efficiency – reflects how well the system may be produced, operated, and maintained.[68] It also reflects the degree to which the logistic infrastructure and footprint have been reduced to ensure an agile, deployable, and operationally effective system.

68 DAU, "Defense Acquisition Guidebook," para. 5.2.2.

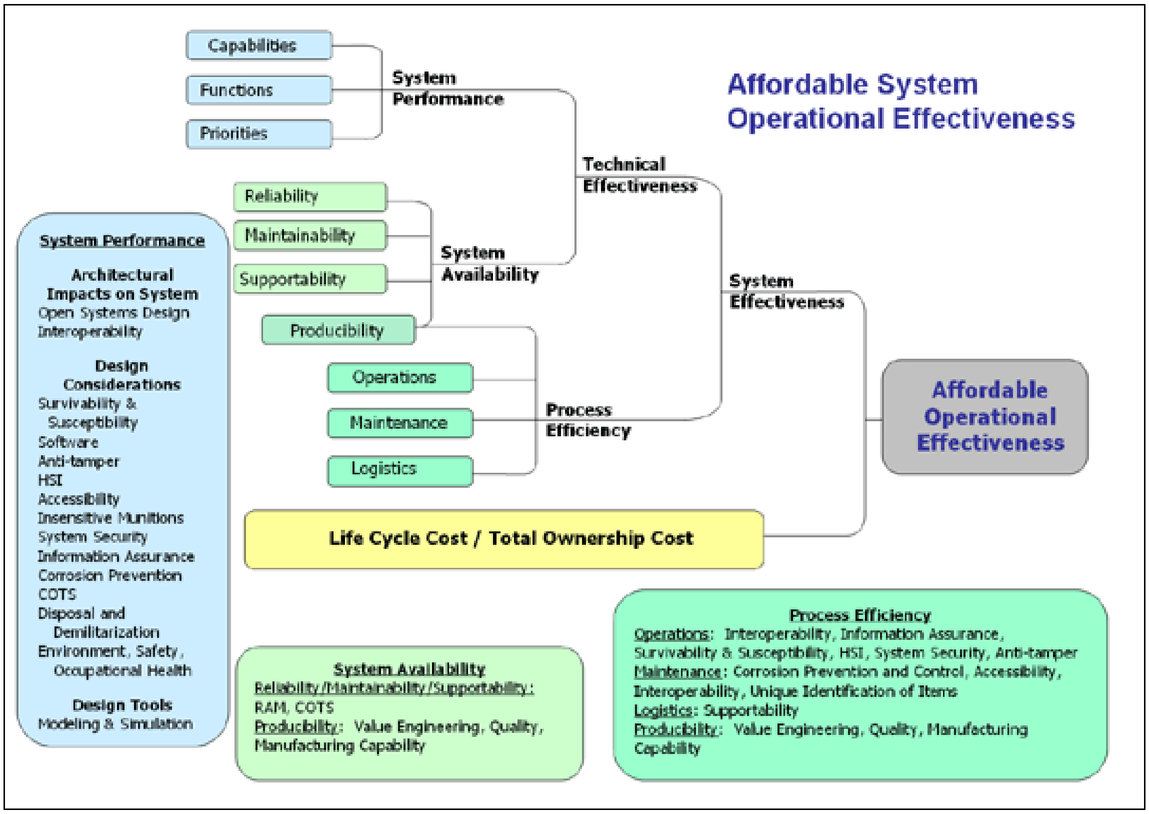

Figure 15. Affordable System Operational Effectiveness (From: DAU, "Defense Acquisition Guidebook" (2004) paragraph 5.2.2).

2. Performance Based Logistics (PBL)

Performance Based Logistics is the DoD's approach to product support implementation.

> [The] PM shall develop and implement performance based logistics strategies that optimize total system availability while minimizing cost and logistic footprint. Sustainment strategies shall include the best use of public and private sector capabilities through government/industry partnering initiative, in accordance with statutory requirements.[69]

PBL uses performance based acquisition strategies which are developed, refined and implemented during the acquisition program or as a result of assessment support alternatives in a fielded system. The essence of PBL is to buy performance, unlike the traditional approach of buying individual parts and repair actions. PBL does not favor either commercial or governmental providers. The decision is based upon best value

69 DoD, DoDI 5000.1, Enclosure 1.17.

determinations, the best mix of public and private capabilities and strategies, infrastructures, skills, and performance to meet weapon system requirements. This is the main objective of PBL and changes the approach to logistics: the PM does not tell provider how to do it but the PM will tell what he/she wants.[70] That approach allows the best private business practices to enter the public sector.

Buying performance outcomes is common to every PBL practice, in theory. However, to meet specific requirements, PBL must be tailored to the final product which is ready to be fielded. Application of PBL to, for example, Fighter Aircraft and Armed Fighting Vehicles may look similar in concept, but will be completely different in application. That is why the application of PBL to fielded systems may have a variety of shapes and forms.

Because PBL is defined as a strategy for buying performance, it is important to set metrics to measure that performance. These allow the PM to select the component to buy with the highest value for the weapon system. In order to establish metrics, the PM must work with the users, who have potential capability to define requirements of the weapon system. By establishing accurate requirements, PBL has a higher probability to be implemented in the most efficient way.

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[70] Defense Acquisition University, "Performance Based Logistics: Program Managers Product Support Guide," (Fort Belvoir, VA: Defense Acquisition University Press, 2005), para. 2.2., http://handle.dtic.mil/100.2/ADA435149 (accessed March 26, 2006).

Figure 16. Spectrum of PBL Strategies. (From: Acquisition Community Connection, PBL Toolkit – Allocate Work, https://acc.dau.mil/simplify/ev_en.php?ID=29846_201&ID2=DO_TOPIC).

The top five PBL top-level metric objectives are defined in the Under Secretary of Defense Memorandum:[71]

- Operational Availability – the percent of time a weapon system is available for a mission
- Operational Reliability – a weapon system reliability measurement to meet mission's needs and objectives (objectives may by sortie, launch, destination, et cetera. Cost Per Unit Usage – total operating cost divided by unit performance measurement for a given weapon system
- Logistic Footprint – government or contractor presence while deploying the weapon system. It includes inventory, equipment, facilities, personnel, real estate, transportation, and others Logistic Response Time – elapsed time for the logistics system after demand signal has been received.

Recent examples of PBL implementation in already fielded systems show that PBL is an effective technique to optimize total system supportability (see Appendix I).

[71] DAU, "Performance Based Logistics," para 2.2.

C. CONCLUSION

The decision to acquire and field a modern weapon system is multidimensional. It will determine military capability; it is always connected with the problems of resource allocation and making trade-off decisions while the system is developed. That is why Total Life Cycle System Management is essential – from the decision to create requirements to removal from service. TLCSM begins when the requirements are approved. It continues through the Concept & Technology Development phase, System Development & Demonstration phase, Production & Deployment phase, and Operation & Support phase. During these phases, the appropriate management of the costs of the weapon system will result in the most affordable Total Ownership Cost. Failure in TLCSM will result in TOC increase (and decrease in affordability). To better understand that concept, our next chapter will focus on TOC - emphasizing the O&S cost which consists of 78 percent of overall TOC.

IV. OPERATING AND SUPPORT (O&S) COSTS

Typically, the primary concern for countries acquiring a new weapon system from arms exporters is the initial acquisition cost. Not enough attention is given to all Life Cycle Costs (LCC) in general, and to Operating and Support (O&S) costs in particular. The United States handled its own defense acquisition process in this way before the 1980s. The subject of estimating O&S costs gained the attention of government officials and lawmakers during the 1980's when they realized that "roughly half of the budget for the DoD pays for annual O&S costs."[72]

As mentioned in the preceding chapter, the most important element of a successful strategy to contain O&S costs is ensuring that fielded systems are supportable. Reducing O&S costs is as important as reducing acquisition costs. This chapter provides a brief overview of how to assess O&S costs by means of Life-Cycle Cost Analysis (LCCA). It also summarizes the foundational literature used in this research to establish a Cost Estimating Relationship (CER) for LCC and O&S. In addition, methods and outcomes from previous research regarding O&S are presented.

A. LIFE-CYCLE COST / TOTAL OWNERSHIP COST

Life-Cycle Costs (LCC) and Total Ownership Cost (TOC) constitute the main concepts used by DoD for reliability and maintenance for complex weapon systems in defense. DoD Directive 5000.1, *The Defense Acquisition System* and DoD Instruction 5000.2, *Operation of the Defense Acquisition System* (further referred as DoD 5000.2), make reference to these concepts. A basic attribute of a fighter aircraft is the ability to provide high performance over a long service life but with significant periods of downtime and high costs maintenance.

The Defense Acquisition Guide defines LCC and TOC; it mentions that they "are similar in concept, but significantly different in scope and intent."[73] The LCC of a

72 Congress of the United States, "Operation and Support Costs for the Department of Defense" (Washington D.C.: Congressional Budget Office, July 1988), http://ftp.cbo.gov/ftpdoc.cfm?index=5542&type=1 (accessed March 20, 2006).

73 DAU, "Defense Acquisition Guide," para. 3.1.1.

defense program includes Research and Development (R&D) costs, Investment costs, Operating and Support (O&S) costs and Disposal costs over the entire life-cycle. In addition to cost elements included in LCC, TOC consists of other costs associated with, for example, infrastructure and business processes that are not necessarily attributable to the weapon system program. Thus, LCC and TOC concepts are similar, but TOC is more comprehensive than LCC.

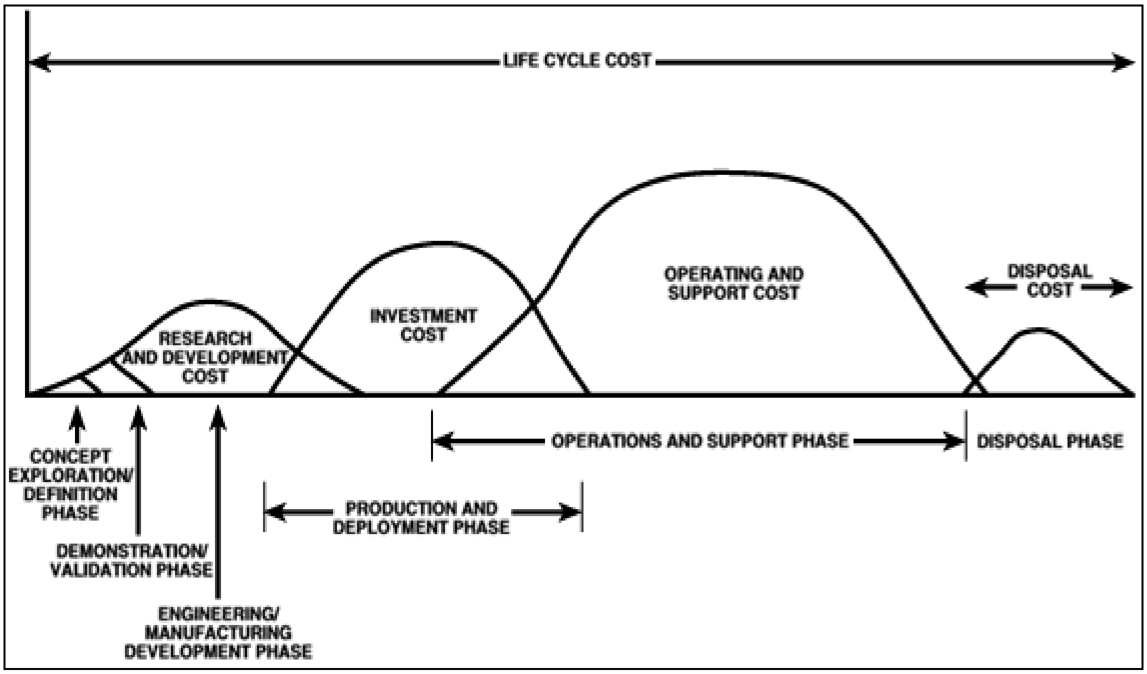

Figure 17. Program Life Cycle (Illustrative) (From: Office of the Secretary of Defense, Cost Analysis Improvement Group, "Operating and Support Cost-Estimating Guide" (May 1992)).

In condensed form, LCC includes the acquisition and ownership costs. Seldom affirms that "*ownership costs* – those of operation and support or maintenance - have frequently far exceeded procurement costs."[74] This fact has been proven by much empirical data. For instance, Table 1 provides a breakout of the costs incurred during the key program phases for two different weapon systems: a fighter aircraft (F-16) and a fighting vehicle (M-2).

[74] Robert M. Seldon, *Life Cycle Costing: A Better Method of Government Procurement*, (Boulder, CO: Westview Press, 1979), 1.

Table 1. Percentage of Life-Cycle Costs Incurred in Various Program Phases.[75]

Weapon System		R&D	Investment	O&S
F-16	Fighter Aircraft	2%	20%	78%
M-2	Fighting Vehicle	2%	14%	84%

In addition, other authors suggest that both LCC and TOC need to be considered holistically because all the costs are interrelated.[76] The components of LCC must be considered in all acquisition decisions of a major weapon system. Accordingly, the USAF has incorporated the LCC concept to ensure that ownership cost objectives are established and that LCC is considered from the initial phases of the acquisition programs.[77]

An LCCA is particularly important to determine the cost-effectiveness of a system in terms of O&S. In addressing this issue, the role of LCCA is to capture all the costs and to create visibility as conveyed through the "iceberg effect" showed in Figure 18.[78] In addition, LCC analysis is used to evaluate alternative support policies for maintenance of the weapon system. The following section introduces the concepts of LCCA which represent the practical application of LCC/TOC concepts.

[75] OSD, GAIG, "Operating and Support Cost-Estimating Guide," 2-3.

[76] Michael W. Boudreau and Brad R. Naegle, "Reduction of Total Ownership Cost," NPS Acquisition Program, 25, http://www.nps.navy.mil/gsbpp/ACQN/publications/FY03/AM-03-004.pdf (accessed at April 11, 2006).

[77] Aeronautical Systems Center, "Life Cycle Cost Management Guidance for Program Managers," (Wright-Patterson AFB, OH, January 1994).

[78] Blanchard, *Logistic Engineering and Management*, 81.

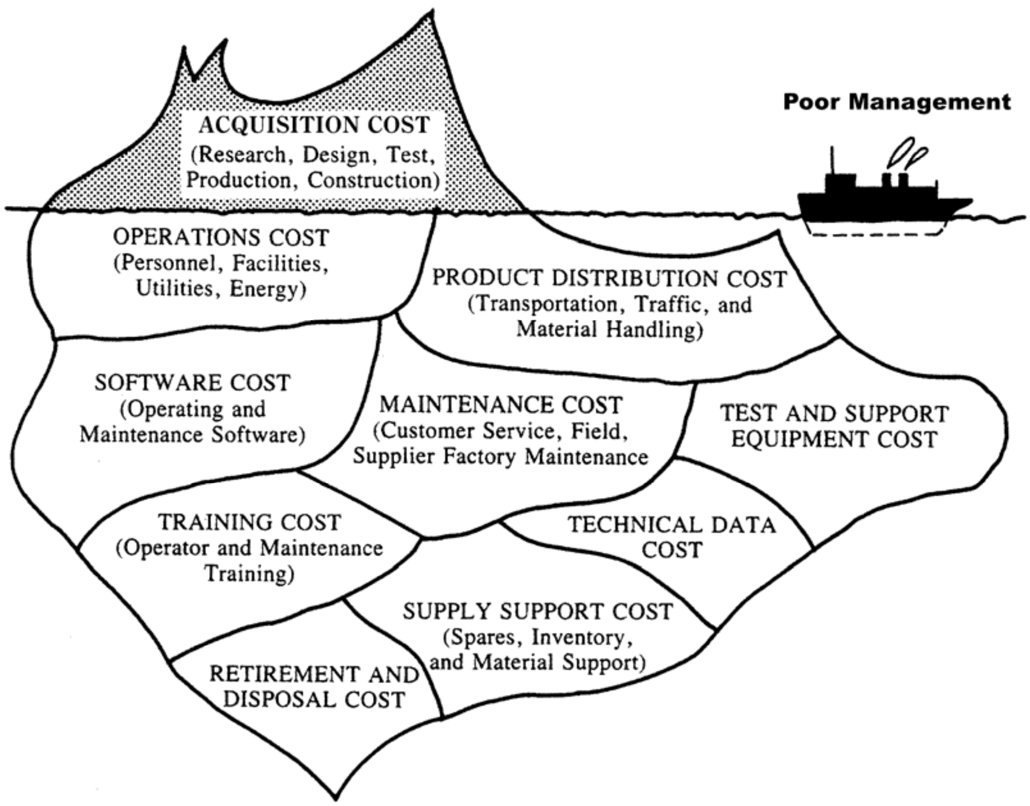

Figure 18. Total Visibility Cost (From: Blanchard, Logistic Engineering and Management, 81).

1. Life Cycle Cost Analysis (LCCA)

The LCCA is a sequence of analytical steps for evaluating alternative designs in terms of life-cycle costs. Blanchard presents an extended life-cycle cost analysis.[79] Based on his model, an LCC cost estimate generally involves the use of a three-step procedure. In the first phase, the relevant categories of costs are identified. During the second step, a Cost Estimating Relationship (CER) is derived. Finally, the necessary data are collected from reliable databases and adjusted for inflation and other factors. The same steps should be followed in assessing the O&S costs, a component of LCC.

a. Cost Breakdown Structure

In the first step, the cost analyst should develop a Cost Breakdown Structure (CBS). In other words, costs may be broken down into logical, definite

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[79] Blanchard, *Logistic Engineering and Management*, 465.

subdivisions, considering the functional activity area or the major elements of the system. According to Blanchard,[80] the CBS ought to exhibit the following basic characteristics:

- all costs should be considered and identified in the Cost Breakdown Structure
- all cost categories should be well defined; there should not be any doubling or omissions
- the cost structure and categories should be coded in such a manner to allow for in-depth analysis of certain areas of interest while covering other areas with gross estimates
- the CBS should be directly compatible with the Work Breakdown Structure (WBS)[81] and with management accounting procedures used in collecting costs
- the cost structure should allow for the identification of specific work packages that require close monitoring

In developing a CBS one could follow two approaches: top-down or bottom-up. The top-down approach is employed with the purpose of determining the initial allocation of cost as a Design-to-Cost (DTC) requirement. The second technique, bottom-up, which will be used in our project, implies successive collection and summarizing of costs.

As previously mentioned, LCC is typically divided into four phases: research and development, procurement, O&S, and disposal phase. This division is used mainly for cost estimating purposes. The following descriptions provide a brief summary of the costs associated with each life-cycle phase:

- Research and Development costs start with program initiation at the conceptual phase through the end of engineering and manufacturing development. R&D includes costs for feasibility studies, modeling, tradeoff analyses, engineering design, development, fabrication, assembly and test of prototype hardware and software, system test and evaluation, developing support equipment, and documentation
- Production or Procurement includes costs associated with producing or procuring the physical parts of the system, and costs associated with initial logistic support requirements (i.e., support equipment, training, data, initial spares, and facilities)

[80] Blanchard, *Logistic Engineering and Management*, 467.

[81] The concept of Work Breakdown Structure (WBS) will be developed later.

- Operation and support costs are incurred when systems are deployed and fielded. They include costs of sustaining operation, personnel and maintenance, consumable and reparable parts, and system modification
- Retirement and Phase-out costs are associated with deactivating or disposing of a materiel system at the end of its useful life. Disposing of a materiel system can result in additional costs or a salvage value. These costs are normally insignificant compared to the total LCC. In some cases, disposal cost may be avoided by making the system available for sale

Program phases overlap considerably; in particular, R&D may not be completed before procurement begins. Cost is a major consideration of system management and must be addressed in making decisions during all life-cycle phases. Having generated a CBS, the next step is to estimate the costs of each category. The paragraphs below summarize the key features of the three estimating techniques used in LCC assessments.

Undoubtedly, several aspects of TOC are not controlled or even influenced by acquisition managers. For that reason, program cost estimates are normally focused on life-cycle cost or its elements. Situations where cost estimates support the acquisition system include affordability assessments, analyses of alternatives, cost-performance trades, and establishment of program cost goals. In addition, more refined and discrete life-cycle cost estimates are used within the program office to support internal decision-making such as evaluations of engineering changes or competitive source selections. The following section presents relevant definitions of costs and summarizes the key features of the estimating techniques used in LCC assessments.

The taxonomy of costs comprises different categories of costs. The definitions of costs provided below will serve to illustrate the concept of LCC and may help in LCCA. During LCCA, the analyst's objective is to capture all costs and to create desired visibility.

- First or Investment Cost - cost elements that do not recur after the system is acquired. They may include design and development costs, test and evaluation costs, unit purchase price, and installation and training costs. In some instances, these first costs are very high, exceeding the capabilities of the buyer.

- Fixed Cost - cost elements that are independent of variations in the level of operational activity; that is, are not related to the amount of system usage. Depreciation, maintenance, insurance, interest on invested capital, research, and part of administrative expenses are good examples of such costs. Fixed costs are usually difficult to change in the short run.
- Variable Cost – a group of costs which are related in some way to the level of operational activity. These costs are normally associated with direct labor and material, fuel, energy, and so on; they may include direct and indirect costs.
- Direct Cost - the cost elements most easily perceived. They are a direct result of system utilization. Taking an airplane as an example, the costs of fuel and the salary of mission personnel would be direct costs of the flying activity.
- Indirect Cost - generally, these costs are difficult to evaluate, because they are not directly related to the operation of the system. Looking at the previous example, expenses with tires and maintenance personnel would be indirect costs.
- Sunk or Past Cost – a group of costs that were already incurred in the past and cannot be altered by any future action. Although they may be significant in some circumstances, they should influence the decision making process only to the extent that they may serve as a basis for predictions.

Given the categories of cost, it is appropriate to estimate all applicable costs for each of the categories in the CBS and for each year of the life-cycle.[82]

2. Estimating Methods of Costs

The Society of Cost Estimating and Analysis (SCEA) provides the following definition of cost estimating: "The art of approximating the probable cost or value of something based on information available at the time."[83]

As summarized in the "AoA Handbook",[84] there are both formal and informal methodologies available to the analyst to estimate cost. There are three primary formal

82 Blanchard, *Logistic Engineering and Management*, 81.

83 Society of Cost Estimating and Analysis, "Glossary," http://www.sceaonline.org/prof_dev/glossary-c.cfm (accessed April 13, 2006).

84 Air Force Materiel Command, Analysis Handbook, A Guide for Performing an Analysis of Alternatives (AoA) (Kirtland AFB, NM: Office of Aerospace Studies, February 2002), http://www.oas.kirtland.af.mil/AoAHandbook/index.html (accessed April 14, 2006).

approaches as follows: (a) the parametric estimating technique, (b) engineering build-up (bottom-up or grass roots), and (c) the analogy technique. The description and limitations of each technique is discussed below.

a. Parametric Method

The parametric method consists of one or more Cost Estimating Relationships (CERs) to develop projections of weapons costs using simple mathematical equations and logic. Developing CERS will be discussed in detail in a separate section of this chapter. A CER is an equation that relates one or more characteristics of a system to some element of its cost, where cost is related to one or more variables (i.e. volume, weight, or power). Since CERs are based on actual program cost history, they reflect the impacts of system growth, schedule changes, and engineering changes.

The technique is used to measure and/or to estimate the cost associated with the development, manufacture, or modification of a specified end item and the measurement is based on the technical, physical, or other end item characteristics. This method is often used for training, data, peculiar support equipment, and systems engineering and program management. Factors and ratios allow the estimator to capture a large part of an estimate with limited descriptions of both: the historical database used to develop the factor and the program to be estimated. The use of a factor or ratio relating the cost of one entity to another is considered a form of parametric estimating (i.e. training and development costs might be estimated as 20% of production costs).

Given the nature of the method, it appears appropriate at the early stages of a program, when there is limited program information and technical definition. Less visibility might be seen as main limitation, especially when costs are captured at a very high level.

b. Engineering Build-Up Approach

The engineering build-up approach is performed at a detailed level of the WBS. According to this technique, cost can be estimated for basic tasks (such as engineering design, tooling, fabrication of parts, manufacturing engineering, and quality control), but also for materials.

Engineering estimation produces detailed "bottom-up" estimates. The objective is to determine as accurately as possible all of the actions that occur in the "real world," which usually involves breaking the system into sub-components, each cost being estimated separately.[85]

Among disadvantages of this approach, the following are the most important: it is time-consuming, as the modeled processes must be well understood, and it requires detailed, accurate data.

c. Analogy Method

The analogy method uses actual costs from a similar program and adjusts for the new program's complexity and technical or physical differences to derive the estimate.

This method is normally used early in a program cycle when there is insufficient actual cost data to use as a basis for a detailed approach. Engineering assessments are at the core of the approach, as they are necessary to ensure the best analogy has been selected and proper adjustments are made. On the other hand, they can also be a limiting factor.

Thus, the analogy estimation is widely used as it avoids the weaknesses of the CERs. Historical databases available through the Visibility and Management of Support Costs (VAMOSC) system may be used to identify the operating costs of weapon systems. It also relies heavily on informal approaches that can be used when formal techniques are not practical, such as experts' opinions.[86]

A fourth technique, **extrapolation** from **actual costs**, is described by the DoD 5000.2**.** The actual cost method uses cost experience or trends (from prototypes, engineering development models, and/or early production items) to project estimates of

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[85] OSD, "Operating and Support Cost-Estimating Guide," 3-11.

[86] Ibid.

future costs for the same system. A key possible mistake to be avoided is using contract prices, which are associated with profitable ventures, as a substitute for actual cost experience.[87]

3. Developing Cost Estimating Relationships (CER's)

A short but comprehensive definition of Cost Estimating Relationships (CERs) is offered by "Parametric Cost Estimating Handbook". Thus, CERs are "*mathematical expressions relating cost as the dependent variable to one or more independent cost driving variables.*"[88]

CERs are the key tool used in all phases involved by estimating program costs. Thus, CERs can be used as the primary basis for an estimate during the validation phase (because there is insufficient system definition to use anything else), or in later phases of estimating as a cross check of another estimating procedure. Once valid CERs have been developed, then parametric cost modeling can proceed.

Given the above, proper CER development and application rely heavily upon mastering certain mathematical and statistical techniques. They also rely on estimating, meaning that probability plays a crucial role in predicting the actual cost of the project. Sound statistical concepts and techniques constitute the basis of the development of any valid CER.

DoDI 5000.2 mentions that system definition typically includes Work Breakdown Structure (WBS) defined as a "hierarchy of product-oriented elements – hardware, software, data and services – that collectively comprise the system to be developed or produced."[89] The WBS provides the framework for a series of activities that cover all the steps involved by the program – from program planning to status reporting, including cost estimating, resource allocation, performance measurement, and technical assessment.

[87] DoD, DoDI 5000.2, art. 3.7.3.

[88] Parametric Estimating Initiative Steering Committee, "Parametric Cost Estimating Handbook," Bill Brundick eds., 38, http://www1.jsc.nasa.gov/bu2/PCEHHTML/pceh.htm (accessed February 20, 2006).

[89] DoD, DoDI 5000,2, art. 3.7.1.

As observed in the "Parametric Cost Estimating Handbook," consistency in system engineering and project management is directly correlated with the accuracy of each of the WBS elements and cost estimating capability on the one hand, and (even more important), with the resulting cost model on the other hand.

The usefulness of a CER is dependent upon the soundness of the database from which it is developed and the appropriateness of the CER to what is to be estimated. While assembling the database is especially important, it is a difficult and time-consuming activity. The lack of appropriate databases is a primary cause for there being only a small number of valid CERs. There is no agreement among specialists regarding the primacy of either the development of a good database or hypothesizing what the CER should be. In either case, the analyst must accomplish a series of activities.

First, the analyst hypothesizes a series of logical estimating relationships, which may be linear or curvilinear. The second activity consists of assembling a database**:** as noted, the data problem is fundamental. Considerable time and effort is dedicated to collecting data, adjusting that data to ensure consistency and comparability, and providing for proper storage of information so that it can be rapidly retrieved when needed.

In any case, developing an estimating relationship involves discussions with engineers to identify potential cost driving variables, scrutiny of the technical and cost proposals, and identification of key cost relationships.

Once the database is developed and hypothesis is determined and tested, the next activity to be accomplished by the analyst is to mathematically model the CER using linear and curvilinear forms, such as the graphical method and the Least Squares Best Fit (LSBF) or the linear regression model method, all of which are provided by many statistical PC packages.

In addition, application of the CER is necessary to forecast future costs or to cross check an estimate done with another technique. In this respect, it is important to observe the difference between using either generic CERs or CERs which have been built for a specific forecast. Obviously, the second category may be used with far more confidence than the first one. However, each type has both strengths and weaknesses.

The following strengths of the CERs are the most cited in the literature: a) they are quick and easy to use, being based on an equation and the required input data; b) CERs can be used with limited system information, and thus are especially useful in the R&D phase; c) a CER is a statistically sound predictor, if derived from a sound database, so that it is a reliable indicator of further estimates.

The following are among the major weaknesses of the CERs. First, they are sometimes too simplistic to forecast costs; if available, another estimating approach should be selected. Second, database-related problems may impact negatively on the applicability of a particular CER. In this respect, the user has the responsibility to validate the purpose of the CER estimates, the quality of data used, and how they were normalized.

The modeling uncertainties translate into "risk" of producing an unrealistic cost estimate within a given percentage of the actual project cost. Such uncertainties can be grouped into two major categories, which are described below.

The first category of risk refers to the uncertainty of any organization to perform as planned due to unexpected resource or scheduling delays in the scope of effort to produce the design, prototype, or product. Given the causes attached, this sort of uncertainty can be controlled through specifications in the scope of work agreed between the customer and contractor, which would result in a decrease in the amount of contract and engineering change proposals (CCE/ECPs) and unnecessary rework.

The second category refers to uncertainty associated with the development and thus usefulness of any cost model, which includes: a) uncertainty associated with omission of a key cost driver; b) misspecification of the form of the model equation; c) modeling limitations associated with a lack of data to validate the cost model, and, d) lack of data consistency across multiple project databases.

In order to reduce the risks above, appropriate measures can be used to keep uncertainty within reasonable limits. For instance, uncertainty associated with omission of key cost drivers is addressed through development of historical cost data by product line, defined as WBS, and systematic understanding of the types of costs associated with development, prototype, and production programs. The avoidance of the misspecification of the model equation requires careful review of in-house and available industry data, in order to establish the basis of the model. The use of additional relevant data would reduce the uncertainties attached to the third modeling limitations. In this respect, as the literature emphasizes, cost modeling of a new technological or programmatic area usually involves lack of data. Fourthly, risks associated to data consistency can be diminished by using WBS cost elements which are standardized across projects.[90]

In conclusion, knowledgeable use of Life-Cycle Cost can be crucial in assuring affordability of fielded systems. The challenge to the acquisition logistician is to implement these concepts actively and aggressively through participation in the various Integrated Process Teams (IPTs). One task for the lead acquisition logistics manager is to provide support for the O&S cost estimate, the largest component of LCC.

B. OPERATING & SUPPORT (O&S) COSTS

O&S costs have a double role in conducting the life cycle management of a weapon system. First, O&S costs represent a major part of the LCC, and are therefore important in assessing affordability. Second, as a RAND study explicitly mentions, "O&S costs reflect the commitment of a military establishment to readiness."[91] O&S cost information could support a design-to-cost program and management reviews during the first two phases of life cycle, assist in choosing between alternate systems, and support budget estimates. Therefore, O&S cost estimates have taken on greater importance in acquisition decisions and in resource planning.

O&S costs have a number of distinctive characteristics that single them out from other factors of LCC. O&S costs occur annually, over a long time-span. Therefore, cost analysts have to predict trends for different types of costs such as personnel or material costs. This endeavor is particularly difficult in today's context and it makes the O&S

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90 PEISCP, "Parametric Cost Estimating Handbook," 35-37.

91 Gregory G. Hildebrandt and Man-bing Sze, *An Estimation of USAF Aircraft Operating and Support Cost Relations*, (Santa Monica, CA: The RAND Corporation, May 1990), 1.

estimates more sensitive to assumptions than other types. The next sections will present some of the complexities of O&S estimating, O&S cost breakdown structure, and O&S cost drivers.

1. O&S Cost Breakdown Structure

Stewart points out that because weapon systems must often serve a long lifetime and because the maintenance, operation, and repair of many weapon systems exceed their initial acquisition costs, the DoD put a considerable emphasis on analysis and exposure of LCC.[92]

O&S costs are those incurred for peacetime operations and maintenance of a system throughout its life cycle. O&S costs comprise expenses with fuel, lubricants, and repair parts and their related maintenance, plus the costs associated with modifications. For a typical weapon system O&S costs represent 70% or more of the system LCC.[93] Figure 19 illustrates a typical distribution of LCC.

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[92] Rodney D. Stewart, *Cost Estimating*, 2nd ed. (New York: John Wiley and Sons, 1991), 201-202.

[93] United States General Accounting Office, "Air Force Operating and Support Costs Reductions Need Higher Priority," (Washington D.C.: National Security and International Affairs Division, August 2000), http://www.gao.gov/archive/2000/ns00165.pdf (accessed March 26, 2006).

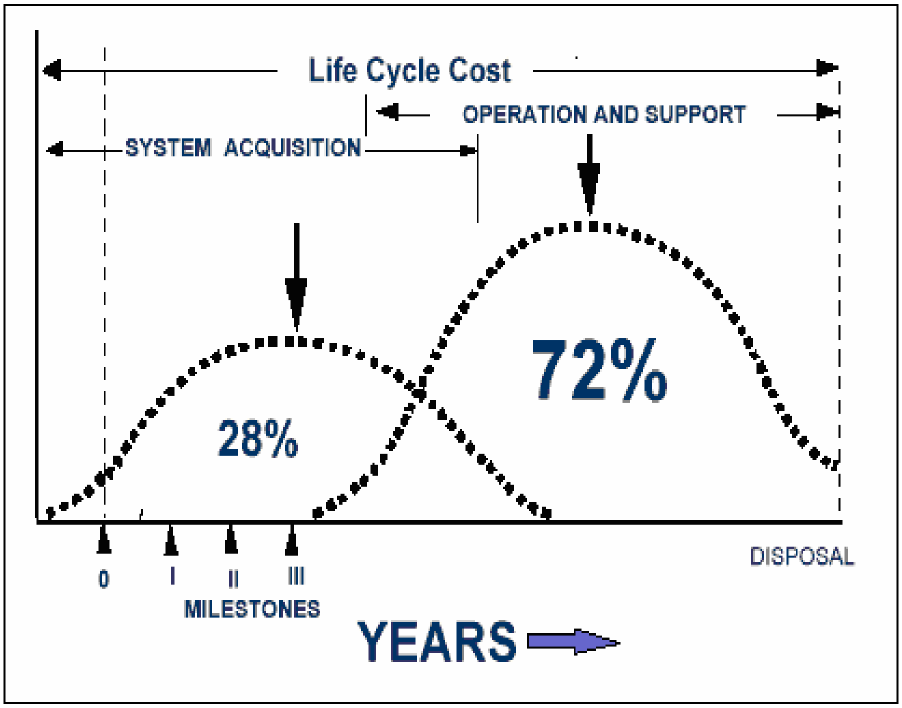

Figure 19. Nominal Life-Cycle Cost of Typical 1980 DoD Acquisition Program (From: United States General Accounting Office, "Air Force Operating and Support Cost Reductions Need Higher Priority," (August 2000)).

While DoD Handbook 881 provides a common framework for procurement cost estimates, the Operating and Support Cost-Estimating Guide provides a standardized cost element structure for O&S cost estimates. Regarding O&S costs, the 1992 version of the Guide has seven major cost elements: mission personnel, unit-level consumption, intermediate maintenance (external to unit), depot maintenance, contractor support, sustaining support, and indirect support. A schematic representation of O&S cost breakdown structure is presented in Figure 20.

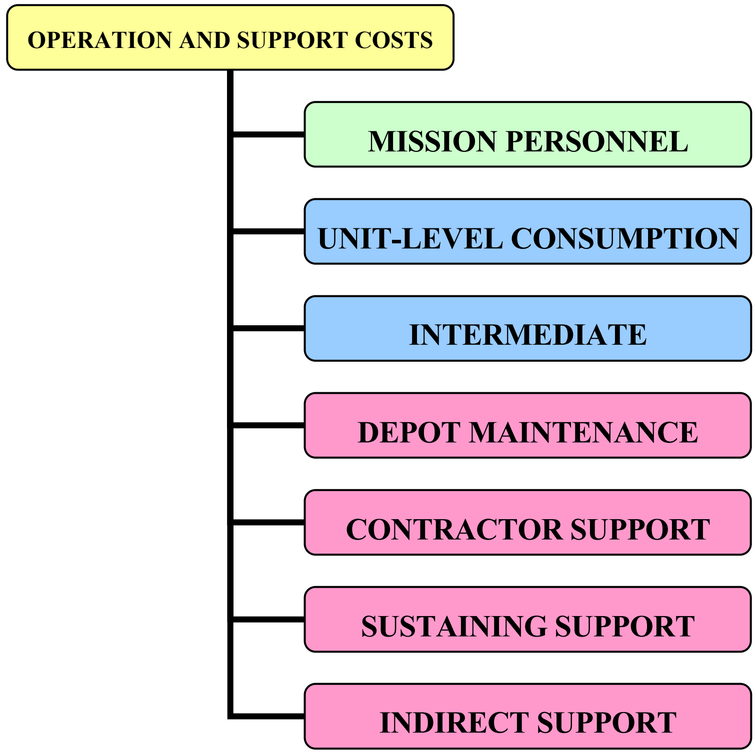

Figure 20. O&S Cost Breakdown Structure.

A detailed Cost Breakdown Structure for an aircraft, as offered in the 1992 Operating and Support Cost-Estimating Guide, is presented in Appendix I. The new version of the Operating and Support Cost-Estimating Guide (2002 draft) proposes a generic O&S cost-estimating structure with six cost elements. The CBS is designed to capture as many relevant costs as practical within the O&S phase and is essential to LCC analysis.

2. O&S Cost Drivers

Since O&S costs typically exceed both development and investment costs over the functional life of a system, the O&S costs are a primary concern in assessing the TOC.

O&S cost estimating may be a difficult endeavor because the costs in this category are affected by various considerations. In general, there are four major types of factors which have to be considered: the systems technical characteristics, operating concept, maintenance concept, and relevant cost elements (cost drivers).[94] The analyst should determine the quantitative and qualitative influence of these factors on the system being analyzed.

a. System Technical Characteristics

The analyst has to determine the system characteristics that impact O&S costs, such as:

- design and physical parameters such as weight, size, design approach, and degree of modularity
- required performance characteristics such as reliability and maintainability, availability, redundancy levels, etc
- required interfaces with other systems, equipment, and support equipment
- required level of technology.

Since performance characteristics (reliability, maintainability) and physical characteristics (size, weight, etc.) are strongly related to O&S costs, they are generally used in the O&S cost estimation. For example, to forecast the frequency of maintenance actions that will take place and to predict the duration of repair actions, the cost analyst uses Mean-Time-between-Failure (MTBF) and Mean-Time-to-Recovery (MTTR) measures of system reliability and maintainability, respectively.

b. Operating Concept

The operating concept is closely related to the system usage rate. An increase or decrease in usage has a corresponding in O&S costs. The majority of O&S cost elements vary linearly with usage. In the case of an aircraft, fuel, spare parts, and maintenance and repair costs are directly related to the "op tempo" (operational tempo, generally hours per aircraft per month). Knowing the op tempo, the analyst can properly adjust historical data from analogous systems, or plan for irregular supplementary usage. In addition, deployment concepts may affect everything from the replacement rate of support equipment that needs to be replenished to numbers of unit personnel.

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[94] Federal Aviation Administration, Life Cycle Cost Estimating Handbook, para. 13.4.2, http://www.faa.gov/asd/ia-or/lccehb.htm (accessed April 12, 2006).

c. Maintenance Concept

In the past, system technical requirements related to the accomplishment of the mission. Items such as principal equipment and mission personnel were the elements which got analysts' attention. In newer practices, system maintenance has gained more consideration because resources are diminishing, and there is a requirement to extend the life cycle of operational systems. Therefore, as Blanchard points out, the prime mission-oriented segments and support capability have to be considered on an integrated basis. As a result, a maintenance concept must be developed to state how the system is to be supported and what the effects are on design.[95]

The maintenance concept describes how the system will be maintained and is documented in the maintenance plan, which details procedures and resources for support of the system. In Blanchard's view, the maintenance concept includes: maintenance levels to be used with major functions accomplished at each level, repair policies, organizational responsibilities, maintenance support elements, effectiveness requirements, and environment.[96]

A major component of the maintenance concept definition is the structure of maintenance levels to be used in support of the system. Maintenance, both corrective and preventive, may be accomplished at the site where the system is used (organizational maintenance), at specialized organizations (intermediate maintenance) and/or at a depot or contractor's facilities (depot level). For example, a hypothetical maintenance concept is presented in Figure 21. The figure depicts the levels of maintenance and other effectiveness factors such as MTBF and logistics flow times.

The number of levels of maintenance affects the O&S cost estimate. Moreover, the type of maintenance resources required is important. In summary, the maintenance concept has to be considered in both the design and costs estimating processes.

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95 Blanchard, *Logistic Engineering and Management*, 139.

96 Ibid., 140 – 144.

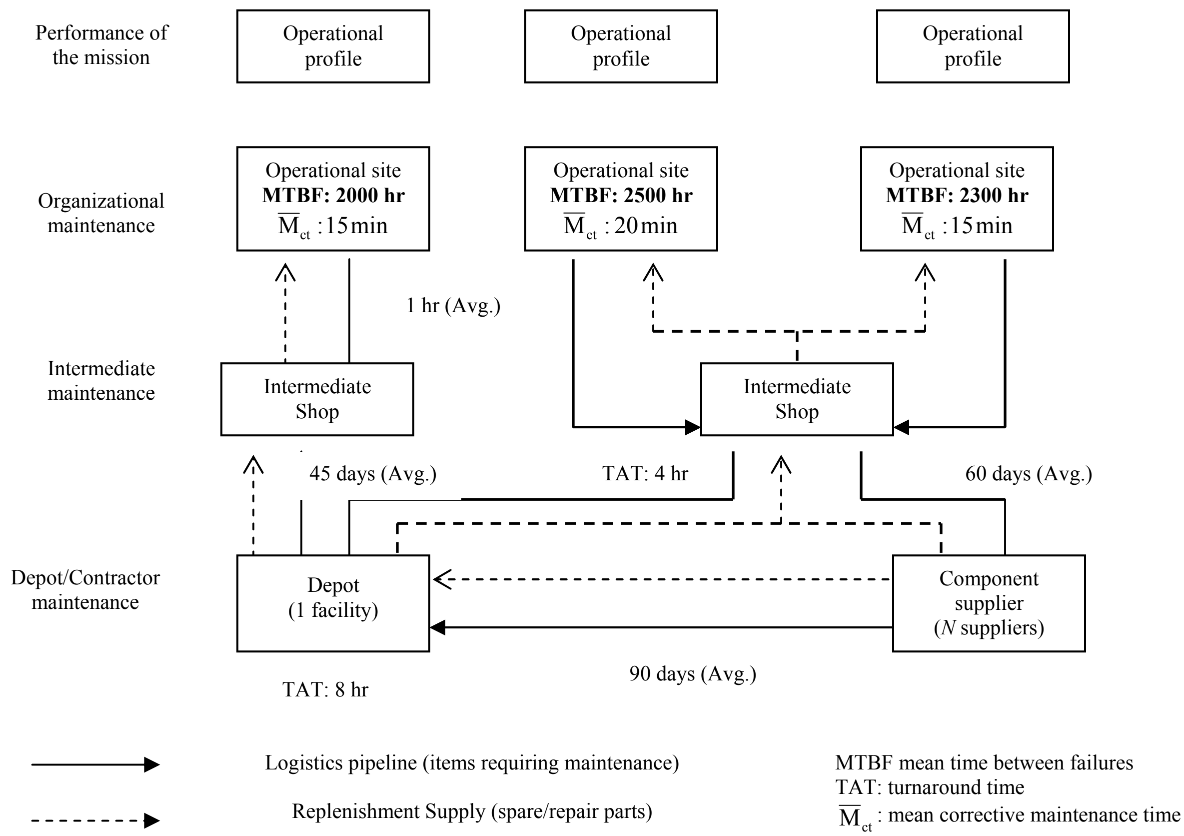

Figure 21. Maintenance Concept (After: Blanchard, Logistic Engineering and Management, 145).

d. Relevant Cost Elements

When developing an estimate, the greatest amount of effort should be expended on those cost elements that account for a significant portion of total O&S costs, can be affected by program decisions or assist in distinguishing among alternatives. These are the cost drivers. In some cases, the term "cost driver" means a parameter or characteristics that drive cost; but in the majority of cases, the "cost driver" represents the parameter or characteristic with a large impact on cost. A cost driver is defined as "a program, system characteristic, or parameter that has a direct or indirect effect of changing cost."[97]

97 DSMC, "Acquisition Logistics Guide," art. 15.3.

O&S costs may be better managed by identifying their cost drivers. This is because it facilitates finding avenues for cost reduction. Therefore it is essential to identify and continuously monitor the cost drivers. The analyst can then lay out a CBS by outlining the expected O&S cost elements. The next step is to estimate these cost elements. The following section presents some of the particulars of the O&S cost estimating process.

3. O&S Cost Estimating

O&S cost estimating is realized by applying one of the cost estimating methods previously presented (analogy, parametric, engineering, or extrapolation from actual costs). Most O&S analyses are accomplished using a combination of these estimating techniques; secondary methods serve to cross-check the primary method employed. Choosing which method(s) to use is the cost analyst's decision, based on the requirement for the cost analysis and what data are available.

Even though the same cost estimating methods are employed for the other components of the LCC, O&S cost estimating has some unique aspects.[98] In O&S estimating, the analyst may well find the following:

- An O&S Cost Estimating Structure (CES) which differs substantially from the acquisition product oriented WBS
- Heavy reliance on predictive models which tie personnel and maintenance considerations together for long range estimates of costs
- Requirements for up to 40 years of projected operational use data to employ most models effectively[99]
- A necessity to consider system constraints extending beyond system hardware (i.e., maintenance personnel, spares pipeline time frame, etc.).

In general, O&S cost estimates are based on historical cost experience. A key factor is therefore a reliable database to track O&S costs. Increased visibility of these costs has become a requirement for DoD major systems since 1974 when the VAMOSC system was established. To facilitate a better visibility of O&S costs, the Air Force established the Air Force Total Ownership Cost (AFTOC) data system. AFTOC became

98 FAA, art. 13.4.

99 The O&S costs estimate period is typically based on the nominal service life of the system.

the primary tool to assist analysts in the management and control of LCC. The historical data are also a major consideration in identifying the cost drivers, the topic of the previous section.

In the last decades, cost analysts have deepened understanding of LCC/TOC. Summarizing these studies, two senior DoD officials, involved in the acquisition process, point out that “as modernization is deferred, weapons systems age and costs for operations and support (O&S) increase.”[100] In the new economic context, with relatively flat budgets for defense, the higher O&S costs reduce the budgets for new, more reliable systems based on new technologies. This will lead to increasing costs and decreasing readiness, creating a vicious circle. For that reason, defense acquisitions policies have recently focused on controlling and reducing TOC. DoD approaches toward this goal are presented in the last part of this chapter.

C. APPROACHES TO REDUCTION OF TOC: CAIV AND R-TOC

The Cold War finished in the early 1990s and the Cold War arms race wound down. As a result, there was a dramatic fall in defense acquisition budgets. DoD has therefore implemented new strategies and rethought its acquisition processes. Recognizing that the majority of costs are determined early in the program, DoD put into practice Cost As an Independent Variable (CAIV). However, this initiative should not imply that cost could not be influenced later on. In a memorandum from 1999 Dr. Gansler urged services “to reduce the O&S of fielded systems (excluding manpower and fuel) by 20 percents.”[101] In accomplishing this goal, DoD has implemented several pilot programs to minimize the cost of ownership in the context of a total system approach, i.e., Reduction of Total Ownership Cost (R-TOC). These two new initiatives, CAIV and R-TOC will be presented in the following sections.

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[100] Jay Mandelbaum and Spiros Pallas, “Reducing Total Ownership Cost in DoD. Increasing Affordability of DoD Systems,” *PM* (July, 2001), 76.

[101] Jacques S. Gansler, “Memorandum: Future Readiness,” (Washington D.C.: Office of the Secretary of Defense, May 10, 1999), http://ve.ida.org/rtoc/open/gansler051099.pdf (accessed April 26, 2006).

1. Cost as an Independent Variable (CAIV)

The budgetary constraints forced the acquisition system to perceive cost as an independent variable; as a result cost has become as important as performance and has a major influence in weapon system decisions. Previously collected data proved that the best time to reduce costs is during initial acquisition or modification of the system. CAIV is defined as "an acquisition strategy focusing on cost-performance trade-offs in setting program goals."[102] Cost is first treated as a formal military requirement. The tradeoff denotes an Analysis of Alternatives (AoA) which takes place in the pre-acquisition phase to compare the estimates of costs, suitability, effectiveness, advantages, and disadvantages of the various alternative systems.[103]

The CAIV concept is presented in detail by Dr. Benjamin Rush in an article in *Acquisition Review Quarterly*. Dr. Rush defines CAIV as a "new DoD strategy that makes total life-cycle cost as projected within the new acquisition environment a key driver of system requirements, performance characteristics, and schedules."[104] Mentioning that the "life-cycle cost-performance/requirements tradeoff process is the heart of CAIV,"[105] the author gives attention to requirements/cost-performance trades. Previously, available technology drove the performance goals. Currently, the system user has to consider lesser but acceptable performance; therefore, the user became a critical player in the CAIV process. In addition, when performance is stated as an overall system, performance goals or the number of system performance parameters is minimized.

The CAIV process focuses on all four phases of the LCC of a program: R&D, production, O&S, and disposal. Notwithstanding, the main emphasis is given to production and O&S cost objectives. As Dr. Rush mentions, there are significant problems estimating production and O&S costs during the development phase. For instance, in the case of O&S, cost objectives typically would be an annual cost per

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[102] Defense Acquisition University, Defense Acquisition Deskbook, Version 3.1, 30 September 1999, http://akss.dau.mil/docs/ord0d.doc (accessed April 20, 2006).

[103] Boudreau and Naegle, "Reduction of Total Ownership Cost," 25.

[104] Benjamin C. Rush, "Cost As an Independent Variable," *Acquisition Review Quarterly* (Spring 1997), 162.

[105] Ibid., 162.

deployable unit (e.g. squadron) or individual system (e.g. aircraft). Most difficult to predict are O&S costs, primarily because they occur over many years. Supportability-related cost-performance parameters, such as Cost-Per-Operating-Hour (for aircraft), should influence CAIV principles; as the flagship program proved, the CAIV process can reduce O&S costs by establishing aggressive goals for key performance parameters such as MTBF and MTTR.[106]

The Defense Acquisition Guidebook describes how a CAIV strategy should be implemented. The CAIV plan has to be adjusted to each type of system. In general, it would consist of the following elements: cost goals for unit production cost and O&S costs, timing and content of trade-off studies, a cost performance integrated product team, incentives for supporting the CAIV plan, and metrics to assess progress and achievement of production and O&S cost goals.[107]

In brief, the CAIV process involves developing, setting, and refining forceful production and O&S cost targets while meeting system requirements and affordability. Once system performance and objective costs are decided, through cost-performance trade-offs, cost becomes more of a constraint and less of a variable in meeting the mission need. CAIV is an initiative to reduce life-cycle costs and is particularly effective during system development. During the O&S phase CAIV is not effective. Therefore, another methodology has to be employed for reducing Total Ownership Cost later in the system life cycle.

2. Reduction of Total Ownership Cost (R-TOC)

Another approach to TOC is the Reduction of Total Ownership Cost (R-TOC); its focal point is the reduction of the O&S costs of a weapon system. R-TOC programs are mainly employed after the system is fielded. The purpose of the R-TOC program is to achieve readiness improvements in weapon systems by improving the reliability of the systems or the efficiency of the processes used to support them.[108]

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[106] Rush, "Cost As an Independent Variable," 168-169.

[107] DAU, "Defense Acquisition Guide," para. 3.2.4.

[108] Institute for Defense Analysis, "Reduction of Total Ownership Costs," http://rtoc.ida.org/rtoc/rtoc.html (accessed April 29, 2006).

In implementing R-TOC, the DoD adopted a Business Process Reengineering (BPR) perspective using elements such as: increasing the visibility and priority of the problem, changing the behavior of organizations and individuals regarding R-TOC, and institutionalizing R-TOC processes. The DoD has combined three strategies for approaching the R-TOC issue: setting strategic goals and objectives, starting to build momentum early, and developing and implementing a refined tactical plan.[109]

Implementing the strategies previously mentioned through several pilot programs, the DoD achieved positive results. These were obtained by adopting private sector improvements in logistics and supply chain management. A memorandum from the Under Secretary of Defense for Acquisition, Technology and Logistics summarizes these facts:

> Current R-TOC Pilot Programs are demonstrating that cost avoidance can be achieved by a variety of best practices. They include replacing high cost and low reliability components; enhancing supply chain efficiency; using smart decision support tools with cost visibility; establishing performance logistics support arrangements; leveraging commercial-off-the-shell components; and initiating public-private partnerships."[110]

The 30 R-TOC Pilot programs, 10 for each service, have contributed significantly to reducing TOC, mainly because they were implemented for high–demand weapon systems. Therefore, even small O&S cost reduction resulted in drastic improvements in readiness and contributed to reducing Department of Defense ownership costs.

Both strategies, CAIV and R-TOC, focus on cost reduction and are designed to reduce the total ownership cost of weapons systems. CAIV is a continuous, user-oriented, overarching acquisition strategy. Through this strategy, performance requirements are assessed against costs to maximize the value of a weapon system. The costs, however, are

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[109] Mandelbaum and Pallas, "Reducing Total Ownership Cost in DoD," 77.

[110] Michael W. Wynne, Memorandum: Transformation through Reduction of Total Ownership Cost (R-TOC), (Washington D.C.: Office of the Secretary of Defense, December 16, 2003), http://rtoc.ida.org/rtoc/open/SignedVersion-RTOC-Wynne%20Ltr-16Dec03.pdf (accessed April 26, 2006).

still too high for current budgets. While continuing to attack acquisition costs, there is need to reduce O&S costs as well. Initiatives such as CAIV and R-TOC reduce costs and improve readiness.

D. CONCLUSION

Understanding and identifying TOC is crucial to determining the operational success and cost-effectiveness of any weapon system. Recognizing this, current DoD policies require that program management ensure LCC considerations influence system design, systems engineering, and logistics engineering processes during the weapon system life cycle. In realizing this objective, the LCC estimate supports each management decision where cost is significant. The decisions with the highest probability of affecting LCC are those impacting O&S costs. Therefore, program managers must focus on the major factors that influence O&S costs, such as design characteristics, reliability, maintainability, and mission requirements.

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V. ANALYSIS AND FORECASTING OF OPERATING AND SUPPORT COST FOR F-16 C/D

This chapter provides an analysis of O&S costs for the F-16C/D. It begins with a brief description of the AFTOC database and how data was collected for the empirical portion of this research. Then the chapter focuses on the details of O&S data from the FY04 Cost Analysis Improvement Group (CAIG) format for O&S data. The percentage breakout for each fiscal year will be compared to one another to identify any trends that might be present. Actual CPFH expenditures of F-16C are then analyzed, exploring different forecasting options to determine which option best fits each data series. After the best forecasting option is selected, the forecast figures are analyzed by comparing them with the actual expenditures for FY04. The results of this comparison are then analyzed by comparing them to the results of the actual expenditures versus budgeted values. The last section presents several results of implementation of the R-TOC program in the case of the F-16 Fighting Falcon.

A. AFTOC DATABASE

Each service keeps records of operation and support costs – spending on Operation and Maintenance (O&M) plus spending on military personnel. As mentioned in Chapter IV, the Navy (1974) was the first service to implement a database for presenting all O&S cost information for weapon systems, called the Visibility and Management of Operating and Support Costs (VAMOSC). However, Logistic Management Institute (LMI) study concluded in 1995 that "no service was capturing actual cost by weapon system."[111] After this study, the Army and Air Force created their own systems for reporting O&S cost information. The Army's version of the VAMOSC is the Operating and Support Management Information System (OSMIS). The Air Force named their system the Air Force Total Ownership Costs (AFTOC) database.

[111] Jerry Schmidt and Ellis Hitt, "Air Force Total Ownership Costs and Reduction in Total Ownership Costs – Twin Pillars of the Air Force Affordability Initiatives," *IEEE* (1999), SS.2-1, http://ieeexplore.ieee.org/iel5/6600/17621/00863675.pdf?arnumber=863675 (accessed April 13, 2006).

The purpose of these databases is to provide visibility of O&S costs for use in cost analysis of Major Defense Acquisition Programs (MDAPs) and force structure alternatives in support of the Planning, Programming, Budgeting and Execution (PPBE) process, and satisfy the congressional requirement that DoD capture and report O&S cost for MDAPs.[112] These databases make possible the management of O&S costs; the LCC of a weapon system can therefore be controlled and reduced.

The AFTOC database is compiled from hundreds of other databases that collect cost data as well as data on operations (hours flown) or equipment in inventory. For instance, it contains actual expenditures from the Command On-line Accounting & Reporting System (COARS), and flying hour data and aircraft inventory data is extracted from the Reliability and Maintainability Information System (REMIS).

B. O&S COSTS ANALYSIS

As noted in Chapter IV, the AFTOC database contains the necessary data for the empirical O&S cost breakout analysis. AFTOC includes all costs associated with the USAF total obligation authority, including costs associated with personnel, infrastructure, operation and maintenance (O&M), research, development, test and evaluation, and acquisition of new systems.

Schmidt and Hitt illustrate the link between AFTOC and R-TOC analyzing the O&S costs of the F-16 weapon system.[113] To a large extent, our analysis draws upon their paper.

Table 2 and Figure 22 show the FY04 total costs and FY04 O&M costs of the F-16C/D weapon system. The data were obtained by adding up the costs for F-16C and F-16D found in AFTOC. More than half are O&M costs. The second largest expenditure category is Military Personnel.

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[112] Department of Defense, "DoDR 5000.4-M – Cost Analysis Guidance and Procedures," (Washington DC: Assistant Secretary of Defense for Program Analysis and Evaluation, May 2002), 53, http://www.dtic.mil/whs/directives/corres/pdf2/p50004m.pdf (accessed April 14, 2006).

[113] Schmidt and Hitt, "AFTOC and R-TOC," SS.2-4.

Table 2. FY04 Obligations: F-16C/D.

F-16C/D	**FY04**[114]
RDT&E	$139,223,580
Procurement	$436,615,552
O&M	$,377,851,821
Milpers	$1,614,171,291
Total	$4,567,862,244

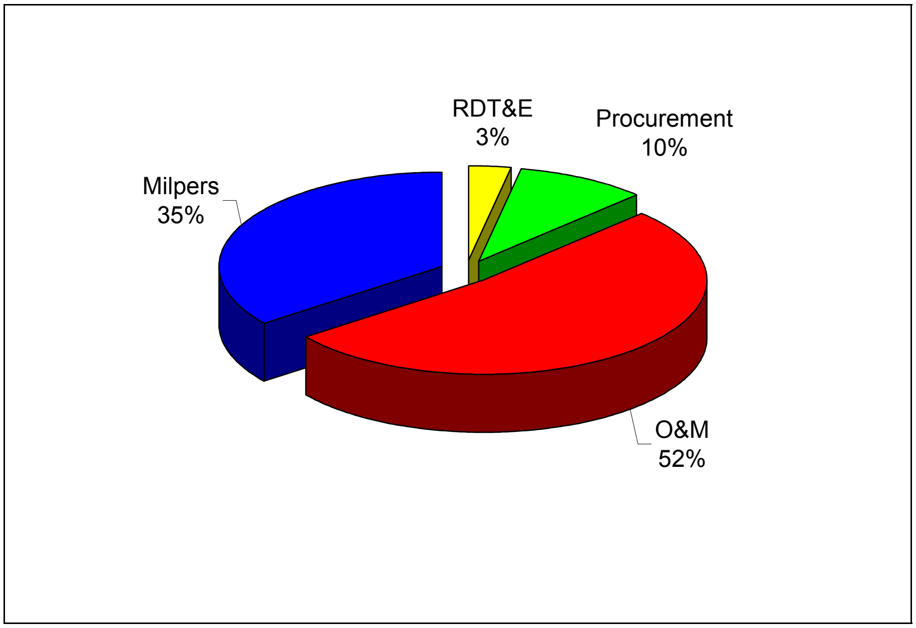

Figure 22. FY04 Obligations: F-16C/D.

Figure 23 shows the FY04 O&M cost of the F-16C/D weapon system. The total costs are USD 2,378 million. Note that the major cost driver of O&M costs is Depot Level Reparables (DLRs). They constitute USD 885,800,885, or 38 percent of the expenditures. Therefore these costs are principally targeted for cost reduction.

114 All data are Then-Year dollars.

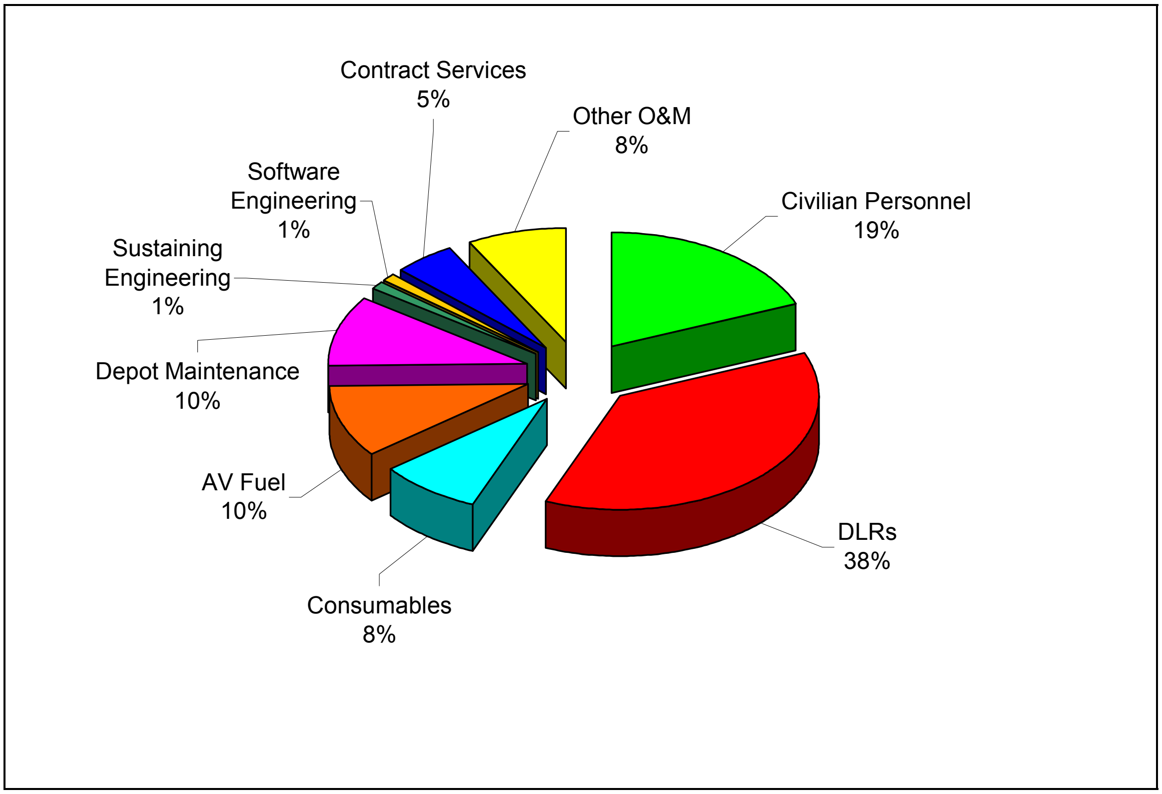

Figure 23. F-16C/D FY04 O&M Costs.

Table 3. F-16C/D FY04 O&M Costs.

F-16C/D	**FY04**
Civilian Personnel	$449,632,870
DLRs	$885,800,885
Consumables	$197,946,097
AV Fuel	$242,967,000
Depot Maintenance	$236,283,078
Sustaining Engineering	$27,738,383
Software Engineering	$26,820,104
Contract Services	$116,709,154
Other O&M	$193,954,249
Total	$2,377,851,820

After an empirical study, a GAO report concluded that about 25 parts, especially parts associated with engines and electronic subsystems dominate the maintenance and repair costs of an aircraft.[115] The report gives the example of F-16, which in the fiscal year reported showed that 25 most fault-prone parts accounted for about 44 percent of the system's total repair part cost, from a possible field of approximately 7,000 repairable parts.

Figure 24 illustrates the F-16C/D high cost of the top DLRs. In the FY04, the top twenty-five DLRs cost 37 percent (USD 325.7 million) of the total of all the DLRs. Each of these DLRs is now being upgraded or studied for future upgrades within the R-TOC program. The last section of this chapter will present how the R-TOC program is implemented in the case of the F-16.

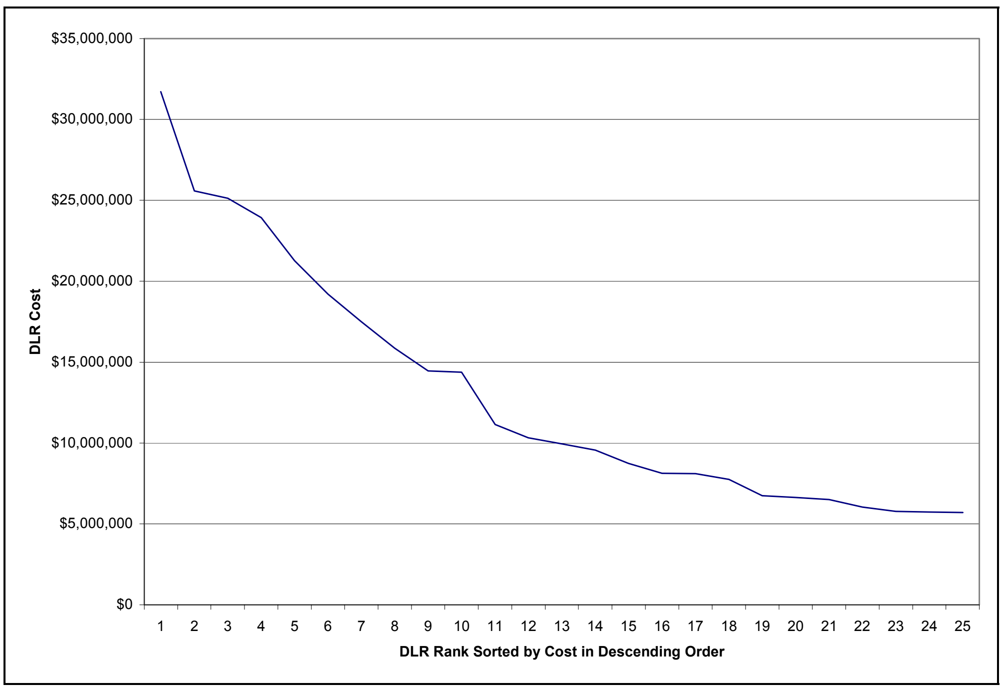

Figure 24. F-16C/D DLR Cost Curve.

The distribution of expenditures on the top twenty-five DLRs is presented in Figure 25. The engines are clearly the high cost drivers for the aircraft. The APG-68 radar system is also an especially expensive item that can be modernized to reduce O&S costs.

[115] GAO, "Air Force Operating and Support Costs Reductions Need Higher Priority."

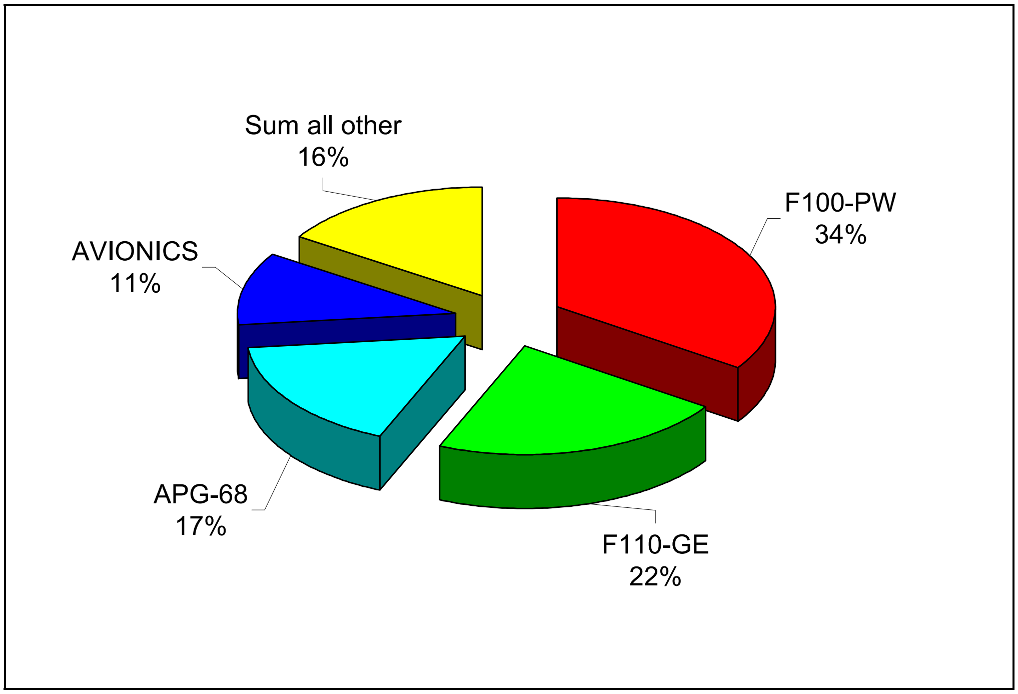

Figure 25. F-16C/D Top Twenty-Five DLR Cost Drivers.

1. Level 1 CAIG Data - Empirical O&S Breakout

Another data format available from AFTOC is the Level 1 CAIG Data, used for our empirical O&S breakout. The Level 1 CAIG Data (FY04, F-16C/D) is presented in Table 4. In this case, the data for FY 2005 were available; however, the FY04 data are presented to offer a complete image of cost for one year. There are seven 1st level cost elements, which each of these being a summation of lower levels (2nd and, in some cases 3rd) of indenture.

Table 4. FY04, F-16C/D Level 1 CAIG Data.

CAIG	CAIG Description	Total
1.0	Mission Personnel	$1,743,230,041
2.0	Unit-Level Consumption	$1,501,968,295
3.0	Intermediate Maintenance	$313,000
4.0	Depot Maintenance (not DLRs)	$215,992,330
5.0	Contractor Support	$43,313,391
6.0	Sustaining Support	$ 88,012,063
7.0	Indirect Support	$ 472,177,913
Total	Total Expenditures	$ 4,065,007,033

Note: in Then-Year Dollars.

A graphic depiction of Table 4 is presented in Figure 26. As can be observed, the major cost drivers are Mission Personnel and Unit-Level Consumption. These two elements determined at the operating unit level are the major cost drivers for total cost, Cost per Flight Hour (CPFH), and cost per aircraft.

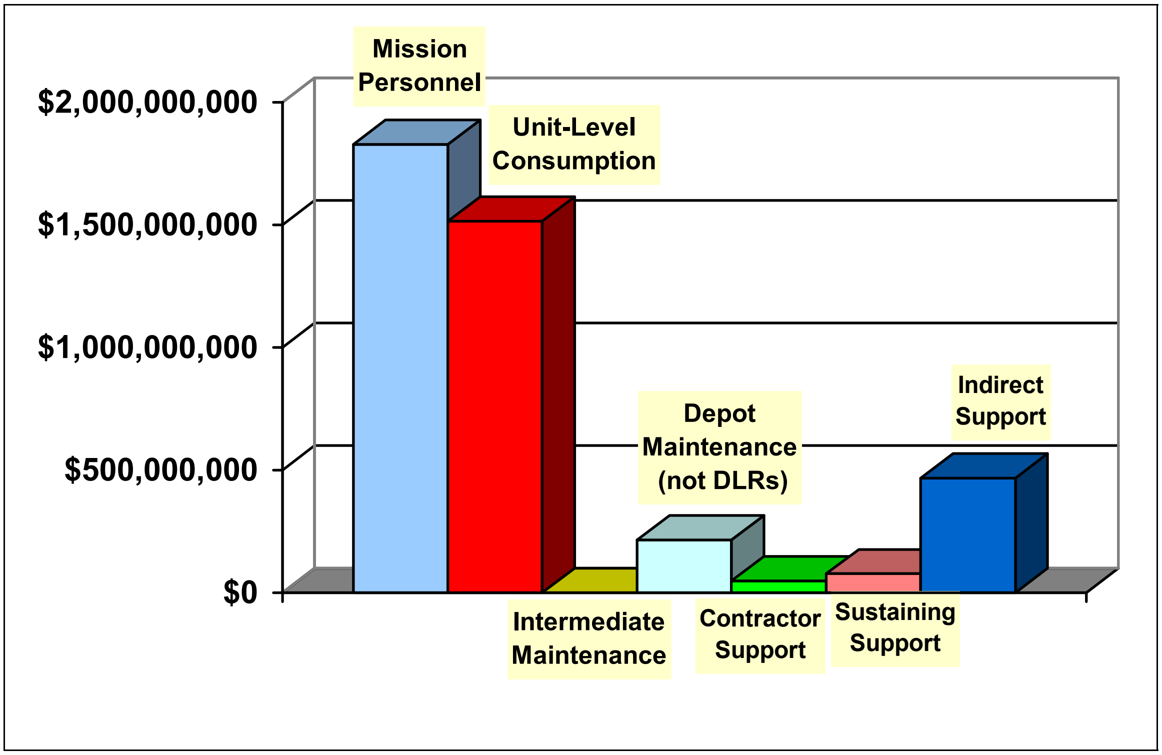

Figure 26. FY04, F-16C/D Level 1 CAIG Data.

The Level 1 CAIG data is also used in a trend analysis. The F-16 weapon system is evaluated from FY98- FY04. The costs incurred by both models, F-16C and F-16D are presented. Line charts are created showing the percentage that each of the seven CAIG O&S cost categories contributes to the entire cost for each fiscal year. The percentage that each of the seven categories contributes to O&S costs provides a means to compare the costs from year to year without the outside influence of inflation, because increases due to inflation will apply to all of the categories.

From FY96 through FY04, the largest portions of overall cost consistently came from costs associated with mission personnel and unit-level consumption. These two categories constitute 80 percent of total cost in each year. One can observe a decline of these cost percentages between FY98 to FY02 for mission personnel and between FY99 to FY05 for unit-level consumption. However, these costs were not lower than in previous years: very much the contrary. With the exception of FY03 (when the unit-level consumption costs were lower than in the previous year), costs increased. These decreases are attributable to the dramatic rise of costs associated with contractor support (almost doubled in FY02) and depot maintenance. The causes of these increases are probably related to upgrades installed in 1999 and 2000, such as Active Flutter Suppression System and electric brakes (e-brakes), as well as modifications within the Common Configuration Implementation Program (CCIP), which started in 2002.[116]

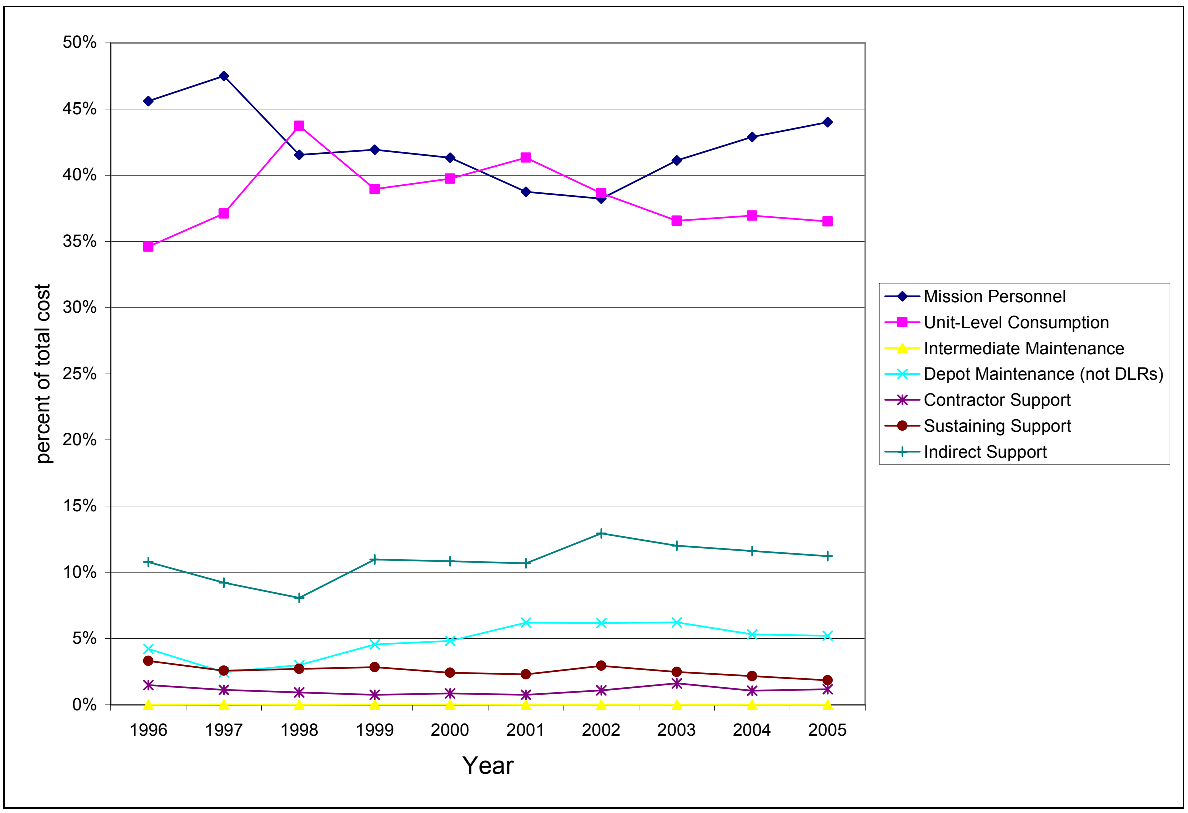

Figure 27. F-16 C/D O&S Costs.

116 See Lockheed Martin, "Latest Lockheed Martin F-16 Upgrade Version Completed on Schedule," http://www.lockheedmartin.com/wms/findPage.do?dsp=fec&ci=12553&rsbci=1&fti=133&ti=0&sc=400 (accessed April 13, 2006).

As can be observed, during recent years, the unit-level consumption costs percentage stabilized at around 37 percent. Three of the 3rd level cost elements in this category are the factors estimated within the Cost per Flying Hour (CPFH) Program. The next section discusses the CPFH, a subset of the O&S portion of the budget.

2. Cost per Flying Hour (CPFH)

CPFH drives a large fraction of O&S and directly addresses actual aircraft operation and maintenance costs. The USAF uses the CPFH metric to estimate budget needs. CPHF factors allocate dollars against flying hours included in Air Force's program. This program encompasses the number of hours needed to attain and maintain combat readiness for aircrews, to test the weapon system and tactics, and to fulfill collateral requirements such as air shows and ferrying aircraft.[117]

There is no standard understanding of the CPFH concept. An Air Force weapon system cost analyst defines CPFH as "a metric used to estimate the costs of fuel, consumables, and DLRs necessary to operate a particular weapon system (aircraft) for a one hour period."[118]

a. CPFH Recorded in AFTOC

In the AFTOC database, however, the CPFH are calculated by dividing the O&S costs by the flying hours. (O&S costs are the sum of mission personnel and O&M costs) Figure 28 displays actual and budgeted Cost per Flying Hour for F-16C/D, as extracted from the AFTOC.

One useful set of steps to calculate annual budget costs for an active duty unit is mentioned by Edwards in his thesis.[119]

- (Primary Authorized Aircraft per Sqdn) x (Crew Seat Ratio) = Allowed Crews per Squadron
- (Allowed Crews) x (Aircrew Manning Factors) = Budgeted Crews per Squadron

117 GAO, "Air Force Operating and Support Costs Reductions Need Higher Priority," 1.

118 Pat A. Rose, "Cost Per Flying Hour Factors: A background and Perspective of How They Are Developed and What They Do," *Air Force Comptroller* 31, no. 3 (July 1, 1997), 4.

119 Michael V. Edwards, "Flight Hour Costing at the Type Commander and Navy Staff Levels: An Analytical Assessment," (master thesis, Naval Postgraduate School, 1992), 17-18.

- (Budgeted Crews) x (Req. Hrs/Crew/Month) x (12 mos.) = Annual Flying Hours Required per Sqdn
- (Ann. Flying Hrs Req. per Sqdn) x (Number of Sqdns) = Total Annual Flying Hours Required
- (Total Ann. Flying Hrs Req.) x (Primary Mission Readiness percentage) = Annual Budgeted Flying Hours
- (Ann. Budgeted Flying Hours) x (CPFH) = Annual Budgeted Cost, Active Duty forces (converted to "then-year" dollars)

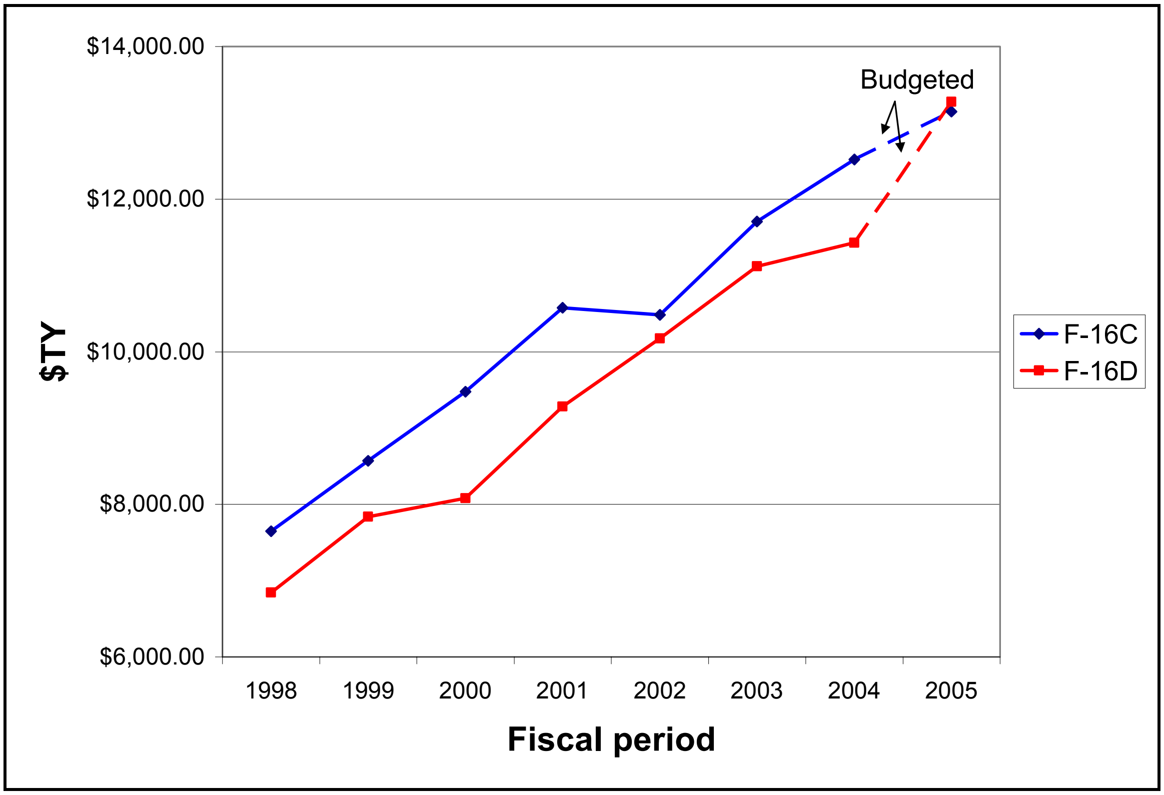

Figure 28. Actual/Budgeted Cost Per Flying Hour: F-16C/D.

Because the Flying Hour Program is an important part of the budget proposal, forecasting CPFH has become a critical task for cost analysts. An underestimate would lead to an additional funding, typically taken from modernization programs.[120]

[120] GAO, "Air Force Operating and Support Costs Reductions Need Higher Priority," 3.

b. Forecasting CPFH

Theoretical approaches to CPFH suggest that there are three main forecasting models: time-series, causal and physics-based. The first model will be applied using AFTOC data. The other two models are discussed briefly.

As suggested by a study related to analysis and forecasting of operation and support costs for rotary aircraft, there are three different time-series forecasting techniques to evaluate CPFH: Three-Year Moving Average (MA3), the Single Exponential Smoothing (SES) method, and Holt's method (Exponential Smoothing with trend). Holt's method outperformed the other two methods primarily because it considers trends. Both the Mean Absolute Error (MAE) and the Mean Absolute Percentage Error (MAPE) were twice as good as the MAE and MAPE for the other two forecasts.[121]

The second model (causal) used in another study (Hawkes), employs simple and multiple regressions. To forecast the CPFH for the F-16C/D the author identifies nine possible explanatory variables. The most important appear to be the following: aircraft age, OPTEMPO, utilization rate, and base location. Hawkes performs a one-way analysis of variance for all explanatory variables in order to determine which of them are statistically significant. Based on the above, the author builds six models, three for active duty wings and three for Air National Guard (ANG).[122]

An example of one model is given below.

$$CPFH = 4106.96 - 3.67 * (util\_rate) - 932.91 * (\%50) + 1199.48 * DV(Nellis) - 841 * DV(Alaska)$$

The model relates the CPFH of active duty fighter wings to four explanatory variables: utilization rate (numbers of hours flown divided by the number of aircraft), percent block 50 (a variable which quantify the proportion of F-16C/D block 50), and two variables which describe the location the wing is assigned to.[123]

121 Mathew E Laubather, "Analysis and Forecasting of Air Force Operating and Support Costs for Rotary Aircraft" (master thesis, Air Force Institute of Technology, 2004), 62-67.

122 Eric M. Hawkes, "Predicting the Cost per Flying Hour for the F-16 Using Programmatic and Operational Variables," (Master's Thesis, Air Force Institute of Technology, 2005), 46-79.

123 Ibid., 49.

The third model (physics-based) used other parameters besides hours to predict consumption costs. It was developed by the Logistics Management Institute (LMI) as an alternative to CPFH, and is relevant during contingencies.[124] The analysis of LMI experts demonstrates that during contingency operations the number of flying hours increases dramatically, but the consumption of parts does not.

The model was verified using the F-16C fighters deployed at Aviano Air Base (Italy). Initially, the model considered four critical factors: ground *cycles* or ground *days* (ground hours divided by 24), flying hours, warm take-off/landing cycle (warm cycles), and cold take-off/landing cycle. The last parameter was subsequently eliminated. The total F-16C fleet model predicts 20.1 percent ground-induced removals, 6.4 percent warm cycle-induced removals, and 73.4 percent flying hour-induced removals.[125]

c. Time-Series Forecasting Methods of CPFH

Time-series forecasting methods are applied to F-16C/D data extracted from AFTOC. Appendix J describes in detail these three forecasting techniques. In addition, the evaluation measures (Mean Error [ME], Mean Absolute Error [MAE], Mean Percentage Error [MPE] and Mean Absolute Percentage Error [MAPE]) are also presented. Appendix K displays the entire data set used for employing the time-series forecasting methods. The Solver function within Excel was used to find the optimal value of coefficients used for SES and Holt's forecast. Tables 5 and 6 below show the evaluation measures that were calculated for F-16C and F-16D.

Table 5. F-16C Evaluation Measures (Nominal Data).

F-16C	MA	SES	Holt
ME	1,520.03	811.49	180.13
MAE	1,520.03	841.59	574.96
MPE	13.46%	7.79%	1.92%
MAPE	13.46%	8.08%	5.68%

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124 John M. Wallace, Scout A. Houser and David A. Lee, "A Physics-Based Alternative to Modeling Aircraft Consumption Costs" (report, Logistics Management Institute, McLean, Virginia, August 2000), http://www.dodcas.osd.mil/ DoDCAS2003%20presentations/Advanced/Lee.pdf (accessed May 12, 2006).

125 Wallace, Houser and Lee, "A Physics-Based Alternative to Modeling Aircraft Consumption Costs," 4-21.

Table 6. F-16D Evaluation Measures (Nominal Data).

F-16D	MA	SES	Holt
ME	1,662.70	764.80	73.97
MAE	1,662.70	764.80	490.20
MPE	16.00%	8.11%	1.24%
MAPE	16.00%	8.11%	5.50%

Of the three forecasting techniques evaluated, Holt's method definitely achieves the lowest errors. The explanation for this fact is that Holt's method, unlike the other two techniques employed, can exploit trends within the data. The graphs in Figure 7 illustrate a positive trend of CPFH experienced by the USAF in the case of the F-16C/D. Consequently, Holt's method proved to be an appropriate technique to forecast CPFH.

Another advantage of Holt's method is that it can forecast more than one period ahead if needed. However, this method has a few negative aspects. One is that it can take a long time to overcome the influence of a one-period shift in the opposite direction of the overall trend. The shift in an opposite direction is evident in the case of the F-16C for the year 2002. The data observed was USD 10484.21, USD 90.30 lower than the previous year. Therefore, for 2002 the percentage error given by the variation between the observed value and the forecasted value was 11.3 percent. However, for FY04 the CPFH forecasted for the F-16C with Holt's method is the exact value recorded in AFTOC.

Another important observation regarding the evaluation measures is that none of the ME or MPE is negative. This indicates that the forecasted values are, on average, lower than observed values. Therefore, one disadvantage of these forecasting methods is the risk of underfunding.

A source of the positive trend observed is inflation. To eliminate this factor, actual data from AFTOC are adjusted to 2005 dollars. In Figure 29 the observed data (in FY05 dollars) are graphed and the budgeted values for FY05 and forecast values obtained using Holt's method again offered the lowest errors.

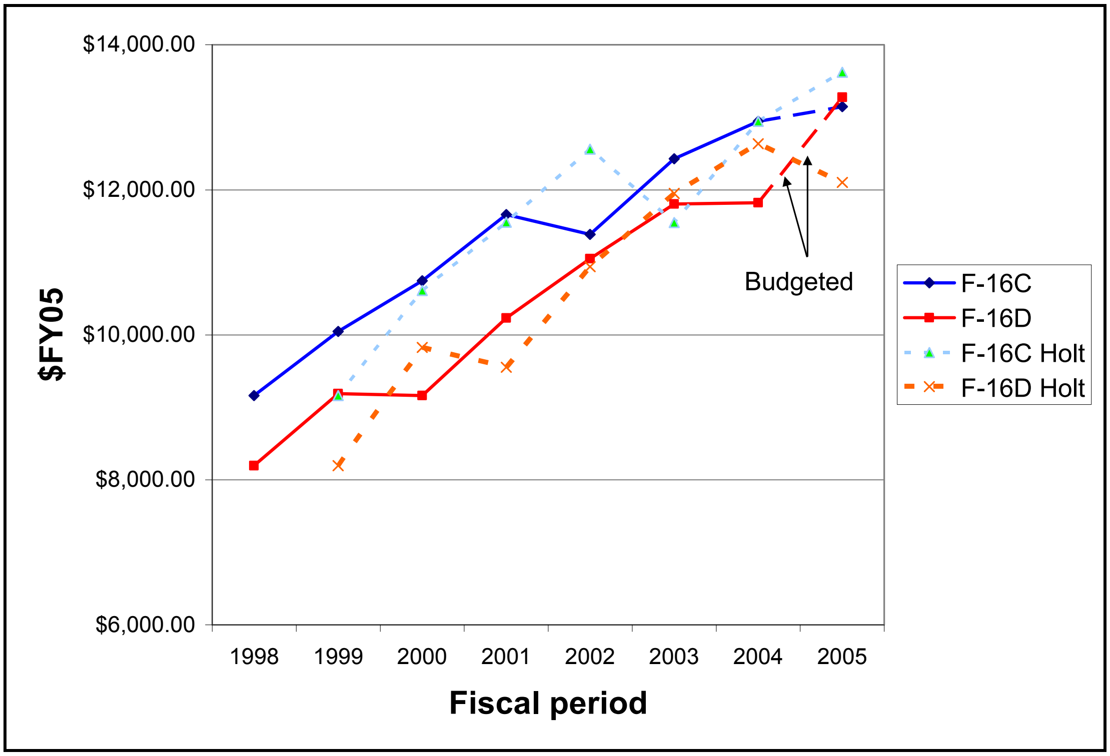

Figure 29. Actual/Budgeted and Forecasted Cost Per Flying Hour: F-16C/D (in 2005 dollars).

The inflation conversion factors have been extracted from the Conversion Factor Table offered by Oregon State University.[126] They are shown below in Table 7.

Table 7. Inflation Conversion Factors.

Year	CF
1998	0.835
1999	0.853
2000	0.882
2001	0.907
2002	0.921
2003	0.942
2004	0.967
2005	**1.000**

126 Robert Sahr, Inflation Conversion Factors for Dollars 1665 to Estimated 2016, Oregon State University, http://oregonstate.edu/Dept/pol_sci/fac/sahr/sahr.htm (accessed June 3, 2006).

Adjusting the observed values to correct for inflation does not change the overall results obtained, but the forecast results are improved. Tables 8 and 9 below show the evaluation measures that were calculated for the F-16C and F-16D after adjustment for inflation.

Table 8. F-16C Evaluation Measures (Adjusted Data for Inflation).

F-16C	MA	SES	Holt
ME	1,132.90	630.76	137.24
MAE	1,132.90	722.51	529.27
MPE	9.35%	5.52%	1.28%
MAPE	9.35%	6.33%	4.72%

Table 9. F-16D Evaluation Measures (Adjusted Data for Inflation).

F-16D	MA	SES	Holt
ME	1,339.03	604.47	27.50
MAE	1,339.03	612.94	566.76
MPE	12.01%	5.82%	0.52%
MAPE	12.01%	5.91%	5.63%

The majority of the evaluation measures are lower and the smallest margins for error are obtained using Holt's method. Once more the forecast value for 2004 for the F-16C is identical with adjusted observed data using Holt's method. In addition, the MAPEs obtained are lower, even though the slope of the positive trend was reduced by applying the inflation conversion factors.

The first section of this chapter identified the main cost drivers in the case of the F-16C/D and the second section showed how CPFH, a significant determinant of O&S costs, can be forecasted. The last part of this chapter exemplifies how F-16 O&S costs are reduced within the R-TOC program.

C. R-TOC PRACTICES FOR F-16 PROGRAM

As mentioned in Chapter IV, the R-TOC program is the DoD-wide effort to reduce Total Ownership Cost of fielded weapon systems. The F-16 weapon system was selected along with other 29 programs. The aging of the F-16 fleet has increased O&S costs, endangering operational ability and readiness of the most popular aircraft in the

USAF inventory. The F-16 System Program Office (SPO) has sought to introduce R-TOC practices throughout the F-16 community. To achieve this objective, a Cost Reduction Integrated Product Team (CRIPT) was established to identify O&S cost drivers. For the international F-16 community (including Poland), one of the SPO's objectives is to explore possible international cooperation to support TOC reduction efforts. The F-16 SPO has also implemented two R-TOC initiatives: a system of Service-Level Agreements and Government Performance Reports for improving supply support and the Combined Life-Time Support Program.[127]

The F-16 R-TOC program is one of the best examples of R-TOC practices as a process of continuous development. However, F-16 R-TOC efforts are complex and difficult because the inventory of F-16s consists of more than 4,000 units worldwide in variety of versions. Additionally, because of continuing international sales, the F-16 is unique in the sense that many of the opportunities for TOC reduction initiatives come about as a result of international sales opportunities.[128]

R-TOC practices for the F-16 program consist of following elements: R-TOC Management, Reliability and Maintainability (R&M) Improvement Initiatives, Supply Chain Response Times/Footprint Reduction, and Combined Life Time Support (CLTS).

In R-TOC Management, reduction of TOC for the F-16 was not expected to meet 20 percent savings for FY2005. However, even the forecast 3.6 percent for the FY 2005 was a significant amount of money saved.[129] Results of R-TOC implementation showed that R-TOC savings practices are worth doing: "The program office's persistence has resulted in development approval and funding of new R-TOC initiatives. In August 2000, projected FY05 savings totaled only USD 20.1 Million; this estimate has grown to USD 65.5 Million, and life cycle savings exceed USD 1.5 Billion."[130]

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[127] DoD Reduction of Total Ownership Costs official Web site, "Pilots Programs to Reduce Total Ownership Costs (R-TOC) – F-16 Fighting Program," http://ve.ida.org/rtoc/open/pilots/f16.html (accessed May 12, 2006).

[128] Department of Defense, "Reduction of Total Ownership Costs (R-TOC) Best Practices Guide" (Washington D.C.: Office of Defense Systems, Under Secretary of Defense for Acquisition, Technology and Logistics, September 2003), 10, http://www.dmsms.org/file.jsp?storename=OSD_version.doc (accessed May 12, 2006).

[129] DoD, "Reduction of Total Ownership Costs (R-TOC) Best Practices Guide," 10.

[130] Ibid., 10.

R&M Improvements Initiatives for the F-16 encountered the following problems: diminishing manufacturing capacity, aging fleet issues, and decreasing reliability. The Program Manager (PM) and Supply Chain Manager (SCM) developed the Falcon Flex program. The main objective was reduction of O&S costs and improvement of reliability. Falcon Flex has 17 initiatives. The principal focus is to identify cost drivers in order to proactively forecast solutions among them. After cost driver identification, costs are ranked, causes are also identified, and solutions are formulated.

Results of the Falcon Flex program are also impressive. Two initiatives for redesigns of two of the top three O&S cost drivers of the APG-68 radar system programmable single processor (PSP) were considered. The PSP memory card replacement project replaced a USD 14,000 component which had a 500 hour MTBF and a USD 3,000 repair cost with a USD 6,000 throw-away component with a 40,000 hour MTBF. Similarly, the power supply replacement for the same unit replaced a USD 70,000 component with a 500 hour MTBF and USD 6,000 repair cost with USD 8,000 throw-away unit with 10,000 hour MTBF.[131]

The Supply Chain Response Times/Footprint Reduction initiative was meant to improve fill rates and reduce cycle times for the F-16 maintenance line and landing gear shop at Ogden Air Logistics Center (OO-ALC). As a result of the ongoing initiative, Total Ownership Costs have declined due to improved fill rates for low cost consumable bench stock items such as fasteners, gaskets, seals, o-rings, etc. Also, cycle times have been reduced and government owned inventory for bench stock items were reduced or eliminated.[132]

Combined Life Time Support (CLTS) is a program which takes a new approach to system sustainment. The contractor is held responsible for Diminishing Manufacturing Sources (DMS) management and determines timing and approach to DMS prevention and resolution. This proactive solution to DMS problems is carried out before DMS

131 DoD, "Reduction of Total Ownership Costs (R-TOC) Best Practices Guide," 21.

132 DoD, "Reduction of Total Ownership Costs (R-TOC) Best Practices Guide," 22.

impacts sustainment. Material management responsibilities are shared by government and contractor equally. Shared responsibility motivates contractors to improve reliability.

The CLTS practices have brought benefits for the government and contractors as well. Government keeps the core of workload while reducing TOC: contractors partner with government. Contractors have an opportunity to promote design changes as well as having support of their product lines.[133]

The R-TOC initiatives implemented in the F-16 program has brought improvement in TOC reduction and readiness. They allow sustaining readiness of an aging weapon system such as the F-16 with reduction of logistic footprint. However, the Polish and Romanian cases indicate that age of the aircraft will not be a factor (Poland purchased new planes and Romania is considering that option), because new user of the F-16 weapon system may need to implement best practices of the R-TOC program in the near future. Additionally, R-TOC initiatives may be implemented in the early phases of weapon system development.

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133 DoD, "Reduction of Total Ownership Costs (R-TOC) Best Practices Guide," 32.

VI. CONCLUSIONS AND RECOMMENDATIONS

Total Life Cycle System Management (TLCSM) could be an affective tool to identify, track, and manage the Total Ownership Cost, if implemented properly. The difficulties in implementation come from the complexity, multidimensionality, and different avenues of approach. Also, the TLCSM concept is not yet mature in Poland and Romania. However, TLCSM should be a main priority when acquiring new weapon systems such as the F-16. Therefore, concepts such as TLCSM and TOC/LCC should become standard practices because they constitute a foundation for the effective management of complex weapon systems. Moreover, these concepts have been demonstrated in practice by the U.S. DoD.

Costs after initial investment are significant and require serious consideration. O&S costs represent the majority of the TOC for USAF weapon systems. That fact is widely recognized, and in recent years the focus has shifted from reducing acquisition costs to reducing total ownership costs. The analysis included in this report confirmed that the F-16 C/D is not an exception. For instance, the O&S costs of the F-16C/D were 87 percent of total costs in 2004 (35 percent Military Personnel, 52 percent Operating and Maintenance).

The analysis also identified DLRs as the main cost drivers of O&M. They must be addressed when considering reduction of TOC in general, with careful attention to the top 25 DLR items, which include components of engines (F100-PW and F110-GE), APG-68 radar and avionics. Management of these cost drivers will be particularly difficult since the PoAF and RoAF fly a relatively small number of aircraft. As suggested by Professor Engelbeck, this would create unique spares for the PoAF and RoAF.[134] The search for appropriate solutions among alternatives such as establishing a Reliability Centered Maintenance (RCM) or consolidation of DLR maintenance capabilities within the European Union F-16 users may constitute a topic for further study.

134 While the RoAF has not yet selected its multi-role combat aircraft, the recommendations made here for F-16 would apply to any such aircraft.

Holt's model (exponential smoothing with trend) applied in this study using 1998-2004 AFTOC data provided a useful method for forecasting CPFH. In another study (Laubacher) Holt's model proved to be valuable in predicting the CPFH of rotary aircraft as well. Therefore, this model can be viewed as an effective decision-making tool to obtain realistic estimates of CPFH, and consequently of O&S costs. However, because the forecast values are, on average, lower than observed values this method should be used with caution in budgeting O&S costs to avoid underfunding.

The chief recommendation of this study is that the Polish and Romanian Air Forces should establish databases to record O&S costs. The compilation of several data bases into one integrated database is an essential step for efficient forecasting and managing TOC in general and O&S costs in particular. Efforts to reduce O&S costs of multi-role aircraft in the PoAF and RoAF should be preceded by establishment of a reliable and consistent O&S cost database. Moreover, as an F-16 user, Poland should take advantage of U.S. and other user countries' experience with this fighter aircraft to obtain access to common digitized data.[135] Romania should include acquiring of the cost database of its future multi-role fighter aircraft in the acquisition process.

Simultaneous with the acquisition process, the PoAF and RoAF should adopt the best practices of managing and reducing TOC. Furthermore, they should become actively engaged in exploring new possible R-TOC initiatives.

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[135] This new database is mentioned in a report of the Air Force Logistics Management Agency. Timothy Smith, "USAF Condition-Based Maintenance Plus (CBM+) Initiative" (Maxwell-Gunter AFB Montgomery, AL: Air Force Logistics Management Agency, September 2003), 35. http://www.acq.osd.mil/log/logistics_materiel_readiness/organizations/mppr/assetts/cbm+/Air_Force/AFLMA%20CBM%20final%20Sep%2003.pdf (accessed June 7, 2006).

APPENDIX A. OFFSET MULTIPLIERS FOR DIRECT OFFSET COMMITMENTS IN THE REPUBLIC OF POLAND[136]

Subject of the commitment	Multipliers
1. Capital and tangible equity investments:	0.7 – 1.9
1) purchase of stock or shares from the State Treasury,	1.1 – 1.6
2) cash contribution to the share capital of a company,	1.1 – 1.9
3) in-kind contribution to the share capital of a company.	0.7 – 1.3
2. Intangible investments:	0.9 – 2.0
1) transfer of a technology and know-how connected with the production of:	1.2 – 2.0
a) rifles and ammunition,	1.7 – 2.0
b) armored and mechanized weapon,	1.2 – 1.5
c) aviation equipment,	1.8 – 2.0
d) electronic and optoelectronic equipment,	1.9 – 2.0
e) vessels,	1.4 – 1.8
f) logistical security equipment.	1.2 – 1.4
2) transfer of a license connected with production of:	0.9 – 1.7
a) rifles and ammunition,	1.5 – 1.7
b) armored and mechanized weapon,	0.9 – 1.3
c) aviation equipment,	1.5 – 1.7
d) electronic and optoelectronic equipment,	1.6 – 1.7
e) vessels,	1.1 – 1.3
f) logistical security equipment.	0.9 – 1.1
3) participation in the program of modernization of delivery's subjects (purchased armament or military equipment).	1.5 – 2.0
3. Direct purchase of goods and services manufactured on the territory of Republic of Poland:	0.5 – 2.0
1) connected with the subject of delivery of the armament or military equipment,	1.0 – 2.0
2) although not connected with the subject of delivery of the armament or military equipment, but	0.5 – 2.0
a) connected with production of rifles and ammunition,	1.6 – 2.0
b) connected with production of armored and mechanized weapon,	1.5 – 1.9
c) connected with production of aviation equipment,	1.7 – 2.0
d) connected with production of electronic and optoelectronic equipment,	1.8 – 2.0

[136] Republic of Poland. Ministry of Economy, "Ordinance of the Counsel of Ministers of 2 July 2002 concerning the detailed principles for crediting offset commitments of a foreign supplier of armament or military equipment against the offset agreement value," http://www.mgip.gov.pl/NR/rdonlyres/44734642-D9A7-4BFB-82F1FB48A5443547/12516/offset_mult_ordin_eng.pdf (accessed April 29, 2006).

Subject of the commitment	**Multipliers**
e) connected with production of vessels,	1.1 – 1.7
f) connected with production of logistical security equipment.	0.5 – 1.3
4. Development of the research, development and implementation potential (R+D+I):	1.0 – 2.0
1) offsettee's participation in an international:	1.0 – 2.0
a) aviation program,	1.8 – 2.0
b) other program.	1.0 – 1.7
2) foreign supplier's capital participation in offsettee's R+D works,	1.0 – 2.0
3) implementation of Polish development (e.g. establishment of the Venture Capital	1.0 – 2.0
5. Support of export of goods manufactured on the territory of Republic of Poland including:	0.5 – 1.5
1) sales of goods manufactured on the territory of Republic of Poland through an own marketing network,	0.5 – 1.5
2) marketing and promotion support for the export of the Polish goods in third markets,	0.5 – 1.2
3) other actions not specified in items 1 and 2.	0.5 – 1.2
6. Training:	0.5 – 1.1
1) connected with the transfer of technology or know-how,	0.7 – 1.1
2) connected with purchased armament or military equipment,	0.9 – 1.1
3) other.	0.5 – 0.9
7. Other fields not specified in items 1 through 6.	0.5 – 2.0

APPENDIX B. OFFSET MULTIPLIERS FOR INDIRECT OFFSET COMMITMENTS IN THE REPUBLIC OF POLAND[137]

Subject of the commitment	Multipliers
1. Capital and tangible equity investments:	0.7 – 1.9
1) purchase of stock or shares from the State Treasury,	1.1 – 1.6
2) cash contribution to the share capital of a company,	1.4 – 1.9
3) in-kind contribution to the share capital of a company.	0.7 – 1.3
2. Intangible investments:	0.9 – 2.0
1) transfer of modern technology and know-how in:	0.9 – 2.0
a) metallurgic, iron, and steel industry,	1.5 – 1.8
b) electro-machinery industry,	1.4 – 1.7
c) automotive industry,	1.2 – 1.5
d) chemical industry,	1.9 – 2.0
e) rail-train industry,	0.9 – 1.2
f) pharmaceutical industry,	1.9 – 2.0
g) light industry,	0.9 – 1.1
h) electronic industry,	1.5 – 2.0
i) shipyard industry,	1.5 – 2.0
j) IT field,	1.9 – 2.0
k) other sectors,	0.9 – 1.1
2) transfer of modern licenses in:	0.9 – 1.7
a) metallurgic, iron and steel industry,	1.4 – 1.7
b) electro-machinery industry,	1.2 – 1.5
c) electronic industry,	1.2 – 1.5
d) automotive industry,	1.1 – 1.3
e) shipyard industry,	1.1 – 1.3
f) chemical industry,	1.5 – 1.7
g) rail trains industry,	0.9 – 1.1
h) pharmaceutical industry,	1.4 – 1.7
i) light industry,	0.9 – 1.1
j) IT field,	1.5 – 1.7
k) other sectors,	0.9 – 1.1
3) direct purchase of goods and services manufactured on the territory of Republic of Poland in:	0.5 – 1.8

137 Republic of Poland, Ministry of Economy, "Ordinance of the Counsel of Ministers of 2 July 2002 concerning the detailed principles for crediting offset commitments of a foreign supplier of armament or military equipment against the offset agreement value," http://www.mgip.gov.pl/NR/rdonlyres/44734642-D9A7-4BFB-82F1FB48A5443547/12516/offset_mult_ordin_eng.pdf (accessed April 29, 2006).

Subject of the commitment	Multipliers
a) metallurgic, iron and steel industry,	1.5 – 1.8
b) electro-machinery industry,	1.6 – 1.8
c) electronic industry,	1.6 – 1.8
d) automotive industry,	1.2 – 1.4
e) shipyard industry,	1.2 – 1.4
f) chemical industry,	1.2 – 1.4
g) rail-train industry,	1.1 – 1.3
h) pharmaceutical industry,	1.3 – 1.6
i) light industry,	0.9 – 1.1
j) IT field,	1.5 – 1.8
k) other sectors.	0.5 – 1.1
3. Development of R+D+I potential:	1.0 – 2.0
1) offsettee's participation in an international program,	1.0 – 2.0
2) foreign supplier's capital participation in offsettee's R+D works,	1.0 – 2.0
3) implementation of the Polish development (e.g. establishment of the Venture	1.0 – 2.0
4. Support of export of goods manufactured on the territory of Republic of Poland:	0.5 – 1.5
1) sales of goods manufactured on the territory of Republic of Poland through an own	0.5 – 1.5
marketing network,	0.5 – 1.2
2) marketing and promotion support for the export of the Polish goods in third	0.5 – 1.2
5. Training:	0.5 – 1.1
1) connected with the transfer of technology or know-how,	0.7 – 1.1
2) other.	0.5 – 0.9
6. Other fields not specified in items 1 through 5.	0.5 – 2.0

APPENDIX C. OFFSET MULTIPLIERS USED IN CASES SPECIALLY JUSTIFIED BY THE ECONOMY OR DUE TO THE SECURITY AND DEFENSE OF THE STATE IN THE REPUBLIC OF POLAND[138]

Cases in which offset multipliers ranging from 2.0 to 5.0 may be applied	**Multipliers**
1. Transfer of modern technology, substantiated by prospective orders, which will result, within the implementation of the same offset agreement, in initiation of production basing on that technology.	3 – 5
2. Participation in modernization and restructuring of defense industry sector through capital equity investments, which will result in significant increase of export production and number of work places.	2 - 4
3. Transfer of technology with exclusivity for prospective production and sales on foreign market.	2 – 5
4. Free-of-charge and non-returnable transfer to a budgetary entity, for which the armament or military equipment was bought and delivery of which was subject to offset, of equipment for operation of that armament or military equipment and its technical documentation, enabling usage in accordance with the purpose of the purchased armament or military equipment and its maintenance in technical operation.	2 – 4
5. Transfer to the research and development entity or Polish higher education entity, of software or other modern IT tool which will support that entity's operation within the scope of design, production, or marketing.	2 – 3
6. Commissioning to a research and development entity or Polish higher education entity, within a joint R+D+I program, of package of works leading to rapid development of science sectors weakly recognized in Poland, which will result in significant increase research and production potential.	2 – 5
7. Commissioning to a research entity, within a joint R+D+I program, guarantee the undertaking of production Polish entrepreneurs.	2 – 4

138 Republic of Poland, Ministry of Economy, "Ordinance of the Counsel of Ministers of 2 July 2002 concerning the detailed principles for crediting offset commitments of a foreign supplier of armament or military equipment against the offset agreement value," http://www.mgip.gov.pl/NR/rdonlyres/44734642-D9A7-4BFB-82F1FB48A5443547/12516/offset_mult_ordin_eng.pdf (accessed April 29, 2006).

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APPENDIX D. OFFSET COMMITMENTS LIST INCLUDED IN MASTER OFFSET AGREEMENT[139]

No	ID no	Offset commitment	Offsetor	Offsetee
1	1-100	Creation of the professional nation mobile communication system according to the Tetra standard.	Motorola Inc.	ZR Radmor S.A., Gdynia, Computerland S.A., Procom S.A.
2	1-105	Support for the FAA certification and export to South and North America of the M-28 and M-18 aircraft. Upgrade of this aircraft models. Cooperation with PZM Mielec for assembly other types of aircraft.	Addison Equipment Company; AvCraft Aviation	Polskie Zakłady Lotnicze Sp. z o.o., Mielec
3	1-107	Transfer of technology for manufacturing wind power stations and the rights to sell them to the European Union's market.	Winvid, Belgium	CNPEP Radwar S.A., Warszawa PZL-Świdnik S.A., Świdnik
4	1-110	Capital contribution to the modernization of WSK PZL-Rzeszów S.A.	United Technologies Corporation / Pratt&Whitney, East Hartford, Ct. U.S.	WSK PZL-Rzeszów S.A. , Rzeszów
5	1-112	Creation of the Materiel Analysis Center at the Aeronautics Institute.	United Technologies Corporation/ Pratt&Whitney, East Hartford, Ct. U.S.	Instytut Lotnictwa, Warszawa
6	1-114	Purchase of aircraft parts from Polskie Zakłady Lotnicze Sp. z o.o.	United Technologies Corporation/ Pratt&Whitney, East Hartford, Ct. U.S.	Polskie Zakłady Lotnicze Sp. z o.o., Mielec
7	1-115	Accommodation of the Wojskowe Zakłady Lotnicze (Military Aeronautics Plant) # 4	United Technologies Corporation /	Wojskowe Zakłady Lotnicze Nr 4, Warszawa

139 Republic of Poland, Ministry of Economy, "List of Offset Commitments Included in the Master Offset Agreement,"http://www.mgip.gov.pl/NR/rdonlyres/565CC648-937F-4F03-99B2-C256C67BD475/0/lista_zobowiazan.doc (accessed April 29, 2006).

No	ID no	Offset commitment	Offsetor	Offsetee
		to the tests of F-100-PW-229 engines.	Pratt&Whitney, East Hartford, Ct. U.S.	
8	1-132	Purchase of aircraft components from PZL-Świdnik S.A.	Textron (Cessna Aircraft)	PZL-Świdnik S.A., Świdnik
9	1-133	Purchase of aircraft components from Polskie Zakłady Lotnicze Sp. z o.o.	Textron (Cessna Aircraft)	Polskie Zakłady Lotnicze Sp. z o.o.
10	1-134	Purchase of helicopters components from PZL-Świdnik S.A.	Textron (Bell Helicopter)	PZL-Świdnik S.A., Świdnik
11	1-137	Purchase of aircraft components from Kombinat PZL-Hydral S.A.	Textron Lycoming	Kombinat PZL-Hydral S.A. , Wrocław
12	1-139, 1-140	Modernization, repair and maintenance of the American aircraft for export purposes.	Aircraft Technologies Inc	Wojskowe Zakłady Lotnicze Nr 2, Bydgoszcz
13	1-145-1	Purchase components of superchargers and power equipments from WSK PZL-Rzeszów S.A.	Royston Components Ltd	WSK PZL-Rzeszów S.A. , Rzeszów
14	1-145-2	Purchase components of superchargers and power equipments from ZM Bumar-Łabędy S.A.	Royston Components Ltd	ZM Bumar-Łabędy S.A., Gliwice
15	1-2-126	Purchase metal products from HSW S.A.	Omniquip Textron	Huta Stalowa Wola S.A., Stalowa Wola
16	1-2-127	Purchase hydraulic gears from HSW S.A.	Textron Power Transmission, David Brown Hydraulics, U.S.	Huta Stalowa Wola S.A., Stalowa Wola
17	2-100	Export support system for polish small and middle businesses to the U.S.	US Chamber of Commerce; Washington DC; Sandia National Labs; Albuquerque, NM	Krajowa Izba Gospodarcza, Warszawa, Bartimpex, Warszawa
18	2-102	Modernization of the Gdańsk Refinery	Kellogg, Shell, DSD, Uhde, JGC	Rafineria Gdańska S.A., Gdańsk
19	2-103	Technology Accelerator	University of Texas-Austin, Austin, Texas, U.S.	Uniwersytet Łódzki, Łódź, Fundacja F.I.R.E. - Warszawa
20	2-104	Creation of a crisis coordination	LM Mission	Computerland S.A.,

No	ID no	Offset commitment	Offsetor	Offsetee
		system.	Systems	Prokom S.A.
21	2-106	Creation and implementation of the Medical Services Registry	Lockheed Martin Mission Systems	Computerland S.A., Prokom S.A.
22	2-1-109	Purchase RO-RO ships from Stocznia Szczecińska Nowa Sp. z o.o.	Lockheed Martin Aeronautics Co.	Stocznia Szczecińska Nowa Sp. z o.o., Szczecin
23	2-1-113	Modernization and export of P&W Kalisz Sp. z o.o.	United Technologies Corporation/ Pratt&Whitney, East Hartford, Ct. U.S.	PW Kalisz Sp. z o.o. , Kalisz
24	2-1-129	Purchase aircraft components from Goodrich Krosno S.A.	Goodrich	Goodrich Krosno S.A. , Krosno
25	2-1-135	Purchase of services from Goodrich Krosno S.A.	Textron (Cessna Aircraft)	Goodrich Krosno S.A. , Krosno
26	2-1-136	Purchase of services from WSK Gorzyce S.A.	Textron (Lycoming)	WSK Gorzyce S.A., Gorzyce
27	2-1-138	Purchase parts form Zakład Obróbki Plastycznej Świdnik Sp. z o.o.	Textron (Lycoming)	Zakład Obróbki Plastycznej Świdnik Sp. z o.o., Świdnik
28	2-116	Start-up production at Opel Polska Sp. z o.o. of a new model car T-3000 Astra and the production of spare parts.	Lockheed Martin Aeronautics Co.	Opel Polska Sp. z o.o., Gliwice
29	2-120-1	Capital investments in production and purchase of machine components.	Caterpillar World Trading; 76 route de Frontenex; CH-1211 Geneva 6, Switzerland	Caterpillar Poland Sp. z o.o., Janów Lubelski
30	2-120-2	Purchase components from Fabryka Aparatury i Urządzeń FAMET S.A. w Kędzierzyn Koźle	Caterpillar World Trading; 76 route de Frontenex; CH-1211 Geneva 6, Switzerland	Fabryki Aparatury i Urządzeń FAMET S.A., Kędzierzyn Koźle
31	2-120-3	Purchase components from Fabryka Maszyn Sp. z o.o.	Caterpillar World Trading; 76 route de Frontenex; CH-1211 Geneva 6, Switzerland	Fabryka Maszyn Sp. z o.o., Janów Lubelski
32	2-124	Purchase automotive components from Pezetel-Melex Sp. z o.o.	Textron Golf & Turf Care	Pezetel-Melex Sp. z o.o., Mielec
33	2-125	Purchase components from Alpha	Greenlee Textron	Alpha Sp. z o.o.,

No	ID no	Offset commitment	Offsetor	Offsetee
		Sp. z o.o.		Kraków
34	2-128	Capital investment and purchase electronic car components from Kimball Electronics Polska Sp. z o.o.	Kimball Electronics Group, Jasper, Indiana, U.S.	Kimball Electronic Polska Sp. z o.o., Poznań
35	2-131	Building of a simulators and training systems by ETC-PZL	Environmental Tectonics Corp.	ETC-PZL Sp. z o.o., Warszawa
36	2-133	Production of F-16 aircraft simulators	L-3 Communications; Link Simulation & Training; 2200 Arlington Downs; Arlington, Texas 76011 U.S.	ETC-PZL Sp. z o.o., Warszawa
37	2-134-1	Purchase aircraft components from Wytwórnia Aparatury Wtryskowej Mielec Sp. z o.o.	Royston Components Ltd	Wytwórnia Aparatury Wtryskowej Mielec Sp. z o.o., Mielec
38	2-134-2	Purchase supercharger components from Przedsiębiorstwo Automatyki Przemysłowej in Rzeszów	Royston Components Ltd	Przedsiębiorstwo Automatyki Przemysłowej, Rzeszów
39	2-134-3	Purchase supercharger components from Kuźni Glinik Sp. z o.o.	Royston Components Ltd	Kuźnia Glinik Sp. z o.o., Gorlice
40	2-134-4	Purchase automotive components from Teksid Aluminium Poland Sp. z o.o.	Royston Components Ltd	Teksid Aluminium Poland Sp. z o.o., Bielsko-Biała
41	2-134-5	Purchase automotive components from Andoria-MOT Sp. z o.o.	Royston Components Ltd	Andoria-MOT Sp. z o.o., Andrychów
42	2-134-6	Purchase machine components from Sipma S.A.	Royston Components Ltd	Sipma S.A., Lublin
43	2-137	Investment to restructuring of the Polish pharmaceutical industry and start-up of drug production.	Lockheed Martin Aeronautics Co.	Instytut Biotechnologii Antybiotyków, Warszawa, Bioton Sp. z o.o., Ożarów Mazowiecki
44	2-138	Production and export of blue laser	LM Areo	TopGaN Sp. z o.o., Warszawa Instytut Wysokich Ciśnień PAN, Warszawa

APPENDIX E. THE LIST OF LOCKHEED MARTIN'S OFFSET[140]

No	Number of commit-ments	Nominal value (without multi-plier)	Offset value (with applied offset multi-plier)	Type of commitment	Number of commit-ments	Nominal value (without multiplier)	Offset value (with applied offset multiplier)	% of total value
Direct Offset Commitments								
1	16 (27)	2,665	4,902	Purchase of goods and services	16	1,701	2861	22.7
				Transfer of technology and training	5	740	1510	12
				Financial/materiel contribution	5	199	481	3.7
				Other	1	25	50	0.7
Indirect Offset Commitments								
2	28 (47)	5,086	7,645	Purchase of goods and services	26	3,450	4785	38.1
				Transfer of technology and training	10	537	1268	10,1
				Financial/materiel contribution	7	291	627	5.0
				Other	4	808	965	7.7
	44	**7,751**	**12,547**	**Total**	**74**	**7,751**	**12547**	**100**

140 Republic of Poland, Ministry of Economy, "The Juxtaposition of Lockheed Martin's Offset Commitments," http://www.mgip.gov.pl/NR/rdonlyres/D388B4F0-F028-4D79-A15F-B5EFD29BDC8F/0/zestawienie_zbiorcze.doc (accessed April 29, 2006).

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APPENDIX F. LIST OF OFFSET AGREEMENTS IN POLAND AS OF 1 MARCH 2006[141]

No	Foreign supplier	Issue	Signed	Value*
1	EADS Construcciones Aeronauticas, Spain	connected with the delivery of C295M transport aircrafts for the Polish Air Force	28th of August 2001	212.04 million $
2	GEIE Eurotorp, France	connected with the delivery of light torpedoes for the Polish Navy	13th of December 2001	26.99 million €
3	THALES Nederland B.V., Netherlands	connected with the delivery of systems for ORKAN class ships for the Polish Navy	21st of December 2001	76.28 million€
4	Lockheed Martin Corporation, U.S.	connected with the delivery of F-16 fighters for the Polish Air Force	18th of April 2003	6.028 billion $
5	Patria Vehicles Oy, Finland	connected with the delivery of Armored Wheeled Vehicles (AMV) for the Polish Army	1st of July 2003	482 million €
6	Oto Melara S.p.A, Italy	connected with the delivery of Armored Wheeled Vehicles (AMV) for the Polish Army	1st of July 2003	308 million €
7	Rafael Armament Development Authority Ltd., Israel	connected with the delivery of Anti-Tank Guided Missiles for the Polish Army	17th of February 2004	440 million $

141 Republic of Poland, Ministry of Economy and Labor "List of offset agreements in Poland as of 1 January 2005," http://www.mgip.gov.pl/NR/rdonlyres/44734642-D9A7-4BFB-82F1-FB48A5443547/17854/www_ang_agreements_060303.pdf (accessed April 29, 2006).

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APPENDIX G. AOA PLAN[142]

The first major step for successful AoA plan is construction and coordination of the analysis plan. A recommended outline of the AoA plan may incorporate following points:

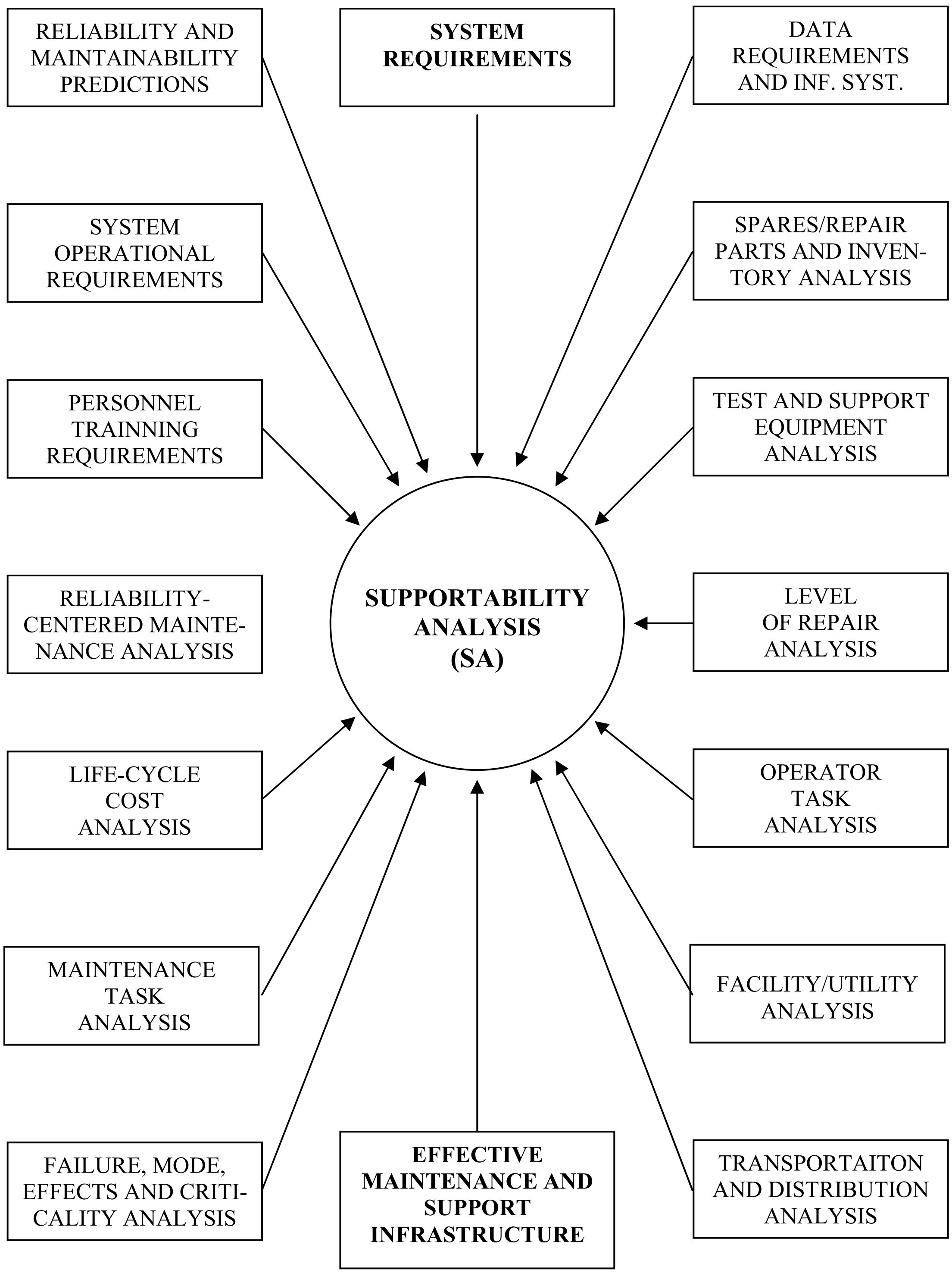
- Introduction
  - Background
  - Purpose
  - Scope
- Ground Rules
  - Scenarios
  - Threats
  - Environment
  - Constraints and Assumptions
- Alternatives
  - Description of Alternatives
  - Nonviable Alternatives
  - Operation Concepts
  - Support Concepts
- Determination of Effectiveness Measures
  - Mission Task
  - Measures of Effectiveness
  - Measures of Performance
- Effectiveness Analysis
  - Effectiveness Methodology
  - Model, Simulations and Data
  - Effectiveness Sensitivity Analysis
- Cost Analysis
  - Lifecycle Cost Methodology

[142] DAU, "Defense Acquisition Guidebook," para. 3.3.1.

    - Models and Data
    - Cost Sensitivity or/and Risk Analysis
- Cost Effectiveness Comparison
    - Cost Effectiveness Methodology
    - Displays or Presentation Formats
    - Criteria for Screening Alternatives
- Organization and Management
    - Study Team/Organization
    - AoA Review Process
    - Schedule

It must be pointed that every AoA is unique and may be adjusted to the particular situation. The proposal of AoA plan above may be used as a framework to tailor AoA to support given situation.

APPENDIX H. SUPPORTABILITY ANALYSIS[143]



[143] From: Blanchard, *Logistic Engineering and Management*, 199.

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APPENDIX I. AIRCRAFT OPERATING AND SUPPORT COST ELEMENT STRUCTURE[144]

1.0 **MISSION PERSONNEL**
- 1.1 OPERATIONS
- 1.2 MAINTENANCE
- 1.3 OTHER MISSION PERSONNEL

2.0 **UNIT-LEVEL CONSUMPTION**
- 2.1 POL/ENERGY CONSUMPTION
- 2.2 CONSUMABLE MATERIAL/REPAIR PARTS
- 2.3 DEPOT-LEVEL REPARABLES
- 2.4 TRAINING MUNITIONS/EXPENDABLE STORES
- 2.5 OTHER

3.0 **INTERMEDIATE MAINTENANCE (EXTERNAL TO UNIT)**
- 3.1 MAINTENANCE
- 3.2 CONSUMABLE MATERIAL/REPAIR PARTS
- 3.3 OTHER

4.0 **DEPOT MAINTENANCE**
- 4.1 OVERHAUL/REWORK
- 4.2 OTHER

5.0 **CONTRACTOR SUPPORT**
- 5.1 INTERIM CONTRACTOR SUPPORT
- 5.2 CONTRACTOR LOGISTICS SUPPORT
- 5.3 OTHER

6.0 **SUSTAINING SUPPORT**
- 6.1 SUPPORT EQUIPMENT REPLACEMENT
- 6.2 MODIFICATION KIT PROCUREMENT/INSTALLATION
- 6.3 OTHER RECURRING INVESTMENT
- 6.4 SUSTAINING ENGINEERING SUPPORT
- 6.5 SOFTWARE MAINTENANCE SUPPORT
- 6.6 SIMULATOR OPERATIONS
- 6.7 OTHER

7.0 **INDIRECT SUPPORT**
- 7.1 PERSONNEL SUPPORT
- 7.2 INSTALLATION SUPPORT

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144 From: OSD, "Operating and Support Cost-Estimating Guide," Appendix C.

AIRCRAFT OPERATING AND SUPPORT COST ELEMENT STRUCTURE DEFINITIONS

1.0 MISSION PERSONNEL

The mission personnel element includes the cost of pay and allowances of officer, enlisted, and civilian personnel required to operate, maintain, and support a discrete operational system or deployable unit. This includes the personnel necessary to meet combat readiness, unit training, and administrative requirements. For units that operate more than one type of aircraft system, personnel requirements will be allocated on a relative workload basis. The personnel costs will be based on manning levels and skill categories.

> Note: Pay and allowances for officer and enlisted personnel should be based on the standard composite rate, which includes the following elements: basic pay, retired pay accrual, incentive pay, special pay, basic allowance for quarters, variable housing allowance, basic allowance for subsistence, hazardous duty pay, reenlistment bonuses, clothing allowances, overseas station allowances, uniform allowances, family separation allowances, separation payments, and social security contributions.
>
> Pay and allowances for civilian personnel should be based on the standard composite rate, which includes the following elements: basic pay, additional variable payments for overtime, holiday pay, night differentials, cost-of-living allowances, and the government contribution to employee benefits, insurance, retirement, and the Federal Insurance Contribution Act.

1.1 OPERATIONS. The pay and allowances for the full complement of aircrew personnel required to operate a system. Aircrew composition includes the officers and enlisted personnel (pilot, non-pilot, and crew technicians) required to operate the aircraft of a deployable unit.

1.2 MAINTENANCE. The pay and allowances of military and civilian personnel who perform maintenance on and provide ordnance support to assigned aircraft, associated support equipment, and unit-level training devices. Depending on the maintenance concept and organizational structure, this element will include maintenance personnel at the organizational level and possibly the intermediate level[145]. A brief description of these maintenance categories is shown below:

- Organizational Maintenance. Personnel who perform on-equipment maintenance for unit aircraft.
- Intermediate Maintenance. Personnel who perform off-equipment

[145] For example, in a typical deployable Air Force unit, intermediate-level maintenance personnel are normally assigned to the same wing as the organizational maintenance personnel. Depending upon the weapon system, the other DoD components may integrate required intermediate-level maintenance personnel into a composite deployable unit according to the number of systems to be deployed.

maintenance for unit aircraft. If intermediate-level maintenance is provided by a separate support organization (e.g., a centralized intermediate maintenance support activity) the costs should be reported in element 3.0, Intermediate Maintenance (External to Unit).

- Ordnance Maintenance. Personnel performing maintenance and service functions for aircraft munitions, missiles, and related systems. Also includes personnel needed for loading, unloading, arming, and rearming of unit munitions; inspecting, testing, and maintaining of aircraft weapons and release systems; activation and deactivation of aircraft gun systems; and maintenance and handling of the munitions stockpile authorized by the war reserve material plan.

- Other Maintenance Personnel. Personnel not covered above. Includes those personnel that support equipment maintenance, simulator maintenance, and Chief of Maintenance functions related to the system whose costs are being estimated.

1.3 OTHER MISSION PERSONNEL. The pay and allowances of military and civilian personnel, who perform unit staff, security, and other mission support activities. The number and type of personnel in this category will vary depending on the requirements of the particular system. These billets exist only to support the system whose costs are being estimated. Some examples are:

- Unit Staff. Personnel required for unit command, administration, flying supervision, operations control, planning, scheduling, flight safety, aircrew quality control, etc.

- Security. Personnel required for system security. Duties may include entry control, close and distant boundary support, and security alert operations.

- Other Support. Personnel required for staff information, logistics, ground safety, fuel and munitions handling, and simulator operations as well as for special mission support functions such as intelligence, photo interpretation, etc.

2.0 UNIT-LEVEL CONSUMPTION

Unit-level consumption includes the cost of fuel and energy resources; operations, maintenance, and support materials consumed at the unit level; stock fund reimbursements for depot-level reparables; operational munitions expended in training; transportation in support of deployed unit training; temporary additional duty/temporary duty (TAD/TDY) pay; and other unit-level consumption costs, such as purchased services for equipment leases and service contracts.

2.1 POL/ENERGY CONSUMPTION. The unit-level cost of petroleum, oil, and lubricants (POL), propulsion fuel, and fuel additives required for peacetime flight operations. Includes in-flight and ground consumption, and an allowance for POL distribution, storage, evaporation, and spillage. May also include field-generated electricity and commercial electricity if necessary to support the operation of the system.

2.2 CONSUMABLE MATERIAL/REPAIR PARTS. The costs of material consumed in the operation, maintenance, and support of an aircraft system and associated support equipment at the unit level. Depending on the maintenance concept or organizational structure, consumption at the intermediate level should be reported either in this element or in element 3.0, Intermediate Maintenance (External to Unit). Costs need not be identified at the level of detail shown below; the descriptions are intended merely to illustrate the various types of materials encompassed in this element:

- Maintenance Material. The cost of material expended during maintenance. Examples include consumables and repair parts such as transistors, capacitors, gaskets, fuses, and other bit-and-piece material.

- Operational Material. The cost of non-maintenance material consumed in operating a system and support equipment. Examples include coolants, deicing fluids, tires, filters, batteries, paper, diskettes, ribbons, charts, and maps.

- Mission Support Supplies. The cost of supplies and equipment expended in support of mission personnel. Examples include items relating to administration, housekeeping, health, and safety.

2.3 DEPOT-LEVEL REPARABLES. The unit-level cost of reimbursing the stock fund for purchases of depot-level reparable (DLR) spares (also referred to as exchangeables) used to replace initial stocks. DLRs may include repairable individual parts, assemblies, or subassemblies that are required on a recurring basis for the repair of major end items of equipment.

> Note: Defense Management Report Decisions (DMRDs) 901 and 904 of November 1989 proposed the establishment of a Defense Business Operations Fund (DBOF) under which DLRs would be consolidated under stock fund management. The cost of DLRs, previously a free issue to the consumer, must now be funded and budgeted by the resource user. A surcharge is added to the price of DBOF items to recover the cost of stock fund operations.

2.4 TRAINING MUNITIONS/EXPENDABLE STORES. The cost of expendable stores consumed in unit-level training. Includes the cost of live and inert ammunition, bombs, rockets, training missiles, sonobuoys, and pyrotechnics expended in noncombat operations (such as firepower demonstrations) and training exercises.

2.5 OTHER. Include in this element any significant unit-level consumption costs not otherwise accounted for. The costs identified must be related to the system whose operating and support requirements are being assessed. Possible examples are:

- Purchased Services. The cost of special support equipment, communication circuits, and vehicles, including service contracts for custodial services, computers, and administrative equipment.

- Transportation. The deployed unit transportation cost of moving primary mission and support equipment, repair parts, secondary items, POL, and ammunition to and from training areas. May also include transportation costs for items procured or shipped by the unit. Excluded are transportation costs for reparables acquired through DBOF.

- TAD/TDY. Temporary additional duty or temporary duty (TAD/ TDY) pay. The cost of unit personnel travel for training, administrative, or other purposes such as crew rotations, deployments, or follow-on tests and evaluation. Includes commercial transportation charges, rental costs for passenger vehicles, mileage allowances, and subsistence expenses (e.g., per diem allowances and incidental travel expenses).

3.0 INTERMEDIATE MAINTENANCE (EXTERNAL TO UNIT)

Intermediate maintenance performed external to a unit includes the cost of labor and material and other costs expended by designated activities/units (third and fourth echelon) in support of an aircraft system and associated support equipment. Intermediate maintenance activities include calibration, repair, and replacement of parts, components, or assemblies, and technical assistance.

3.1 MAINTENANCE. The pay and allowances of military and civilian personnel who perform intermediate maintenance on an aircraft system, associated support equipment, and unit-level training devices.

3.2 CONSUMABLE MATERIAL/REPAIR PARTS. The costs of repair parts, assemblies, subassemblies, and material consumed in the maintenance and repair of aircraft, associated support equipment, and unit-level training devices.

3.3 OTHER. Include in this element any significant intermediate maintenance costs not otherwise accounted for. For example, this could include the cost of transporting subsystems or major end items to a base or depot facility.

4.0 DEPOT MAINTENANCE

Depot maintenance includes the cost of labor, material, and overhead incurred in performing major overhauls or maintenance on aircraft, their components, and associated support equipment at centralized repair depots, contractor repair facilities, or on site by depot teams. Some depot maintenance activities occur at intervals ranging from several months to several years. As a result, the most useful method of portraying these costs is on an annual basis (e.g., cost per aircraft system per year) or an operating-hour basis.

> Note: The cost of depot-level reparables (DLRs) or exchangeables acquired through DBOF should be reported in element 2.0, Unit-Level Consumption.

4.1 OVERHAUL/REWORK. The labor, material, and overhead costs for overhaul or rework of aircraft returned to a centralized depot facility. Includes programmed depot maintenance, analytic condition inspections, and unscheduled depot maintenance. Costs of major aircraft subsystems that have different overhaul cycles (i.e., airframe, engine, avionics, armament, support equipment) should be identified separately within this element.

4.2 OTHER. Include in this element any significant depot maintenance activities not otherwise accounted for. For example, this could include component repair costs for reparables not managed by the DBOF, second-destination transportation costs for weapons systems or subsystems requiring major overhaul or rework, or contracted unit-level support.

> Note: Not all reparable items are acquired through DBOF. Centrally funded accounts may continue to finance items such as classified program DLRs, conventional and nuclear munitions items, and certain cryptologic electronics and telecommunication items.

5.0 CONTRACTOR SUPPORT

Contractor support includes the cost of contractor labor, materials, and overhead incurred in providing all or part of the logistics support required by an aircraft system, subsystem, or associated support equipment. Contract maintenance is performed by commercial organizations using contractor personnel, material, equipment, and facilities or government-furnished material, equipment, and facilities. Contractor support may be dedicated to one or multiple levels of maintenance and may take the form of interim contractor support (ICS) if the services are provided on a temporary basis or contractor logistics support (CLS) if the support extends over the operational life of a system. Other contractor support may be purchased for engineering and technical services.

5.1 INTERIM CONTRACTOR SUPPORT. Interim contractor support (ICS) includes the burdened cost of contract labor, material, and assets used in providing temporary logistics support to a weapon system, subsystem, and associated support equipment. The purpose of ICS is to provide total or partial logistics support until a government maintenance capability is developed.

5.2 CONTRACTOR LOGISTICS SUPPORT. Contractor logistics support (CLS) includes the burdened cost of contract labor, material, and assets used in providing support to an aircraft system, subsystem, and associated support equipment. CLS funding covers depot maintenance and, as negotiated with the operating command, necessary organizational and intermediate maintenance activities. If CLS is selected as the primary means of support, all functional areas included in the CLS cost should be identified.

5.3 OTHER. Include in this element any contractor support costs not otherwise accounted for. For example, if significant, the burdened cost of contract labor for contractor engineering and technical services should be reported here.

> Note: Contractor support during the pre-operational phase of a system is typically funded as a system development or investment cost. However, post-operational contractor support is an O&S cost and should be addressed in this element.
>
> After the ICS period, the government assumes responsibility for supporting a weapon system. However, contractor support may still be employed in specific functional areas, such as sustaining engineering, software maintenance, simulator operations, and selected depot maintenance functions. Applicable contractor costs should be reported against these elements in the CES. To avoid double counting, the contractor support element should be annotated to identify any contractor costs that are reported in other elements.

6.0 SUSTAINING SUPPORT

Sustaining support includes the cost of replacement support equipment, modification kits, sustaining engineering, software maintenance support, and simulator operations provided for an aircraft system. War readiness material is specifically excluded.

6.1 SUPPORT EQUIPMENT REPLACEMENT. The costs incurred to replace equipment that is needed to operate or support an aircraft, aircraft subsystems, training systems, and other associated support equipment. The support equipment being replaced (e.g., tools and test sets) may be unique to the aircraft or it may be common to a number of aircraft systems, in which case the costs must be allocated among the respective systems.

> Note: This element addresses replacement equipment only. The costs of initial support equipment are specifically excluded.

6.2 MODIFICATION KIT PROCUREMENT/INSTALLATION. The costs of procuring and installing modification kits and modification kit initial spares (after production and deployment) required for an aircraft and associated support and training equipment. Includes only those modification kits needed to achieve acceptable safety levels, overcome mission capability deficiencies, improve reliability, or reduce maintenance costs. Excludes modifications undertaken to provide additional operational capability not called for in the original design or performance specifications.

6.3 OTHER RECURRING INVESTMENT. Include in this element any significant recurring investment costs not otherwise accounted for.

6.4 SUSTAINING ENGINEERING SUPPORT. The labor, material, and overhead costs incurred in providing continued systems engineering and program management oversight to determine the integrity of a system, to maintain operational reliability, to approve design changes, and to ensure system conformance with established specifications and standards. Costs in this category may include (but are not limited to) government and/or contract engineering services, technical advice, and training for component or system installation, operation, maintenance, and support.

6.5 SOFTWARE MAINTENANCE SUPPORT. The labor, material, and overhead costs incurred after deployment by depot-level maintenance activities, government software centers, laboratories, or contractors for supporting the update, maintenance and modification, integration, and configuration management of software. Includes operational, maintenance, and diagnostic software programs for the primary system, support equipment, and training equipment. The respective costs of operating and maintaining the associated computer and peripheral equipment in the software maintenance activity should also be included. Not included are the costs of major redesigns, new development of large interfacing software, and modifications that change functionality.

6.6 SIMULATOR OPERATIONS. The costs incurred to provide, operate, and maintain on-site or centralized simulator training devices for an aircraft system, subsystem, or related equipment. This may include the labor, material, and overhead costs of simulator operations by military and/or civilian personnel, or by private contractors.

> Note: On-site simulator operations and maintenance that are an integral part of unit manning and unit consumption should be reported as unit-level mission costs for the system in question. However, the costs of all contract-funded simulator operations and all centralized government simulator operations should be reported in this element.

6.7 OTHER. Include in this element any significant sustaining support costs not otherwise accounted for. Examples might include the costs of follow-on operational tests and evaluation, such as range costs, test support, data reduction, and test reporting.

7.0 INDIRECT SUPPORT

Indirect support includes the costs of personnel support for specialty training, permanent changes of station, and medical care. Indirect support also includes the costs of relevant host installation services, such as base operating support and real property maintenance.

7.1 PERSONNEL SUPPORT. Personnel support includes the cost of system-specific and related specialty training for military personnel who are replacing individuals lost through attrition. Also included in this element are permanent change of station costs, and the cost of medical care. Each of these elements should be addressed separately. Descriptions are provided below:

- Specialty Training. The cost of system-specific training (non-investment funded) and specialty training for military personnel who are replacing individuals lost through attrition. For example, specialty training costs may include undergraduate pilot training, non-pilot aircrew training, non-aircrew officer training, and enlisted specialty training. Replacement specialty training costs should be calculated for those personnel associated with the system being investigated. Training costs should include government non-pay-related training costs (course support costs, materials, per diem, travel, etc.) as well as the cost of pay and allowances for trainees, instructors, and training support personnel. Excluded are recruiting, accession, basic military training, and separation costs.

Note: The cost of initial course development and training of Service instructors at contractor facilities is normally categorized as a system investment cost. However, the follow-on training costs of military and civilian personnel attending factory schools, as well as the cost of attending Service conducted school-house specialty training, are O&S costs and should be reported in this element.

Normally, the costs of acquisition for recruiting, accession, and basic military training will not be included. However, if a significant change in Service recruiting and training objectives is required in order to support the system being assessed, then these costs should be addressed.

- Permanent Change of Station (PCS). The cost of moving replacement personnel to and from overseas theaters and within the continental US.

- Medical Support. The cost of personnel pay and allowances and material needed to provide medical support to system-specific mission and related military support personnel.

7.2. INSTALLATION SUPPORT. Consists of personnel normally assigned to the host installation who are required for the unit to perform its mission in peacetime. Include only those personnel and costs that are directly affected by a change in the number of aircraft and associated mission personnel. Functions performed by installation support personnel include:

- Base Operating Support. The cost of personnel pay and allowances and material necessary to provide support to system-specific mission- related personnel. Base operating support activities may include functions such as communications, supply operations, personnel services, installation security, base transportation, etc.

- Real Property Maintenance. The cost of personnel pay and allowances, material, and utilities needed for the maintenance and operation of system-specific mission-related real property and for civil engineering support and services.

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APPENDIX J. TIME-SERIES FORECASTING TECHNIQUES AND MEASURES OF ERROR[146]

A. TIME-SERIES FORECASTING TECHNIQUES

1. The Three-Year Moving Average (MA3)

The MA3 uses the average of the past three observations to forecast for the current period. The number of data points in each average remains constant and includes the most recent observations.

The formula for an MA3 is:

$$F_{t+1} = \frac{1}{3}\sum_{i=t-2}^{t} Y_i \qquad (1)$$

Where F_{t+1} is the current forecast, Y_i is the ith observation, and t is the sequence order number of the observation before the current forecast. The reason the order of the MA is three and not a higher order, such as five, which could possibly result in better forecasting, is due to the fact that the data series are small and having a larger order would greatly restrict the number of figures forecasted. Applying the method of moving averages to a set of data containing a trend gives forecasts that continually underestimate the actual values. (The same problem of lagging behind actual values exists when randomness is present).[147]

2. Single Exponential Smoothing (SES)

The SES method uses the following formula to forecast for the next period:

$$F_{t+1} = \alpha F_t + \alpha\left(Y_t - F_t\right) \qquad (2)$$

where, F_t is the most recent forecast, F_{t+1} is the current forecast, Y_t is the most recent observation, and alpha is a weight value between 0 and 1. The level of alpha dictates how much the previous forecast error is weighted, the weight of the previous error increases as

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[146] Adapted from Spyros Makridakis and Steven C. Wheelwright, *Forecasting: Methods and Applications*, (New York: John Wiley & Sons, Inc., 1978) and Jeffrey M. Moore and Larry R. Weatherford, Decision Modeling within Microsoft® Excel, 6th ed. (Upper Saddle River, NJ: Prentice Hall, 2001).

[147] Ibid., 55.

alpha increases and becomes closer to 1. This method is valuable because as each new forecast uses the error of the previous forecast it ends up using a weighted scheme that uses decreasing weights as the observations get older. The downfall of this forecasting method is the same as the MA3 in that it doesn't handle trends very well and it will trail any trend in the actual data.

3. Holt's Method[148]

The simple exponential smoothing models don't perform very well on models that have obvious up or down trend in the data. To correct this, Holt developed the following model:

$$L_t = \alpha Y_t + (1-\alpha)(L_{t-1} + b_{t-1}) \qquad (3)$$

$$b_t = \beta(L_t - L_{t-1}) + (1-\beta)b_{t-1} \qquad (4)$$

$$F_{t+m} = L_t + b_t m \qquad (6)$$

where L_t Lt is an estimate of the level of the series at time t and b_t is an estimate of the slope of the series at time t, alpha and beta are smoothing constraints between 0 and 1, Y_t is the most recent observation, L_{t-1} is the last smoothed value, b_{t-1} is trend of the previous period, and m is the number of periods ahead to be forecasted.

B. MEASURES OF ERROR

Three measures of error are:

(i) The *mean error*

$$ME = \frac{1}{n}\sum_{t=1}^{n} e_t$$

(ii) The *mean absolute error*

$$MAE = \frac{1}{n}\sum_{t=1}^{n} |e_t|$$

(iii) The *mean square error*

$$ME = \frac{1}{n}\sum_{t=1}^{n} e_t^2$$

148 Makridakis and Wheelwright call this method Holt's Two-Parameter Linear Exponential Smoothing.

The mean error is not very useful. It tends to be near zero as positive and negative errors tend to cancel. It is only of use in detecting systematic under or over forecasting.

The mean square error is a *squared* quantity so be careful and do not directly compare it with the MAE. Its square root is usually similar to the MAE.

The *relative* or *percentage error* is defined as

$$PE_t = \left(\frac{Y_t - F_t}{Y_t} \right) \times 100$$

The *mean percentage error* is

$$MPE = \frac{1}{n} \sum_{t=1}^{n} PE_t$$

and the *mean absolute percentage error* is

$$MPE = \frac{1}{n} \sum_{t=1}^{n} \left| PE_t \right|$$

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APPENDIX K. RESULTS OF FORECASTING METHODS

A. THREE YEAR MOVING AVERAGE (NOMINAL DOLLARS)

Year	F-16C	MA	Error	Abs Error	% Error	Abs % Error
1998	$ 7,649.80					
1999	$ 8,569.10					
2000	$ 9,475.27					
2001	$ 10,574.51	$ 8564.72	2,009.78	2,009.78	19.01%	19.01%
2002	$ 10,484.21	$ 9539.62	944.58	944.58	9.01%	9.01%
2003	$ 11,706.86	$ 10177.99	1,528.87	1,528.87	13.06%	13.06%
2004	$ 12,518.75	$ 10921.86	1,596.90	1,596.90	12.76%	12.76%
2005	$ 13,146.61	$ 11569.94	1,576.67	1,576.67	11.99%	11.99%

Year	F-16D	MA	Error	Abs Error	% Error	Abs % Error
1998	$ 6,842.45					
1999	$ 7,837.12					
2000	$ 8,081.13					
2001	$ 9,280.20	$ 7586.90	1,693.30	1,693.30	18.25%	18.25%
2002	$ 10,176.31	$ 8399.48	1,776.82	1,776.82	17.46%	17.46%
2003	$ 11,121.22	$ 9179.21	1,942.00	1,942.00	17.46%	17.46%
2004	$ 11,431.25	$ 10192.58	1,238.67	1,238.67	10.84%	10.84%
2005	$ 13,277.08	$ 10909.59	2,367.49	2,367.49	17.83%	17.83%

B. SES METHOD F-16C/D (NOMINAL DOLLARS)

Year	F-16C	SES	Error	Abs Error	% Error	Abs % Error
1998	$ 7,649.80	#N/A				
1999	8,569.10	$ 7,649.80	919.29	919.29	10.73%	10.73%
2000	9,475.27	8,293.31	1,181.96	1,181.96	12.47%	12.47%
2001	10,574.51	9,120.68	1,453.83	1,453.83	13.75%	13.75%
2002	10,484.21	10,138.36	345.85	345.85	3.30%	3.30%
2003	11,706.86	10,380.45	1,326.41	1,326.41	11.33%	11.33%
2004	12,518.75	11,308.94	1,209.81	1,209.81	9.66%	9.66%
2005	13,146.61	12,155.81	990.80	990.80	7.54%	7.54%

Year	F-16D	SES	Error	Abs Error	% Error	Abs % Error
1998	$ 6,842.45	#N/A				
1999	7,837.12	$ 6,842.45	994.66	994.66	12.69%	12.69%
2000	8,081.13	7,538.72	542.42	542.42	6.71%	6.71%
2001	9,280.20	7,918.41	1,361.79	1,361.79	14.67%	14.67%
2002	10,176.31	8,871.66	1,304.64	1,304.64	12.82%	12.82%
2003	11,121.22	9,784.91	1,336.30	1,336.30	12.02%	12.02%
2004	11,431.25	10,720.33	710.92	710.92	6.22%	6.22%
2005	13,277.08	11,217.97	2,059.11	2,059.11	15.51%	15.51%

***alpha* =** 0.89

Year	**CPFH/F-16C**	**Fcst EPS**	**Abs. Error**	**Abs. % Error**
1998	7,649.80	NA		NA
1999	8,569.10	$ 7,649.80	919.29	10.7%
2000	9,475.27	$ 8,569.10	906.17	9.6%
2001	10,574.51	$ 9,475.27	1099.24	10.4%
2002	10,484.21	$ 10,574.51	90.30	0.9%
2003	11,706.86	$ 10,484.21	1222.66	10.4%
2004	12,518.75	$ 11,706.86	811.89	6.5%
		$ 12,518.75	**$ 841.59**	
				8.1% = MAPE

***alpha* =** 0.91

Year	**CPFH/F-16D**	**Fcst EPS**	**Abs. Error**	**Abs. % Error**
1998	6,842.45	NA		NA
1999	7,837.12	$ 6,842.45	994.66	12.7%
2000	8,081.13	$ 7,837.12	244.02	3.0%
2001	9,280.20	$ 8,081.13	1199.07	12.9%
2002	10,176.31	$ 9,280.20	896.11	8.8%
2003	11,121.22	$ 10,176.31	944.91	8.5%
2004	11,431.25	$ 11,121.22	310.03	2.7%
		$ 11,431.25	**$ 764.80**	
				8.1% = MAPE

C. HOLT'S METHOD F-16C/D (NOMINAL DOLLARS)

Year	F-16C	Holt	Error	Abs Error	% Error	Abs % Error
1998	$ 7,649.80					
1999	8,569.10	$ 7,649.80	919.29	919.29	10.73%	10.73%
2000	9,475.27	$ 9,249.41	225.86	225.86	2.38%	2.38%
2001	10,574.51	$ 10,442.21	132.29	132.29	1.25%	1.25%
2002	10,484.21	$ 11,668.71	-1,184.50	1,184.50	-11.30%	11.30%
2003	11,706.86	$ 10,719.03	987.83	987.83	8.44%	8.44%
2004	12,518.75	$ 12,518.75	0.00	0.00	0.00%	0.00%
2005	13,146.61	$ 13,459.05	-312.43	312.43	-2.38%	2.38%

Year	F-16D	Holt	Error	Abs Error	% Error	Abs % Error
1998	$ 6,842.45					
1999	7,837.12	$ 6,842.45	994.66	994.66	12.69%	12.69%
2000	8,081.13	$ 8,573.20	-492.07	492.07	-6.09%	6.09%
2001	9,280.20	$ 8,582.36	697.84	697.84	7.52%	7.52%
2002	10,176.31	$ 10,233.89	-57.59	57.59	-0.57%	0.57%
2003	11,121.22	$ 11,178.09	-56.88	56.88	-0.51%	0.51%
2004	11,431.25	$ 12,073.42	-642.18	642.18	-5.62%	5.62%
2005	13,277.08	$ 11,900.83	1,376.25	1,376.25	10.37%	10.37%

alpha = 0.87
beta = 1.00

Year	CPFH/F-16C	Level Term	Trend Term	Fcst EPS	Abs. Error	Abs. % Error
1998	$ 7,649.80	$ 7,649.80	0	NA		NA
1999	$ 8,569.10	$ 8,449.61	799.803	$ 7,649.80	919.29	10.7%
2000	$ 9,475.27	$ 9,445.91	996.303	$ 9,249.41	225.86	2.4%
2001	$ 10,574.51	$ 10,557.31	1111.401	$ 10,442.21	132.29	1.3%
2002	$ 10,484.21	$ 10,638.17	80.861	$ 11,668.71	1184.50	11.3%
2003	$ 11,706.86	$ 11,578.46	940.291	$ 10,719.03	987.83	8.4%
2004	$ 12,518.75	$ 12,518.75	940.292	$ 12,518.75	0.00	0.0%
				$ 13,459.05	**$ 574.96**	
						5.7% **= MAPE**

alpha = 0.87
beta = 1.00

Year	CPFH/F-16C	Level Term	Trend Term	Fcst EPS	Abs. Error	Abs. % Error
1998	$ 6,842.45	$ 6,842.45	0	NA		NA
1999	$ 7,837.12	$ 7,707.83	865.374	$ 6,842.45	994.66	12.7%
2000	$ 8,081.13	$ 8,145.09	437.268	$ 8,573.20	492.07	6.1%
2001	$ 9,280.20	$ 9,189.49	1044.400	$ 8,582.36	697.84	7.5%
2002	$ 10,176.31	$ 10,183.79	994.298	$ 10,233.89	57.59	0.6%
2003	$ 11,121.22	$ 11,128.61	944.816	$ 11,178.09	56.88	0.5%
2004	$ 11,431.25	$ 11,514.72	386.111	$ 12,073.42	642.18	5.6%
				$ 11,900.83	**$ 490.20**	
						5.5% **= MAPE**

D. THREE YEAR MOVING AVERAGE (FY05 DOLLARS)

Year	F-16C/$TY	F-16C/ $05	MA ($FY05)	Error	Abs Error	% Error	Abs % Error
1998	7,649.80	9,161.44					
1999	8,569.10	10,045.84					
2000	9,475.27	10,742.93					
2001	10,574.51	11,658.77	9,983.40	1,675.37	1,675.37	14.37%	14.37%
2002	10,484.21	11,383.50	10,815.85	567.66	567.66	4.99%	4.99%
2003	11,706.86	12,427.67	11,261.74	1,165.93	1,165.93	9.38%	9.38%
2004	12,518.75	12,945.97	11,823.31	1,122.66	1,122.66	8.67%	8.67%
2005	13,146.61	13,146.61	12,252.38	894.23	894.23	6.80%	6.80%

Year	F-16D/$TY	F-16D/ $05	MA ($FY05)	Error	Abs Error	% Error	Abs % Error
1998	6,842.45	8,194.55					
1999	7,837.12	9,187.71					
2000	8,081.13	9,162.28					
2001	9,280.20	10,231.75	8,848.18	1,383.57	1,383.57	13.52%	13.52%
2002	10,176.31	11,049.19	9,527.25	1,521.95	1,521.95	13.77%	13.77%
2003	11,121.22	11,805.96	10,147.74	1,658.22	1,658.22	14.05%	14.05%
2004	11,431.25	11,821.35	11,028.97	792.38	792.38	6.70%	6.70%
2005	13,277.08	13,277.08	11,558.84	1,718.24	1,718.24	12.94%	12.94%

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