2010-09

A comparison of the fully burdened cost of fuel methodologies used across the Department of Defense

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http://hdl.handle.net/10945/5135

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

A COMPARISON OF THE FULLY BURDENED COST OF FUEL METHODOLOGIES EMPLOYED ACROSS THE DEPARTMENT OF DEFENSE

by

Scott A. Roscoe

September 2010

Thesis Advisor: Daniel A. Nussbaum

Second Reader: Douglas R. Burton

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REPORT DOCUMENTATION PAGE — *Form Approved OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2010	Master's Thesis

4. TITLE AND SUBTITLE A Comparison of the Fully Burdened Cost of Fuel Methodologies Employed Across the Department of Defense

5. FUNDING NUMBERS

6. AUTHOR(S) Scott A. Roscoe

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES)
OPNAV N81

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number ________________.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (maximum 200 words)

This thesis describes the various Fully Burdened Cost of Fuel (FBCF) methodologies under development across the Department of Defense. A comparison of the Air Force FBCF Calculator and the OSD (AT&L) FBCF Calculator is performed and identifies the similarities and differences between the methodologies to include an analysis of the output of each calculator.

Our analysis indicates that while the methodologies used to calculate the FBCF vary among the Services, the underlying principles that those calculations are based upon are common. The FBCF Methodologies can produce similar results.

Recommendations for follow on studies are provided.

14. SUBJECT TERMS
Fully Burdened Cost of Fuel, FBCF, Analysis of Alternatives, AOA, acquisition, life-cycle costs, Monte Carlo

15. NUMBER OF PAGES 89

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

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ABSTRACT

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Our analysis indicates that while the methodologies used to calculate the FBCF vary among the Services, they share common underlying principles and the FBCF methodologies can produce similar results.

Recommendations for follow on studies are provided.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADP	Assured Delivery Price
AESIS	Army Energy Security Implementation Strategy
AFEPPM	Air Force Energy Program Policy Memorandum
AFTOC	Air Force Total Ownership Cost
AoA	Analysis of Alternatives
CAMS-ME	Capital Asset Management System
CDR	Commander
COA	Course of Action
CONUS	Continental United States
DAG	Defense Acquisition Guidebook
DAU	Defense Acquisition University
DDR&E	Director of Defense Research and Engineering
DESC	Defense Energy Supply Center
DoD	Department of Defense
DON	Department of the Navy
DSB	Defense Science Board
DUSD(I&E)	Office of the Deputy Under Secretary of Defense (Installations and Environment)
EO	Executive Order
FBCF	Fully Burdened Cost of Fuel
FOB	Forward Operating Base
FORCES	Force and Organization Cost Estimating System
FY	Fiscal Year
GCV	Ground Combat Vehicle
HBCT	Heavy Brigade Combat Team
JASON	The JASON Group
JSTARS	Joint Surveillance and Target Attack Radar System
KPP	Key Performance Parameter
LCC	Life-cycle Cost
LCDR	Lieutenant Commander
LMI	LMI Government Consulting
MDAP	Major Defense Acquisition Program

MORS	Military Operations Research Society
NATO	North Atlantic Treaty Organization
NDAA	National Defense Authorization Act
O&M	Operations and Maintenance
O&S	Operations and Support
OMS/MP	Operational Mode Summary/Mission Profile
OPTEMPO	Operating Tempo
OSD (AT&L)	Office of the Under Secretary of Defense (Acquisition, Technology and Logistics)
QDR	Quadrennial Defense Review
REMIS	Reliability and Maintainability Information System
VAMOSC	Visibility and Management of Operating and Support Costs

EXECUTIVE SUMMARY

The purpose of this thesis is to describe the various methodologies used by the United States Armed Services to calculate the Fully Burdened Cost of Fuel (FBCF). The FBCF includes the Defense Energy Supply Center (DESC) standard price and the indirect costs associated with the delivery of fuel to the end user. The indirect costs are the costs that the Services pay to deliver fuel to the point of use once acquired from DESC. The indirect costs include but are not limited to; manpower, infrastructure, delivery assets and force protection. Indirect costs have the potential to increase the cost of delivered fuel significantly. Legislation has directed the Armed Services to consider the FBCF in all Major Defense Acquisition Programs (MDAP). It follows that the services need to determine how to calculate the FBCF. Each service has been working to develop a FBCF methodology that satisfies the congressional requirements and adds value and insight to the acquisition process.

This thesis performs the following analyses:

- Describes the various FBCF methodologies developed or under development by each branch of the United States Armed Service.
- Compares the similarities and differences among the Service's FBCF methodologies, to include an analysis of the various estimates and any numerical differences produced by the methodologies employed across the Department of Defense (DoD).

This study finds that each of the service branches have incorporated the fundamental concept of using a seven-step process into their methodologies. While the definition of the units of the FBCF is not consistent across the Department of Defense, the Services do agree and understand the underlying principles that the FBCF represents. Those principles are that the Department of Defense undervalues the cost of fuel and the FBCF is a tool that incorporates a number of those costs so that we can properly value

efficiencies and new technologies during the acquisition process. The Services and OSD (AT&L) do not currently agree upon a single method of implementation despite coming to similar results via different methodologies.

Additionally, this study indicates that the different logistical structures of the various services may require different methodologies for calculating the FBCF. A single FBCF tool that is broad enough to be useful for all of the service branches may not provide enough specific functionality to be as useful as individual service methodologies.

The recommendations of this study are first, that the definitions and units of the FBCF be consistent across the Department of Defense. Secondly, that the FBCF require a scenario. Finally, it is necessary to have a stochastic mechanism address the uncertainty associated with all the estimates required as input for the calculation.

ACKNOWLEDGMENTS

A special thanks to Mr. David Bak and Mr. Rick Cotman of OSD (AT&L), Mr. David Hull of ASA FMC, and Mr. Ashton Bulloch of AFCAA FMFS for furthering the development of the Fully Burdened Cost of Fuel and their cooperation and assistance in the completion of this thesis.

My sincerest gratitude goes out to Dr. Daniel Nussbaum and CDR Douglas Burton for their guidance, patience, and wise insight in the accomplishment of this work.

My deepest appreciation goes out to my daughter, Logan, who is an unrelenting source of love in my life, and my son, Jaxon, who more than anyone, has taught me the meaning of strength.

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I. INTRODUCTION

The majority of the life cycle costs for petroleum-using weapon systems are in the operations and support phase. Further, the cost of petroleum product is one of the dominant components of the operations and support phase. The full extent of the energy cost associated with delivered fuel has been difficult to understand in the past. It is the purpose of the Fully Burdened Cost of Fuel (FBCF) concept to allow a proper valuation of the energy costs when choosing among alternatives during the acquisition process.

The purpose of this thesis is to describe the various methodologies used by the United States Armed Services to calculate the Fully Burdened Cost of Fuel (FBCF). The FBCF includes the Defense Energy Supply Center (DESC) standard price and the indirect costs associated with the delivery of fuel to the end user. The indirect costs are the costs that the Services pay to deliver fuel to the point of use once acquired from DESC. The indirect costs include but are not limited to; manpower, infrastructure, delivery assets and force protection. Indirect costs have the potential to increase the cost of delivered fuel significantly. Legislation has directed the Armed Services to consider the FBCF in all Major Defense Acquisition Programs (MDAP). It follows that the services need to determine how to calculate the FBCF. Each service has been working to develop a FBCF methodology that satisfies the congressional requirements while adding value and insight to the acquisition process.

This thesis performs the following analyses:

- Describe the various FBCF methodologies developed or under development by each branch of the United States Armed Service.
- Compare the similarities and differences among the Service's FBCF methodologies, to include an analysis of the various estimates and any numerical differences produced by the methodologies employed across the Department of Defense (DoD).

There are several reasons to consider the FBCF in our employment of energy based weapon systems:

- The resources required to operate our platforms in a theater of war
- The risks to service member lives and equipment

As we will see, force protection or security requirements make up a large portion of the burdens. The reason so much of the costs are in this element of the FBCF is that our logistics tails associated with fuel can be very appealing targets, which require significant resources to protect. Furthermore, by adding additional protection, we are exposing more of our forces to potential attack and risk to life and equipment. The FBCF can inform decisions that have the potential to save lives, as well as conserve resources.

A. PREVIOUS STUDIES

The Defense Science Board (DSB), the JASON Group (JASON), LMI Government Consulting (LMI), and the Naval Postgraduate School have completed studies that discuss the need to decrease the military's reliance on fossil fuels. Additionally, these studies and reports explore ways to achieve a reduced reliance on fossil fuels. Previous work on the FBCF has been motivated by legislative, Presidential, and DoD guidance for economic, environmental, and national defense reasons. While facilities management, especially in the continental United States (CONUS), has produced energy efficiencies, there are potentially large energy savings available in the mobile military forces. In order to realize these savings, the military must have the ability to address energy efficiencies in the acquisition process. Policy and guidance focused primarily on conservation has the potential to reduce the amount of fossil fuels consumed. These reductions can provide some economic and environmental achievements, but can also adversely influence readiness. Methods and technologies need to be developed that allow DoD to maintain readiness while reducing the military's reliance on fossil fuels. The best way, long term, to address the military's reliance on fossil fuels is by increasing efficiency or alternative energy sources, not conservation. The FBCF is a tool that can assist in this process by motivating the engineering of energy efficiencies into our mobile forces. These energy efficiencies should reveal the economic, environmental, and national defense purposes for fossil fuel reduction.

1. DSB Task Force on Improving Fuel-Efficiency of Weapon Systems

The DSB, sponsored by the Under Secretary of Defense (Acquisition, Technology, and Logistics) (OUSD (AT&L)), gathered on June 18, 1999 to "identify technologies that improve fuel efficiency of the full range of weapons platforms (land, sea, and air) and assess their operational, logistics, cost and environmental impacts for a range of practical implementation scenarios" (OUSD (AT&L), 1999, p.1). In 2001, the DSB published the final report of this meeting titled, More *Capable Warfighting through Reduced Fuel Burden.* The findings and recommendations, found in appendix A, address a comprehensive view of fuel costs and suggest ways to capture and properly value those costs in the acquisition process. (DSB, 2001)

2. DSB Task Force on DoD Energy Strategy

OSD (AT&L) sponsored the DSB a second time to address:

- Opportunities to reduce fuel demand and assess the effects on cost, operations and force structure
- Opportunities to deploy renewable and alternative energy sources for facilities and deployed forces
- Institutional barriers to making the transitions recommended by the Task Force
- The potential national benefits from the DoD deployment of new energy technologies.

The findings and recommendations of this meeting were published in the December 2008 report, *More Fight-Less Fuel*. The DSB points out that there is a lack of strategy, policies, metrics, or governance structure necessary to manage its energy risks. It goes on to recommend the development and implementation of energy efficiency Key

Performance Parameters (KPPs) and the use of the FBCF to inform all acquisition tradeoffs and analyses about their energy consequences. (DSB, 2007)

3. JASON Report JSR-06-135

In 2006, the Director of Defense Research and Engineering (DDR&E) charged the JASON Group with “assessing pathways to reduce DoD’s dependence on fossil fuels” (JASON, 2006, p. iii). The JASON report comes from the national defense perspective and focuses on supply to demand and tooth to tail issues.

JASON explored the fossil fuels environment and came to several conclusions that underpin the concept of FBCF. Their report stated that fuel is “characterized by large multipliers and co-factors” and that “fuel use imposes large logistical burdens, operational constraints and liabilities, and vulnerabilities” (JASON, 2006, p. i – p. iv). The report conducted analyses which determined that air-to-air delivered fuel costs $20-$25 per gallon (FY05$) and that the standard price of the fuel was the smallest component of the cost. Additionally, they calculated that delivering fuel to the front lines for the army could range between $100 - $600 per gallon (FY05$) depending on factors such as distance, terrain, security concerns and many other requirements that may be present.

Additionally, the report pointed out that there is time to address energy concerns in the military due to the amount of petroleum reserves in existence and the anticipated global petroleum output. Yet, due to the unpredictable nature of the future, the report advised to begin reduction of DoD’s dependence on fossil fuels.

4. LMI Report FT602T1

Strategic consultants LMI published *Transforming the Way DOD Looks at Energy: an Approach to Establishing Energy Strategy* in 2007. The study describes findings and recommendations aimed at developing a comprehensive DoD energy strategy. LMI identified three primary disconnects between DoD’s current energy consumption practices and the capability requirements of its strategic goals: strategic, operational, and fiscal. The report also describes a fourth parallel disconnect as environmental.

The strategic disconnect addresses our increasing reliance on foreign sources of energy and our need to either ensure security in those regions or reduce our reliance on the foreign controlled sources of energy. Inability to successfully address this disconnect can "limit our ability to shape the future security environment" (LMI, 2007, p. 2–8). The need to protect our foreign sources of energy will dictate our security requirements at the expense of other security needs that have the potential to weaken our security as a whole.

The operational disconnect exists due to our policy of continued forward presence globally, mobility to project deterrence and sustain forces, and our policy of maneuver to quickly defeat any adversary. These goals result in significant energy usage and since the rates of consumption have been trending up over time, even higher energy usage is predicted in the future. DESC estimates that over 20,000 soldiers and over $1 million per day are required to provide fuel to support combat operations. This requirement and long logistic supply lines are significant vulnerabilities for our combat forces. These vulnerabilities represent the major reasons for the urgent calls to reduce reliance on delivered energy at our front line bases.

The fiscal disconnect exists due to rising fiscal pressure and increasing cost to operate and support the armed forces. In between these two forces is the need to recapitalize our forces that demands the engineering of efficiencies into our future force. LMI recommends studying the "delivered cost of fuel for the military" so that we understand the true cost of fuel (LMI, 2007, p. 2–10). The fiscal disconnect is behind one of the pertinent recommendations to this study which is to "incorporate energy considerations (energy use and energy logistical support requirements) in all future concept developments, capability developments, and acquisition actions" (LMI, 2007, p. 4).

5. Naval Postgraduate School Theses on the FBCF

In September 2009, the Naval Postgraduate School published a thesis by LCDR Robert Corley titled *Evaluating the Impact of the Fully Burdened Cost of Fuel* that reviewed current Department of the Navy (DON) Major Defense Acquisition Programs (MDAP) and provided an analysis of those programs that the implementation of the FBCF may affect. LCDR Corley's thesis implemented a developmental model for calculating the FBCF, and conducted an analysis of the estimates obtained. The analysis used the OSD (AT&L) FBCF calculator to determine the FBCF for a notional destroyer (DDG-51) fleet under a couple of varying scenarios. The analysis found that the DESC standard price of delivered fuel can be between 30 to 50 percent of the FBCF in a maritime scenario. This study further recommended the use of the FBCF as a fiscally responsible way to consider fuel-related costs during the acquisition process (Corley, 2009, p. 42).

In June 2010, the Naval Postgraduate School published a thesis by CDR Daniel Truckenbrod titled *Estimating the Fully Burdened Cost of Fuel for Naval Aviation Fixed Wing Platform.* His thesis furthered the understanding of the Fully Burdened Cost of Fuel in a naval aviation environment. Using the OSD (AT&L) calculator, CDR Truckenbrod calculated the FBCF for the F/A-18 E/F aircraft. The FBCF for the F/A-18 E/F aircraft is about twice as high as the FBCF for a notional destroyer (DDG-51) fleet calculated by LCDR Corley in his thesis. CDR Truckenbrod discussed the differences between the two calculations and highlighted the many assumptions that need to be made in order to calculate the FBCF for a particular platform in a specific scenario. CDR Truckenbrod concluded that aerial refueling is a significant part of the logistics support costs and that investment in fuel conservations technologies and platform endurance can be a strategic opportunity for the Department of Defense and Navy Service (Truckenbrod 2010, v).

6. MORS Power and Energy Special Meeting

The Military Operations Research Society (MORS) sponsored a mini symposium entitled the "Power and Energy Special Meeting" in December 2009 to discuss the development and utilization of both an energy key performance parameter and the Fully Burdened Cost of Fuel. It is the author's observation at the "Power and Energy Special Meeting" that the participants of the meeting acknowledged that there is not currently an agreed upon methodology to calculate the FBCF. Additionally, it is the author's view that a consensus was building to accept the seven-step process developed by OSD (AT&L) as the top-level architecture for the calculation of the FBCF.

Vice Admiral (Select) Burke, Director, Naval Warfare Integration Group (NOOX) and the Navy Quadrennial Defense Review (QDR) supported the goals of the meeting by stating, "The Department of Defense (DoD) undervalues the cost of fuel. The cost per barrel is just a small fraction of the cost." He went on to say, "It is best if we all have the same Fully Burdened Cost of Fuel [methodology]" (MORS, Dec 2009). While various methodologies were proposed and shared, a single methodology was not developed or agreed upon during the meeting.

B. DOD ENERGY POSTURE

The reports, studies and meetings above stress the importance of the Fully Burdened Cost of Fuel. Additionally, the 2009 National Defense Authorization Act (NDAA) requires that "the life-cycle cost analysis for new capabilities include the fully burdened cost of fuel during analysis of alternatives and acquisition program design trades" (NDAA, 2009, SEC. 332(c)). Thus, it is important to consider the FBCF for all fuel-consuming systems so it is possible to properly value the impact of supporting and sustaining the energy needs of that system. As a result, we can no longer take the energy needs of our future weapon systems for granted. Furthermore, an assumption that the logistic experts will simply figure out a solution to the energy support system has the potential to compromise the future security of our nation.

1. OUSD (AT&L): Providing the Roadmap

In March 2008, Deputy Under Secretary of Defense (Acquisition & Technology), Mr. Chris DiPetto, testified before the United States House Committee on Armed Services Readiness Subcommittee that "strategic planning and long-term costing should include not only the price of the fuel, but all the logistics effort" associated with delivery of the fuel (DiPetto, 2008, p. 4). OUSD (AT&L) has established itself as the leader in the development of a mature FBCF methodology through their strategic communication at the MORS Power and Energy Special Meeting and through their publication of the Defense Acquisition Guidebook (DAG). DoD Instruction 5000.02, *Operation of the Defense Acquisition System*, revised The DAG in 2008. It directs that "the fully burdened cost of delivered energy shall be used in trade-off analysis for all DoD tactical systems with end items that create a demand for energy" (DAU, 2008). Additionally, OSD (AT&L) has developed several generations of FBCF calculators that the Navy and the Marine Corps used to establish their own calculators based upon the OSD (AT&L) prototypes. While the there is a desire to have a mature methodology and legislation requires the use of the FBCF, the services have not settled on a single methodology to calculate the FBCF.

C. DIRECTION OF THE SERVICE BRANCHES

Since the 2009 National Defense Authorization Act has directed the use of the FBCF, all of the Services have adopted a process by which to calculate the FBCF.

Our investigation into the energy policies of each of the Services shows that they are not all the same, and these differences have the potential to shape how the Services calculate the FBCF. A general idea of the content of an energy policy for a particular service may provide some insight into why that service calculates the FBCF in a particular manner. The following paragraphs describe the energy policies of the Service Branches.

1. Department of the Navy

In the document "Naval Energy: A Strategic Approach" published in October of 2009, the Honorable Mr. Ray Mabus, Secretary of the Navy, states that our sources of energy are vulnerable and the Naval Services must become more energy efficient. The Department of Defense uses 93 percent of the Federal Government's energy and is the single largest consumer of energy in the country (but only one percent of national use). It is the responsibility of the Services to develop practices and technologies that can mitigate our risks associated with the current practices of deliver energy. Mr. Mabus says, "Over-reliance on fossil fuels is bad strategy, bad business, and bad for the planet" (SECNAV, 1). The "Naval Energy: A Strategic Approach" discusses tactical energy security:

> Tactical energy security is protection from vulnerabilities related to the energy requirements of tactical platforms by reducing risk associated with a logistics tail, volatile petroleum prices, and the instability of unfriendly petroleum suppliers. The Navy increases tactical energy security by decreasing overall liquid fuel consumption, increasing the fuel efficiency of tactical platforms, and using alternative fuels (SECNAV, 6).

The "Naval Energy: A Strategic Approach" challenges everyone to find innovative techniques and practices to reduce our reliance on energy.

2. Department of the Army

The Secretary of the Army and the Army Senior Energy Council approved the "Army Energy Security Implementation Strategy (AESIS)" on January 13, 2009. This publication declares that the United States Military is one of the largest consumers of energy in the nation and had expended over $4.1 billion for fuel and energy in 2008. The AESIS cites the high level of energy consumption by the Army as being the leverage available to the Army to institute change. Change is required due to the expected increase in fossil fuel demand and decrease in fossil fuel supplies. The Army's heavy reliance on petroleum sources of energy puts mission accomplishment at risk. The AESIS reports, "lower tactical fuel demands would place fewer soldiers in harm's way during their support of the long logistical fuel tail in theatre" (AESIS, i). Most applicable to this thesis is that AESIS calls for specific implementation activities that support energy security objectives and their associated metrics. Development and implementation of metrics are discussed and AESIS states, "Principal metrics will be based on both quantitative and qualitative requirements for energy performance that have been established by legislation, Presidential Executive Orders (EO), Office of the Secretary of Defense (OSD) mandates and Army policies"

The Army also published five Strategic Energy Security Goals with associated metrics to monitor over time. The goals are:

- Reduced Energy Consumption
- Increased Energy Efficiency Across Platforms and Facilities
- Increased Use of Renewable/Alternative Energy
- Assured Access to Sufficient Energy Supply
- Reduced Adverse Impacts on the Environment

Amplifying guidance says the achievement of these goals is in no way to decrease the operational effectiveness of the Army's forces and shall not inhibit the ability of the Army to accomplish its mission.

3. Department of the Air Force

The Department of the Air Force released the "Air Force Energy Program Policy Memorandum on June 16, 2009. The memorandum states the need to "make energy a consideration in all that we do." (AFEPPM 10-1.1, 5). The strategy goes on to say:

> The Air Force's Energy Strategy addresses all aspects of operations. This strategy balances demand-side energy efficiency measures with a long-term commitment to supply-side alternative energy sources. Executing the strategy will increase energy security and reduce costs.

The Air Force lays out three main components for their Energy Strategy:

- Reduce Demand, which focuses on conservation.
- Increase Supply, which focuses on new and alternative technologies and energy sources.
- Culture Change, which emphasizes the need to create a culture where all Airmen make energy a consideration in everything they do, every day.

The "Air Force Energy Program Policy Memorandum" describes Overarching Goals, Implementation Goals, Overarching Objectives and Metrics for each of the three main components of the strategy. The goals and their associated metrics are:

- Reduce demand
  - Barrels of aviation fuel consumed per flight hour
  - Average amount of energy consumed per building per square foot
  - Average miles per gallon (MPG) of non-tactical ground vehicles
- Increase supply
  - Percentage of alternative/renewable fuel used for aviation fuel requirements
  - Percentage of alternative fuels used for installation energy requirements
  - Percentage of alternative/renewable fuel used for non-tactical ground vehicle requirements

Of particular interest to this thesis is the establishment of the Acquisition and Technology Working Group, which is directed to focus on the development of energy options to increase warfighting capabilities by enabling secure and reliable energy alternatives, increase energy efficiency, and reduce life cycle costs in acquisition (AFEPPM 10-1.1, 19).

D. THESIS OBJECTIVES

This thesis:

- Describes the various FBCF methodologies developed or under development by each branch of the United States Armed Service.
- Compares the similarities and differences among the FBCF methodologies to include an analysis of the various estimates calculated by the methodologies employed across the DoD.

Previous work with the FBCF has ranged from high-level strategic guidance to the development of prototype methodologies. By definition, FBCF incorporates the indirect costs associated with the storage and delivery of the fuel to the end user. The indirect costs are multipliers to the DESC standard price.

While there is commonality among the FBCF calculations of the services due to the utilization of a seven-step process promulgated by OSD (AT&L), the methods by which each of the steps, or elements are determined are not the same. This study will look at the calculations of each of the methodologies, the data sources for those calculations, and the assumptions that underlie these processes.

There may be very good reasons for the services to have their own methods to calculate the FBCF, but we wish to understand how the methodologies differ and how they are similar. However, the statements by Vice Admiral Burke at the 2009 MORS Power and Energy Special Meeting indicate there is a desire to have one methodology that can mature over time. A single methodology may allow the decision makers who will use the FBCF to have a good understanding of what is included in the calculations, whether the utilization of the FBCF is for an Army, Navy, or Air Force program. It is understandable that OSD (AT&L) desires one common perspective across the Services since OSD (AT&L) has responsibility to look across Services.

II. FBCF CALCULATED

A. FBCF DEFINED

The Defense Acquisition Guidebook (DAG) contains a definition of the Fully Burdened Cost of Fuel that the Services have seemed to adopt. The DAG describes the FBCF as "the cost of the fuel itself (typically the Defense Energy Support Center (DESC) standard price) plus the apportioned cost of all of the fuel delivery logistics and related force protection required beyond the DESC point of sale to ensure refueling of [a] system" (DAG, 2009, p.1). The FBCF is measured in dollars per day.

An interim computation, sometimes confused with the FBCF, is the Assured Delivery Price (ADP), which is calculated in dollars per gallon. This calculation is required in the determination of the FBCF.

B. THE GENERALLY ACCEPTED STEPS OF FBCF

The Defense Acquisition Guidebook lays out seven elements required to calculate the ADP and, ultimately, the FBCF.

Element	Burden Description
Commodity Cost of Fuel	DESC standard price for the appropriate type or types of fuel
Primary Fuel Delivery Asset O&S Cost*	Cost of operating service-owned fuel delivery assets including the cost of military and civilian personnel dedicated to the fuel mission.
Depreciation Cost of Primary Fuel Delivery Assets*	Measures the decline in value of fuel delivery assets with finite service lives using straight-line depreciation over total service life
Direct Fuel Infrastructure O&S and Recapitalization Cost*	Cost of fuel infrastructure that is not operated by DESC and directly tied to energy delivery
Indirect Fuel Infrastructure*	Cost of base infrastructure that is shared proportionally among all base tenants
Environmental Cost*	Cost representing carbon trading credit prices, hazardous waste control and related subjects.
Other Service & Platform Delivery Specific Costs*	Includes potential cost associated with delivering fuel such as convoy escort, force protection, regulatory compliance, contracting and other costs as appropriate.

* These costs vary by Service and delivery method (ground, sea, air)

Table 1. OUSD(AT&L) defined cost elements for estimating the FBCF (DAG, 2009, p. 4)

The elements listed in Table 1 are calculated individually and then summed to determine the ADP. Once the ADP is obtained, it is used to calculate the FBCF. Only the first element of this methodology is common to each of the Service's calculations. The calculations of the remaining elements are service specific and the derivations of the elements needs to be calculated with the specific platforms and doctrine of that Service.

There are two particular requirements delineated in the DAG for the Fully Burdened Cost of Fuel calculation: derive

- The service must establish a wartime (operational) scenario and a peacetime (steady state) scenario, which will be used to evaluate the platform or system under development. Anticipated logistical, force protection, and other requirements are derived from the scenarios and used in the calculation of the FBCF. The proportion of time that the system is in the operational vice steady-state environment throughout its service life is obtained from the scenario and factored into the FBCF estimate. The DAG suggests using The Defense Department's approved Joint Defense Planning Scenarios and the Services future force plans to estimate these factors.
- Since no single platform or system uses 100 percent of the fuel delivered by the logistics tail, the proportion of the fuel that platform consumes is used to establish the proportion of the logistics tail (and, therefore, the proportion of the cost of the logistics tail) that is attributed to that specific platform or system. This apportionment process allows the evaluation of the assets that will not be required if a given gallon of fuel is no longer required to be delivered. Significant savings can be realized by the reduction of the logistics tail.

While the seven elements have generally been accepted as the process by which ADP and the FBCF are calculated, there remains plenty of opportunity for variation among the way various methodologies calculate each of the elements. Further, the "Other Service & Platform Delivery Specific Costs" element enables the inclusion of many reasonable costs which may or may not be agreed upon. The next seven paragraphs describe the elements in Table 1, which comprise the ADP and the eighth paragraph explains how the ADP is converted to the FBCF.

1. The Commodity Cost of Fuel

The Defense Energy Supply Center (DESC) is the DoD's single source for petroleum products. DESC procures, stores, and transports petroleum products to various retail points of sale. The cost of the petroleum products is set at the DESC standard price, which is the cost of the fuel and a surcharge to cover the DESC operating costs. The services pay DESC the standard price, which DESC then reimburses the Defense Working Capital Fund. The standard price for the various petroleum products offered by DESC can be found at http://www.desc.dla.mil/ .

DESC operates as a reimbursable fund so its standard price is not the current marketplace price, but, rather, is based on a trailing eighteen-month cycle. This standard price is a tool that protects the military from the volatility of the global market. Throughout the eighteen-month cycle, DESC's reimbursable account may see net gains or net losses depending on the market value of petroleum products. These gains and losses are accounted for in the next cycle when DESC sets the new standard price.

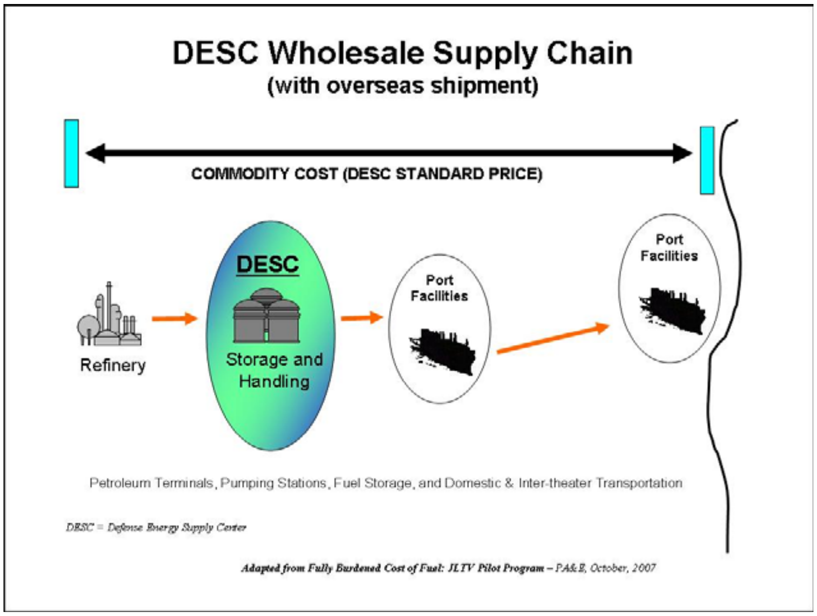

Figure 1. DESC wholesale supply chain (From DAG, 2009, p. 5)

2. Fuel Delivery Operation and Support Costs:

These are the Operating and Support costs associated with the delivery asset. The primary components of the Operating and Support costs include the Operations and Maintenance (O & M) costs and the military and civilian personnel costs associated with the employment of the delivery asset. These assets are generally service specific. Examples of these assets are oilers for the Navy, aerial refueling aircraft for the Air Force, and tanker trucks for the Army. Historical O & S costs for the major fuel delivery systems are available in service specific databases such as the Visibility and Management of Operating and Support Cost (VAMOSC) for the Navy, the Air Force Total Ownership Cost (AFTOC), and the Force and Organization Cost Estimating System (FORCES) suite of models and the Cost Factors Handbook for the Army.

3. Delivery Fuel Asset Depreciation Cost

Most DoD studies focus on recapitalization costs and as a result, do not use depreciation. Yet in the calculation of the FBCF, there is a need to capture the decline in capital value of the fuel delivery asset over time. OSD (AT&L) recommends using a straight line depreciation to account for the depreciation of the fuel delivery asset over its projected service life.

4. Direct Fuel Infrastructure Costs

The Direct Fuel Infrastructure Costs are the O & S and recapitalization costs of the facilities directly utilized for the delivery of fuel. The Direct Fuel Infrastructure Costs need to be limited to assets such as fuel bladders, pumping hoses, and storage sites, which are operated by the military in theater. The Direct Fuel Infrastructure Costs operated by DESC should not be included in this step since DESC's direct fuel infrastructure costs are accounted for in the DESC standard price. Authorized personnel can find Direct Fuel Infrastructure Costs for the military from the Office of the Deputy Under Secretary of Defense (Installations and Environment), (http://www.acq.osd.mil/ie/) (Corley, 12).

5. Indirect Fuel Infrastructure Costs:

These costs are necessary to support the direct fuel infrastructure. In order to determine the cost of the base level operations and support that can be attributed to the FBCF, OSD (AT&L) recommends that the indirect fuel infrastructure costs are allocated on a per capita basis. For example, determine the operations and support costs of a certain base and divide that by the total manpower of that base, then multiply that by the number of personnel working on fuel related enterprises.

6. Environmental Costs:

The environmental costs are the costs such as DoD environmental clean-up, hazardous waste control and potential carbon emission offsets attributed to the delivery of fuel for the platform being evaluated. The environmental costs associated with the delivery of fuel are difficult to measure. To facilitate the calculation of this cost element, the Office of the Secretary of Defense (Program, Analysis and Evaluation) has developed an estimate which is what most of the Services use in their FBCF calculations.

7. Other Service/Platform Unique Costs:

The final element of the FBCF calculation is any applicable cost that has not been captured by the previous six steps. These costs can be service specific, ranging from regulation compliance to force protection of the delivery of fuel in theater. Force protection can easily be the largest cost element for the FBCF in high threat environments since it is necessary to consider the O&S costs, direct fuel costs and the depreciation costs of the force protection assets.

8. The Conversion of ADP to FBCF

The Assured Delivery Price is realized once the seven cost elements are aggregated and is measured in dollars per gallon. In order to find the FBCF in dollars per day, ADP must by multiplied by the percentage of fuel being used by the system at a scenario destination and the daily demand of that system, then divided by the number of systems at the scenario destination.

$$\text{ADP (\$/gal)} = \sum_{k=1}^{7} \text{Element}_k \qquad (2.1)$$

$$FBCF = ADP * \left(\frac{P * D}{N} \right) \qquad (2.2)$$

Where

FBCF = The Fully Burdened Cost of Fuel
ADP = The Assured Delivery Price
P = The Percentage of fuel in a Operational scenario delivered to a base used by the platform being evaluated
D = The daily demand of the platform being evaluated
N = The number of platforms in the Operational scenario

C. A DESCRIPTION OF THE MODELS EMPLOYED

The 2009 NDAA established timelines for the services to develop and implement the use of the FBCF for the analysis of alternatives, evaluation of alternatives and acquisition program design trades. Table 2 shows the deadlines for implementation of the FBCF. It is the responsibility of the Services to develop a methodology within the definition of FBCF established in the 2009 NDAA.

The seven elements provide a framework in which to calculate the FBCF. Yet, the methods for calculating each element and the sources of the data required to derive the specific costs have the potential to vary among the Services and methodologies.

2009 NDAA Legislated Implementation Deadline Summary		
Event/Requirement	Lead Time	Deadline
2009 NDAA Enacted		14-Oct-08
Prepare Implementation Plan	180 days	14-Apr-09
Provide Progress Report	2 years	14-Oct-10
Implement NDAA Requirement	3 years	14-Oct-11
Source: 2009 Duncan Hunter National Defense Authorization Act		

Table 2. 2009 NDAA FBCF Implementation Deadline Summary

OSD (AT&L) developed a prototype Excel based FBCF calculator which has been evolving over time. The OSD (AT&L) calculator, developed by Mr. Richard Cotman, has been embraced by some of the Services and modified to take the appropriate input for their scenarios. The Navy and Marine Corps have adopted the OSD (AT&L) FBCF calculator while the Army and the Air Force have followed the seven element methodology but developed a calculator separate from the OSD (AT&L) prototype. The following paragraphs describe the primary FBCF Calculators in use across the Department of Defense.

1. OSD (AT&L) FBCF Calculator

The ODS (AT&L) FBCF Calculator produces a numerical estimate based upon the guidance provided in the Defense Acquisition Guidebook (DAG). It is an Excel-based program that uses Monte Carlo Simulation to calculate the value of delivered fuel consumed over a period of time by a platform. The calculation of the FBCF, and thus the tool, requires a scenario which provides the data needed for input into the calculator. The FBCF cannot be calculated without a scenario.

This tool contains parameters for all modes of transportation (sea, air and land), but depending on the scenario, only the applicable parameters will be utilized. To ease the use of the OSD (AT&L) FBCF Calculator, its creator, Mr. Cotman, has designed three variants in accordance with the three modes of transportation, one for sea delivery, one for air and one for land delivery.

The "Fully Burdened Cost of Fuel Model Description & Assumptions", found in Appendix B, contains the general assumptions for the OSD (AT&L) FBCF Calculator:

- The FBCF is determined from a scenario-based analytic process.
- The operations tempo (OPTEMPO) sets the pace of equipment usage, and the selection of the scenarios used directly affects the magnitude of the FBCF.
- FBCF cannot be calculated without representing surge, wartime activities. These higher OPTEMPO scenarios incur greater wear and tear on equipment, and the higher fuel logistics demands require protection from threats.
- FBCF is different for every platform because demand varies among systems.
- Because FBCF is to be used for future systems' AoAs, a DoD Component must use derivatives of Defense Planning Scenarios (a future look at a time when planned developmental systems will be in the US inventory) to work from a common analytic baseline and to present a common set of assumptions by which to oversee and assess its application in those AoAs.

Each of the seven cost elements are calculated for a surge (operational) scenario and for a foundational (steady state) scenario, for a total of 14 cost element calculations. Of these 14 cost elements, three are cited by Mr. Cotman as the primary drivers of ADP in the wartime (surge) scenario:

- The wartime Delivery Asset O&S Price (Appendix B, p 58)
- Depreciation Price of the Primary Fuel Delivery Assets (Appendix B, p 59)
- The Other Prices which contain the force protection assets and personnel costs to assure safe transit of the delivery vehicles from the DESC terminal to the operational delivery point and back (Appendix B, p 59)

The 14 cost elements are summed under their respective scenarios, surge or foundational, to determine a surge and foundational ADP which is then converted to the surge and foundational FBCF. The surge and foundational ADP and FBCF are combined into a single ADP and FBCF calculation with the use of an OPTEMPO Ratio. The OPTEMPO Ratio is the percent of time that a particular weapon system is in a surge environment. A description of all of the equations used in the OSD (AT&L) FBCF Calculator can be found in Appendix B, “Fully Burdened cost of Fuel Calculator Model Description and Assumptions”.

The challenges in calculating a single FBCF numerical estimate for a particular weapons system are the selection of a scenario and the collection of the required data for input into the calculator.

2. The United States Navy FBCF Calculations

In his NPS thesis titled *Evaluating The Impact Of The Fully Burdened Cost Of Fuel,* Robert Corley used the OSD (AT&L) FBCF Calculator to determine the FBCF associated with a notional DDG-51 class destroyer. The early version of the OSD(AT&L) FBCF calculator was in accordance with the DAG guidance. It used the seven element methodology along with a Monte Carlo simulation to determine the FBCF.

The calculator calculated the $FBCF_{SOp}$ and the $FBCF_{SSS}$, which are in dollars per gallon and represent the operational and steady state cost of delivered fuel in each of the respective scenarios. Additionally, the calculator produced the $FBCF_{DOp}$ and the $FBCF_{DSS}$, which are in dollars per day, and represent the costs per day of fuel demanded by the system in both the operational and steady state notional scenarios. The more recent FBCF methodology produced by ODS (AT&L) make a distinction between the $FBCF_{SOp/SSS}$ and the $FBCF_{DOp/DSS}$ by renaming them the Assured Deliver Price (ADP) and the Fully Burdened Cost of Fuel (FBCF), respectively.

Additionally, Daniel Truckenbrod wrote an NPS thesis titled *Estimating the Fully Burdened Cost of Fuel for Naval Aviation Fixed Wing Platform.* Truckenbrod used the OSD (AT&L) FBCF Calculator version 7.0, which is the same version used in this thesis. His thesis calculated the FBCF for the F/A-18 E/F aircraft. The FBCF for the F/A-18 E/F aircraft is about twice as high as the FBCF for a notional destroyer (DDG-51) fleet calculated by LCDR Corley in his thesis.

Corley and Truckenbrod's adoption of the OSD (AT&L) FBCF Calculator versions 2.0 and 7.0 represents the most advanced work associated with the FBCF in the United States Navy to date.

3. The United States Marine Corps FBCF Calculations

For the Military Operations Research Society's Power and Energy Workshop held in December 2009, Mr. Edward Blankenship from PA&E and Dr. Randal Cole from CNA presented The leading Marine Corps methodology for calculating the Fully Burdened Cost of Water (FBCW), the ADP for fuel, and the FBCF. They adopted the OSD(AT&L) version 6.1 FBCF calculator for their calculations. The version 6.1 calculator was configured for sea going systems and Mr. Blankenship and Dr. Cole worked with Mr. Cotman to configure it for a Marine Corps ground scenario. They evaluated the FBCF at a Forward Operating Base (FOB) in Afghanistan. The FBCF was calculated three times: first using solely a ground convoy, then a ground convoy with air support, and lastly solely by air delivery.

4. The United States Air Force FBCF Calculations

The Air Force FBCF calculator follows the seven step process outlined in the DAG, but is not based on the OSD(AT&L) prototypes. It is an Excel based deterministic calculator which incorporates the seven step methodology with tabs which lead the user through the development of each of the FBCF cost elements. It then aggregates these cost elements to determine a FBCF, which is in dollars per gallon vice dollars per day as in the OSD (AT&L) methodology. It also takes the percentage of time the aircraft is in a peacetime or wartime scenario and uses those percentages to develop a Weighted FBCF which is in dollars per year. The FBCF and the Weighted FBCF loosely line up with the ADP and the FBCF from the OSD(AT&L) models. The Air Force FBCF calculation primarily uses data from the Air Force Total Ownership Cost (AFTOC) database, the Capital Asset Management System (CAMS-ME) and the Secretary of Defense for Installations and Environment (DUSD (I&E)) Facilities Assessment Database.

5. The United States Army FBCF Calculations

The United States Army FBCF calculation methodology is still under development. Mr. David Hull of the Assistant Secretary of the Army (Financial Management & Comptroller), is in the process of developing a FBCF methodology for the Ground Combat Vehicle (GCV) AoA which will be the first MDAP to use FBCF in an AoA. Mr. Hull described the proposed Army Methodology, but an evaluation of the tool was not possible due to time constraints.

The FBCF tool will be an Excel workbook that will take the fuel burn rate information from a Heavy Brigade Combat Team (HBCT) Operational Mode Summary/Mission Profile (OMS/MP). Several Courses of Action (COA) will be evaluated.

- The base COA using an OMS/MP for the Bradley M2A3 in a HBCT.
- A second COA will evaluate the Bradley Block II upgrade under the same conditions. In other words, use the OMS/MP for the Bradley Block II in a HBCT.
- The Third COA will evaluate the Ground Combat Vehicle (GCV).

The gallons per hour will be used to evaluate the different combat platforms as opposed to gallons per mile. The gallons per hour can account for the vehicles idle consumption rate and the consumption rates of the vehicle while it drives over various types of terrain during different types of missions.

The fuel burn rate for the entire Heavy Brigade Combat Team, for 180 days, is provided by the OMS/MP. The data is then doubled to estimate one-year worth of fuel use. The gallons of fuel used by the HBCT over a year is the denominator in an analysis that will produce a dollar per gallon cost. It is then necessary to use other databases such as the Force Costing Database, the Contingency Operations Database, the Cost Factor Handbook, and the Operations and Sustainment Database to calculate all of the annual burden costs that provide fuel to the HBCT. The OSD (AT&L) Seven Step Methodology will be used to find each of the burdens associated with the logistics system that provide fuel to the HBCT. These burden include parts and fuel of the HBCT deliver trucks, fuel convoy force protection vehicles and any other assets that contributes to the delivery of fuel to the HBCT. All of these burdens are used in the numerator to produce a burdened dollar per gallon fuel cost. The dollars per gallon will be the same for any vehicle or fuel consuming asset in the HBCT. The burdened dollar per gallon fuel cost at the HBCT is then added to the DESC standard fuel price to determine the FBCF in dollars per gallon.

Once the FBCF of the HBCT is calculated it is necessary to apportion it to the combat platform under consideration. This is done by taking the HBCT FBCF dollar per gallon and multiplying it by the system's operational Tempo (OPTEMP). For example, the burn rate of the Bradley M2A3 in gallons per hour is multiplied by the number of hours in the year the Bradley M2A3 is used to get the amount of gallons per year used by the system.

There are some differences between the proposed Army FBCF methodology and the DAG guidance:

- The Army FBCF methodology calculates the FBCF of the HBCT in dollars per gallon; the DAG would call this the ADP.
- The Army FBCF is proposed to be calculated as gallons per year per system; the DAG states that FBCF should be calculated as dollars per day per system.

Since the Army's HBCT FBCF or ADP is already calculated, conversion of gallons per year per system to dollars per day per system is straightforward.

III. COMPARING THE OSD (AT&L) AND AIR FORCE TOOL

A. METHODOLOGY

In this chapter, we exercise the Air Force FBCF calculator and the OSD (AT&L) FBCF Air Interdiction version 7.0 Calculator in order to compare the tools and to see if the different approaches yield different results. The Air Force had calculated the FBCF for the E-8 Joint Surveillance and Target Attack Radar System (JSTARS). It is our desire to calculate the FBCF for the same platform using the OSD (AT&L) FBCF Calculator. The challenge is that the Air Force FBCF Calculator does not accept the same input as the OSD (AT&L) FBCF Calculator.

Since the Air Force FBCF did not have an explicit scenario, it was necessary to research and create a notional scenario, which represents the employment of the E-8 JSTARS for use in the OSD (AT&L) FBCF Calculator. Any data that the Air Force FBCF Calculator incorporated that could be used in the OSD (AT&L) FBCF Calculator was utilized. When the required data for the OSD (AT&L) FBCF Calculator could not be found or derived from the data in the Air Force FBCF Calculator, an estimate was developed.

The Air Force FBCF Calculator's output is each of the seven FBCF elements while the OSD (AT&L) Calculator accepts the seven elements as input and has an additional 24 parameters which describe the platform and the scenario. Once the FBCF for the E-8 JSTARS is determined in the OSD (AT&L) FBCF Calculator, the results will be compared to those of the Air Forces FBCF E-8 JSTARS Study.

B. THE AIR FORCE FBCF CALCULATOR INPUT

All dollars have been converted to FY08 dollars. The paragraphs below identify how the Air Force computes each of the seven cost elements in their study.

1. The Commodity Cost of Fuel

This is computed as the total gallons delivered in FY08, divided that by the total cost of fuel in FY08. Both total gallons delivered in FY08 and the total cost of fuel bought by the Air Force were found in the AFTOC database.

$$\frac{\$7{,}855{,}976{,}079}{2{,}488{,}628{,}101} = \$3.16 \tag{3.1}$$

2. The Primary Delivery Assets O & S Costs

The Air Force separates the delivery assets into ground delivery assets and aerial refueling assets. The ground cost data comes from the 2001 Defense Science Board Study where the total ground delivery O & S costs are divided by the total gallons of fuel delivered on the ground.

$$\frac{\$409{,}700{,}000}{1{,}954{,}000{,}00} = \$0.25 \tag{3.2}$$

The aerial refueling O & S Costs are associated with the aerial tanker refueling fleet. To determine an average annual aerial O & S cost per gallon delivered, the Air Force FBCF Calculator summed all of the annual O & S costs for each type of aerial tanker platforms. The total aerial tanker platform O & S costs were then divided by the annual aerial gallons of fuel delivered. The O & S costs were found in the AFTOC database.

$$\frac{\$4{,}888{,}952{,}844}{227{,}741{,}894} = \$21.47 \tag{3.3}$$

It is important to note that the Air Force accepts the fuel from DESC when it is pumped into the fuel tanks of the aircraft being refueled. Therefore, the O & S costs for fuel delivery on the ground are small when compared to the burden associated with aerial refueling. The cost of the aerial refueling tanker fleet is such a heavy burden for aerial refueling that the Air Force broke out the calculations of the FBCF into “ground peacetime”, “ground wartime”, “aerial peacetime”, and “aerial wartime”.

3. The Depreciation Costs of the Primary Fuel Delivery Assets

The ground depreciation costs are calculated by multiplying the unit cost of each type of ground support equipment with its total quantity in the Air Force. Then that value is divided by the expected life span of that piece of equipment. The calculation is performed for each piece of equipment associated with ground refueling and is added together. Lastly, the sum is divided by the total amount of fuel delivered on the ground.

$$\frac{\$9,870,505}{2,488,628,101} = \$0.00397 \approx \$0.00 \tag{3.4}$$

The aerial asset depreciation used data from the Capital Asset Management System (CAMS-ME). It was calculated as the total book value of the KC-10A tanker fleet divided by its life span of 30 years and then divided by the total annual gallons of aerial fuel delivered.

$$\frac{\$1,619,941,347}{30} = \$53,998,045 \tag{3.5}$$

$$\frac{\$53,998,045}{227,741,894} = \$0.24 \tag{3.6}$$

The F-16 depreciation per gallon was calculated by taking the total book value of the F-16 fleet and dividing that by the life span of an F-16 and then dividing that by the total annual aerial gallons delivered. The F-16 calculation also took into account the percentage of missions that were flown as escort duty. The total annual number of F-16 escort hours was divided by the total annual number of F-16 flight hours. The ratio of escort missions was determined using data from the REMIS data base.

$$\frac{\$20{,}380{,}729{,}038}{26} = \$783{,}874{,}194 \tag{3.7}$$

$$\frac{\$783{,}874{,}194}{227{,}741{,}894} * \frac{1520}{915972.5} = \$0.01 \tag{3.8}$$

The KC-10A and the F-16 depreciation per gallons was then added to obtain the total aerial depreciation per gallon of $0.25.

4. Direct Fuel Infrastructure

Direct fuel infrastructure is calculated as the Fuel Facilities Annual Depreciation divided by the Ground Gallons Delivered. The data comes from the Deputy Under Secretary of Defense for Installations and Environment (DUSD (I&E)) Facilities Assessment Database.

$$\frac{\$181{,}405{,}158}{2{,}488{,}628{,}101} = \$0.07 \tag{3.9}$$

The aerial direct fuel infrastructure took the aircraft maintenance and operations facilities annual depreciation found from DUSD (I&E) and divided that by the total annual aerial gallons delivered. The depreciation per aerial gallon delivered was then multiplied by the ratio of total flight hours to tanker flight hours to get the aerial direct fuel infrastructure that could be associated with the tanker fleet.

$$\frac{\$366{,}090{,}995}{227{,}741{,}894} * \frac{289{,}457}{2{,}071{,}476} = \$0.22 \tag{3.10}$$

5. Indirect Fuel Infrastructure

The indirect fuel infrastructure ground burden was calculated using the AFTOC database to find the installation support cost per person which was divided by the total ground gallons delivered.

$$\frac{\$156,451,783}{2,488,628,101} = \$0.06 \tag{3.11}$$

The aerial indirect fuel infrastructure divided the tanker support costs, found in AFTOC, by the total annual aerial gallons of fuel delivered and then added the tanker indirect fuel infrastructure to the ground indirect infrastructure to calculate the total indirect fuel infrastructure per aerial gallon delivered.

$$\frac{\$156,451,783}{2,488,628,101} + \frac{\$443,936,816}{227,741,894} = \$2.01 \tag{3.12}$$

6. Environmental Costs

The environmental costs were calculated using the AFTOC database that tabulates the environmental costs per base per year. Thus, it was possible to take the aggregate environmental cost and divide that by the total gallons delivered to obtain the environmental burden per gallon.

$$\frac{\$624,189,468.86}{2,488,668,101} = \$0.25 \tag{3.13}$$

7. Platform Delivery Specific Costs

The ground platform delivery specific costs are calculated as:

$$Step\ 7_{Ground} = N_{FP} * (T + I_{TV} + FP + R_{ex}) * (T + FP + R_{ex}) * (1 - R_{ex}) \qquad (3.14)$$

Where:

Step 7_{Ground}	=	Other ground platform delivery specific costs
N_{FP}	=	The NATO fuel price
T	=	Transportation rate
I_{TV}	=	Infrastructure rate
FP	=	Force protection rate
R_{ex}	=	Refinery percentage rate

The data for the ground platform delivery specific costs came from Mr. Brunssum at the NATO Joint Forces Command.

Thus:

$$\$5.00 * .85 * .995 * (1 - .65) = \$1.48$$

The source for the ground platform delivery specific costs was the intra-theater transportation and force protection rates obtained from NATO.

The aerial platform delivery specific costs were calculated as:

$$Step7_{AIR} = \frac{F * C_{FH} * MD}{T_{PO} * DC} \qquad (3.15)$$

Where:

$Step7_{AIR}$	=	Other Air platform delivery specific costs
F	=	Fighters per Orbit
C_{PH}	=	F-15/F-16 Cost per Flight Hour
MD	=	KC-10 Mission Duration

T_{PO} = Tanker per Orbit

DC = KC-10 Delivery Capacity

Thus:

$$\frac{2 * \$22{,}631 * 7.61}{3 * 36{,}000} = \$5.41$$

The data for the aerial platform delivery specific costs came from conversations between the creator of the Air Force FBCF Calculator Mr. Ashton Bulloch (AFCAA/FMFS) and the Air Force Global Mobility Office (A8PM). The $5.41 rate for the aerial refueling was added to the ground platform delivery specific costs to find an aerial platform delivery specific burden of $6.89.

8. Summary

Table 3 shows the output from steps 1–7 calculated in the Air Force FBCF Calculator.

	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Peacetime	Wartime
Ground	$3.16	$0.25	$0.00	$0.07	$0.06	$0.25	$1.48	$3.80	$5.28
Aerial	$3.16	$21.72	$0.25	$0.30	$2.01	$0.25	$6.89	$27.68	$34.57

Table 3. Air Force FBCF Calculator Step 1-7 Output

9. The Analysis of Alternatives Input

The Air Force FBCF Calculator accepts input for three different Courses of Action (COAs). The COAs describe potential characteristics for the platform under consideration. For this analysis, the platform is the E-8 JSTARS utilizing notional data developed by Mr. Bulloch. The three COAs are listed in Table 4.

	COA1	COA2	COA3
# Deployments/Yr	0.4	0.5	0.6
Deployment Distance (miles)	4,200	4,200	4,200
Fuel Consumption (gal/FH)	2,000	4,000	3,000
PAA	17	17	17
FH/PAA (Avg Peacetime FH per year over Life Cycle)	200	300	400
FH/PAA (Avg Wartime FH per year over Life Cycle)	800	900	1000
% Ground Refueled (Peacetime)	75%	80%	85%
% Aerial Refueled (Peacetime)	25%	20%	15%
% Ground Refueled (Wartime)	50%	40%	45%
% Aerial Refueled (Wartime)	50%	60%	55%

Table 4. Air Force FBCF calculator Analysis of Alternatives Input

While the Air force FBCF Calculator evaluates three COAs at once, the OSD (AT&L) model only evaluates one alternative at a time. Due to limited time, the second Air Force Course of Action was used as a basis for input in the OSD (AT&L) FBCF Calculator. The second COA was arbitrarily selected by the author.

C. THE OSD (AT&L) FBCF CALCULATOR INPUT

In order to exercise the OSD (AT&L) FBCF Calculator under the conditions of the second Air Force COA, it is necessary to input the seven FBCF cost elements produced from the Air Force FBCF Calculator. Furthermore, the OSD (AT&L) Calculator accepts an additional 24 parameters that describe the scenario to include the employment doctrine and threat parameters. These parameters are entered as ranges which represent the 5 and 95 percent bounds on the parameter. The Air Force FBCF study does not use a scenario, but the OSD (AT&L) FBCF Calculator requires one. Therefore, a notional Air Force scenario was constructed in which the second COA values are embedded. The parameters for the OSD (AT&L) FBCF Calculator that could not be directly found in the Air Force FBCF calculator were estimated to reflect a two theater scenario with the six E-8 JSTARS aircraft deployed to those theaters. Table 5 lists the parameters that describe the delivery and escort assets in the notional scenario.

Table 6 lists the Air Force FBCF cost elements used in the OSD (AT&L) Calculator. Table 7 lists the parameters associated with the notional scenario that are used as input to the OSD (AT&L) calculator.

Symbols	Parameter Name	Units	Value	5%	95%
CR_V	Fuel Consumption Rate by 1 delivery Vehicle	gal/hour	2,070	1138.5	3002
CR_E	Fuel Consumption Rate by 1 Escort vehicle	gal/hour	0	0	0
CR_A	Fuel Consumption Rate by 1 escort Aircraft	gal/hour	800	440	1160
T	Number of days to deliver fuel (round-trip)	hours	7.6	7.5	7.6
A	Multiplier to keep convoy fuel flowing	#	1.0	1.0	1.0
Q	Capacity of one delivery vehicle	gal	32,000	31,000	33,000
TC_V	Total Life-Cycle Cost (LCC) of 1 delivery Vehicle (Peacetime estimate)	$	$360,000,000	$360,000,000	$360,000,000
PC_V	Procurement Cost fraction of delivery Vehicle's LCC	#	0.33	0.33	0.33
OS_V	O&S cost fraction of delivery Vehicle's LCC	#	0.60	0.60	0.60
P_i	Probability of Interdiction during any one delivery mission	#	0.004	0.004	0.004
λ	Number of delivery vehicles Lost during the interdiction	#	0.00	0	0
LM_V	LCC Multiplier to account for operational usage of delivery Vehicle	#	2.0	2.0	2.0
M_μ	Average age of a delivery vehicle	hours	516,000	516,000	516,000
M_V	Number of delivery hours 1 delivery Vehicle will be used during its lifetime	hours	620,000	620,000	620,000
TC_E	Total life-cycle Cost of 1 Escort vehicle (Peacetime estimate)	$	$1,000	$1,000	$1,000
LM_E	LCC Multiplier to account for operational usage of Escort vehicle	#	1.0	1.0	1.0
ER_E	Escort Ratio (number of delivery vehicles per Escort vehicle)	#	1,000,000	1,000,000	1,000,000
M_E	Number of hours 1 Escort vehicle will be used in its lifetime	hours	6,000	6,000	6,000
TC_A	Total life-cycle Cost of 1 escort Aircraft (Peacetime estimate)	$	$180,000,000	$180,000,000	$180,000,000
LM_A	LCC Multiplier to account for operational usage of escort Aircraft	#	2.0	1.0	3.0
ER_A	Aircraft Escort Ratio (number of delivery vehicles per escort aircraft)	#	0.667	0.666	0.668
M_A	Number of hours 1 escort Aircraft will perform escorts during its lifetime	hours	30,000	30,000	30,000

Table 5. Delivery and Escort Asset Parameters.

Symbols	Price Element Name (All entries are in $/gal)	Operational	Steady-State	5%	95%
OP_1, SP_1	Commodity Cost of Fuel	$3.16	$3.16	$3.15	$3.17
SP_2	Primary Fuel Delivery Asset O&S Cost (Steady-State)		$0.25	$0.24	$0.26
SP_3	Depreciation Cost of Primary Fuel Delivery Assets (Steady-State)		$0.01	$0.00	$0.01
OP_4	Direct Fuel Infrastructure O&S and Recapitalization Cost (Operational)	$0.30		$0.29	$0.31
SP_4	Direct Fuel Infrastructure O&S and Recapitalization Cost (Steady-State)		$0.07	$0.06	$0.08
OP_5	Indirect Fuel Infrastructure O&S Cost (Operational)	$2.01		$2.00	$2.02
SP_5	Indirect Fuel Infrastructure O&S Cost (Steady-State)		$0.06	$0.05	$0.07
OP_6	Environmental Cost (Operational)	$0.25		$0.24	$0.26
SP_6	Environmental Cost (Steady-State)		$0.25	$0.24	$0.26
SP_7	Other Service & Platform Delivery Specific Costs (Steady-State)		$1.48	$1.47	$1.49

Table 6. FBCF Price Element Values.

Symbols	Scenario Parameter Name (units)	Operational	Steady-State	5%	95%
OR	OPTEMPO Ratio (#)	0.60		0.59	0.61
P_O	System Proportion (Operational) (#)	0.300		0.290	0.310
P_S	System Proportion (Steady-State) (#)		0.700	0.690	0.710
D_O	Total fuel Demanded at final delivery location (Operational) (gal/day)	139,732		139,723	139,740
D_S	Total fuel Demanded at final delivery location (Steady-State) (gal/day)		55,930	55,913	55,947
N_O	Number of vehicles located at final delivery location (Operational) (#)	6		5	7
N_S	Number of vehicles located at final delivery location (Steady-State) (#)		11	10	12

Table 7. Scenario Parameters

The parameters in Tables 5, 6, and 7 are run through 1,000 iterations of a Monte Carlo Simulation which utilizes the Excel random number generator and a normal distribution where μ is the average of the 5th and 95th percentiles and σ is the 95th percentile subtracted from the 5th percentile, divided by 3.29. The results of the 1,000 iterations are used to determine the mean, 5th, and 95th percentiles for each parameter that in turn are used to produce:

- Steady State ADP and FBCF
- Operational ADP and FBCF
- Duty-Cycle Weighted ADP and FBCF

For more details on how the OSD (AT&L) Calculator produces the output, refer back to the section on the OSD (AT&L) FBCF calculator (Chapter II.C.1) or Appendix B.

IV. ANALYSIS OF THE FBCF RESULTS

A. THE AIR FORCE FBCF CALCULATOR RESULTS

The output for the Air Force FBCF Calculator, which is in dollars per year for the total population of systems, is not in the same units as the output of the OSD (AT&L) FBCF Calculator, which is in dollars per day per individual system. Therefore, we go through the Air Force FBCF Calculator results and then convert the output to units that are comparable to the OSD (AT&L) FBCF Calculator output.

The results of the Air Force FBCF Calculator took the peacetime ground and aerial ADP and the wartime ground and aerial ADP and used those values along with the second COA input to calculate the results found in Table 8.

	COA2
Ground Fuel (FY08$)	$191,208,108
Aerial Fuel (FY08$)	$1,382,266,293
Other Platform Specific Delivery Cost ((	$222,947
Total Fuel Cost (FY08$)	$1,573,697,348
Total Gallons (gallons)	81,600,000
Weighted FBCF ($/gallon)	$19.29

Table 8. Air Force FBCF Calculator Results (FY08 Dollars)

Since the Air Force Weighted FBCF is in the same units as the OSD (AT&L) ADP, it is possible to use equation 2.10 to convert the Air Forces Weighted FBCF to OSD (AT&L)'s definition of the FBCF.

$$FBCF = ADP * \left(\frac{P * D}{N} \right)$$

$$FBCF = \$19.29 * \left(\frac{.6 * 81{,}600{,}000}{17} \right) = \$55{,}542{,}259.34$$

This comes out to 152 thousand dollars per day.

In summary, the data associated with Air Force COA 2 was used in the OSD (AT&L) FBCF Calculator. Thus, the deterministic results from the Air Force FBCF Calculator that can be compared to the OSD (AT&L) FBCF Calculator results are:

$$ADP_{\text{Duty-Cycle Weighted}} = \$19.29$$

$$FBCF_{\text{Duty-Cycle Weighted}} = \$152{,}170.57$$

B. THE OSD (AT&L) FBCF CALCULATOR RESULTS

For this thesis, we define one "run" of the OSD (AT&L) FBCF Calculator as 1,000 iterations of the Monte Carlo simulation that produces the mean, 5th and 95th percentiles of the Monte Carlo output. A run of the OSD (AT&L) FBCF Calculator could produce a wide range of results, which can be attributed to the stochastic nature of the calculator. In order to obtain output that could be used to compare against the Air Force FBCF Calculator's deterministic answer, we needed to address the wide range of outputs from the OSD (AT&L) FBCF Calculator. The OSD (AT&L) FBCF Calculator was run 100 times and the mean and standard deviation of those results were recorded and used to compare the OSD (AT&L) FBCF Calculator to the Air Force FBCF Calculator.

Occasionally, a run could produce anomalies in the Operational ADP and FBCF. The anomalies were values described as:

- Less than the Steady State ADP and FBCF
- More than three standard deviations away from the mean
- Negative

The source(s) of these peculiar results were not discovered in the course of this thesis. The experiment of running the OSD (AT&L) Calculator 100 times was executed over 10 times and we found that the anomalies were consistently present in 5 percent of the runs. In order to reduce the impact of these anomalies in the results for the sake of comparison, the anomalous values were replaced with the average of the previous two values.

The mean of the Steady State ADP was $5.28 per gallon with no variability. The lack of variability is because the Air Force cost elements used in the OSD (AT&L) FBCF calculator were held constant to see how the OSD (AT&L) FBCF calculator compared to the Air Force FBCF calculator. The mean of the Steady State FBCF was $18,836.49 per day and had a standard deviation of $33.26 per day. The FBCF incorporates the scenario and the platform concept of operations, which do contain significant uncertainty and cause variation in the FBCF.

As expected, even after the anomalies had been addressed in the Operational ADP and FBCF, there was still significant variation. The mean of the Operational ADP was $29.15 per gallon with a standard deviation of $13.20 per gallon. The Operational FBCF was $204,959.69 per day with a standard deviation of $96,703.26 per day. The Operational ADP, unlike the Steady State ADP, incorporates the force protection variation in cost element number 7. Table 9 displays the results of 100 runs of the OSD (AT&L) calculator.

	Steady State		Operational		Duty-Cycle Weighted	
	ADP	FBCF	ADP	FBCF	ADP	FBCF
Mean (100 Runs)	**$5.28**	**$18,836.49**	**$29.15**	**$204,959.69**	**$19.60**	**$130,533.89**
Standard Deviation (100 Runs)	**$0.00**	**$33.26**	**$13.20**	**$96,703.26**	**$7.93**	**$58,121.71**

Table 9. The OSD (AT&L) FBCF Calculator Output (100 Runs)

The full data set for the OSD (AT&L) FBCF Calculator output, in which the anomalies have been addressed, can be found in Appendix C.

C. COMPARISON OF THE FBCF CALCULATOR RESULTS

It was expected that since the Air Force FBCF methodology was deterministic and the OSD (AT&L) FBCF methodology was stochastic, the values would not be the same. Yet, the similarities in the Duty-Cycle Weighted values were surprising. Table 10 lists both the OSD (AT&L) and the Air Forces FBCF results. Note the Duty-Cycle Weighted ADP and FBCF.

	Steady State		Operational		Duty-Cycle Weighted	
OSD (AT&L) FBCF Results	ADP	FBCF	ADP	FBCF	ADP	FBCF
Mean (100 Runs)	**$5.28**	**$18,836.49**	**$29.15**	**$204,959.69**	**$19.60**	**$130,533.89**
Standard Deviation (100 Runs)	**$0.00**	**$33.26**	**$13.20**	**$96,703.26**	**$7.93**	**$58,121.71**
Air Force FBCF Results						
Ground Refueling	**$3.80**		**$5.28**		**$19.29**	**$152,170.57**
Aerial Refueling	**$27.68**		**$34.57**			

Table 10. Results of Air Force and OSD (AT&L) FBCF Calculations

The Steady State and Operational values do not represent the same calculations, so it would not be correct to directly compare the values. The structure of the Air Force fuel logistic system suggests the need for a unique FBCF structure due to the differences encountered in adding burdens to ground refueling compared to aerial refueling.

Yet, the OSD (AT&L) Duty-Cycle Weighted ADP and FBCF can be compared to the Air Force Weighted FBCF (which OSD (AT&L) would consider the ADP) and the adjusted Total Gallons (which is converted to the FBCF in dollars per day). The Air Force ADP is only 1.6 % different from the OSD (AT&L) ADP and is well within one standard deviation of $7.93 per gallon. The Air Force FBCF is about 16 % different from the OSD (AT&L) Duty-Cycle Weighted FBCF and is also well within one standard deviation of $58,121.71 per day. These numbers suggest that the OSD (AT&L) FBCF Calculator and the Air Force FBCF Calculator produce similar answers via different methodologies.

D. MORE FINDINGS ON THE OSD (AT&L) CALCULATOR

While becoming familiar with how to properly utilize the OSD (AT&L) FBCF Calculator, it was noted how sensitive the calculator was to small changes in some of the parameters. To explore this behavior further, some sensitivity analysis was performed to see how the calculator reacted to changes in the inputs.

In particular, the following OSD (AT&L) FBCF Calculator parameters were subjected to sensitivity analysis:

- TC_v - The life cycle cost of the primary delivery asset
- TC_A - The life cycle cost of the primary escort asset
- OR - The operational tempo ratio
- ER_A - The number of escort aircraft per delivery asset
- P_i - The probability of interdiction

The parameters were varied as indicated in Table 11.

Parameter	Base Case Value	Varied From Base Case	Steady State		Operational		Duty-Cycle Weighted	
			ADP	FBCF	ADP	FBCF	ADP	FBCF
Base Case			**$5.28**	**$18,836.49**	**$29.15**	**$204,959.69**	**$19.60**	**$130,533.89**
TC_V	$360,000,000.00	$540,000,000.00	$5.28	$18,838.23	$35.53	$246,322.48	$23.42	$155,300.07
TC_V		$180,000,000.00	$5.28	$18,831.26	$27.82	$194,385.93	$18.86	$124,544.24
TC_A	$180,000,000.00	$270,000,000.00	$5.28	$18,838.87	$43.91	$305,631.38	$28.43	$190,714.72
TC_A		$90,000,000.00	$5.28	$18,841.24	$25.06	$180,020.20	$17.16	$115,633.63
OR	60.00%	90.00%	$5.27	$18,829.82	$33.00	$236,457.49	$30.24	$214,806.15
OR		25.00%	$5.28	$18,824.30	$34.62	$243,838.71	$12.76	$76,204.66
ER_A	0.667	2	$5.28	$18,831.58	$11.38	$80,267.33	$8.69	$53,736.47
P_i	0.40%	0.00%	$5.28	$18,821.43	$33.30	$235,984.70	$22.10	$149,200.58

Table 11. Sensitivity of the OSD (AT&L) FBCF Calculator

Four of the five cases listed above behaved as expected. For example, when the life cycle cost of a KC-10A went up, the ADP and FBCF increased and when the life cycle cost of an F-16 went down, the ADP and FBCF decreased. For each case, the runs were gathered 100 times and the mean and standard deviation of the results were calculated, with the mean of the output of the case listed in Table 11.

ER_A, the number of escort assets per delivery asset, did not respond as expected. When the number of escort assets, in this case F-16 fighters, was increased, the ADP and FBCF went down significantly. One may have thought that this makes sense since the escorts could better defend the delivery asset, in this case a KC-10, but the probability of interdiction in the base case and this particular sensitivity analysis is 0.4 percent. Furthermore, when the probability of interdiction was brought down to zero, and the number of fighters escorts was decreased, the ADP and FBCF was higher than the base case which goes against what one may logically expect.

The Optempo Ratio behaves as expected and provides the weight in the Duty-Cycle Weighted ADP and FBCF. As expected, it is a linear relationship between the Optempo Ratio and Duty-Cycle Weighted ADP and the Optempo Ratio and the Duty-Cycle Weighted FBCF. Figures 2 and 3 illustrate these findings.

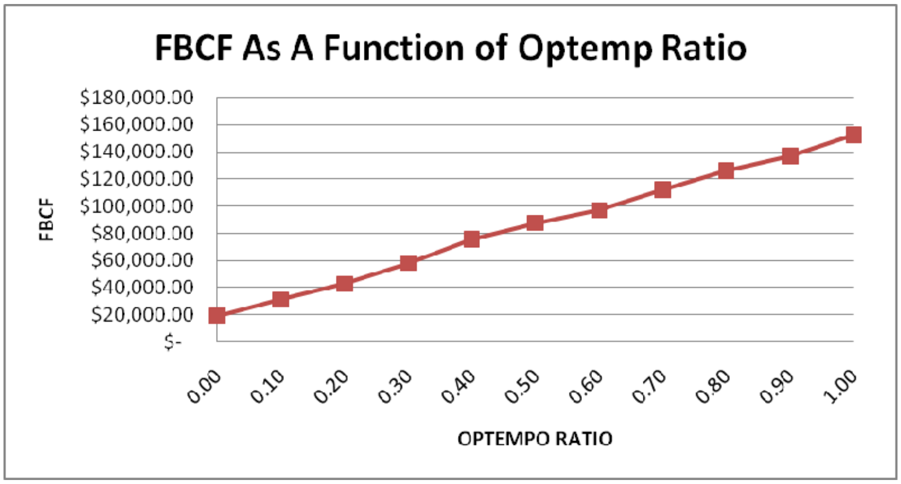

Figure 2. FBCF as a function of the Optempo Ratio

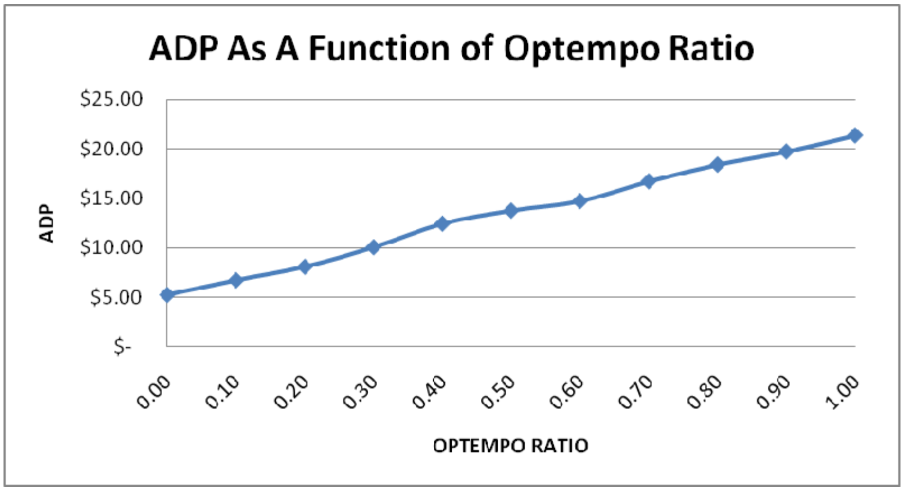

Figure 3. ADP as a Function of Optempo Ration

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V. CONCLUSIONS AND FOLLOW ON STUDIES

A. OBSERVATIONS

There were three major observations from this study

- There are currently a number of different methodologies in development across the Services utilized to calculate the FBCF. The evolution of the concept of the FBCF will continue to develop while the concept of the FBCF matures. Currently the United States Navy and Marine Corps use the same FBCF Calculator as OSD (AT&L), which is different from the United States Air Force FBCF Calculator, which is different from the FBCF Calculator under development by the United States Army.

- The comparison of the Air Forces' FBCF methodology to the OSD (AT&L) FBCF methodology indicates that the different approaches can result in similar FBCF estimates. The major driver for differences in the estimates is more dependent on the input data than on the FBCF computational methodologies.

- Specialized FBCF methodologies for the Services have potential to be the best way forward due to the unique structure of the logistics of a particular service, particularly with regards to the fuel delivery logistics to include accounting as discussed in Chapter III, paragraph B, section 2.

B. CONCLUSIONS

The review by which the various Services calculate the Fully Burdened Cost of Fuel demonstrates that there is a range of methods that can derive the estimate.

Each of the service branches methodologies incorporates the fundamental concept of using the seven-step process. While the Services understand and agree upon the underlying principles that the FBCF represents, the definition of the units for the FBCF is not consistent across the Department of Defense. Those principles are that the Department of Defense undervalues the cost of fuel and that the FBCF is a tool that incorporates a number of those costs so that we can properly value efficiencies and new technologies in the acquisition process. The Services and OSD (AT&L) do not currently agree upon a method of implementation despite achieving similar results via different methodologies.

The question of whether or not all of the Services should use the same methodology remains unsettled. This study indicates that the different logistical structures of the various services may require different methodologies for calculating the FBCF. A FBCF tool that is broad enough to be useful for all of the service branches may not provide enough specific functionality to be as useful as individual service methodologies could be. The different logistical systems of the various service branches to include accounting practices and data sources can make using a common methodology challenging.

The FBCF is an estimate made up of a number of other estimates. To that end, using a stochastic mechanism to develop upper and lower bounds on a FBCF estimate is useful for understanding the uncertainty that is inherent in the FBCF.

C. RECOMMENDATIONS

The recommendations of this study are:

- Establish one definition of the Fully Burdened Cost of Fuel for DoD. While the service branches may have different methodologies for calculating the FBCF, it is important to be able to understand that estimate across the Services. Therefore, if the definition of the FBCF is in dollars per day per platform or in dollars per year per platform population, it should be consistent across the Services.

- All of the methodologies need to use a specific scenario. Without a specific scenario, the inaccuracy related to an estimate would be greater because the estimate is trying to use one estimate to account for a number of different asset employment possibilities.

- The calculation should employ a stochastic mechanism in order to handle the uncertainty that accompanies practically any defense scenario and asset employment concepts.

- Ranges of the FBCF estimate should describe the burdened cost of fuel in a scenario. When a point estimate is required, the development of a policy can establish what to use, such as the mean or 80 percent.

D. FOLLOW ON STUDIES

There is continuation work associated with this and other ongoing studies on the topic of FBCF and its implementation into the acquisition process. The following provides a non-exclusive list for future studies.

- Conduct similar comparisons of future FBCF methodologies such as the Army's FBCF Calculator with methodologies utilized by other service branches.

- Establish a stochastic mechanism that can work with the Air Force FBCF methodology.

- Calculate the FBCF for a platform using an actual Defense Planning Scenario.

- Investigate other commodities that we may undervalue such as food or water.

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VI. APPENDICES

A. 2001 DSB FINDINGS AND RECOMMENDATIONS (DSB, 2001).

Finding #1

> **Although significant warfighting, logistics and cost benefits occur when weapons systems are made more fuel-efficient, these benefits are not valued or emphasized in the DoD requirements and acquisition processes.**

Recommendation #1

> **Base investment decisions on the true cost of delivered fuel and on warfighting and environmental benefits.**

Finding #2

> **The DoD currently prices fuel based on the wholesale refinery price and does not include the cost of delivery to its customers. This prevents an end-to-end view of fuel utilization in decision making, does not reflect the DoD's true fuel costs, masks energy efficiency benefits, and distorts platform design choices.**

Recommendation #2

> **Strengthen linkage between warfighting capability and fuel logistics requirements through wargaming and new analytical tools.**

Finding #3

> **The DoD resource allocation and accounting processes (PPBS, DoD Comptroller) do not reward fuel efficiency or penalize inefficiency.**

Recommendation #3

> **Provide leadership that incentivizes fuel efficiency throughout the DoD.**

Finding #4

> **Operational and logistics wargaming of fuel requirements is not cross-linked to the Service requirements development or acquisition program processes.**

Recommendation #4

> **Specifically target fuel efficiency improvements through investments in Science and Technology and systems designs.**

Finding #5

> **High payoff, fuel-efficient technologies are available now to improve warfighting effectiveness in current weapon systems through retrofit and in new systems acquisition.**

Recommendation #5

> **Explicitly include fuel efficiency in requirements and acquisition processes.**

B. OSD (AT&L) FBCF CALCULATOR DOCUMENTATION VERSION 7.1

Fully Burdened Cost of Fuel Calculator
Model Description & Assumptions

The Fully Burdened Cost of Fuel (FBCF) Calculator computes a numerical estimate of the FBCF using the basic methodology provided in the Defense Acquisition Guidebook (DAG). While the DAG provides a description for computing the FBCF, this model takes the methodology further and provides a mathematical process to arrive at a numerical estimate of the FBCF. The FBCF is a measure of the value of delivered fuel consumed over a period of time by a platform.

The FBCF is a tool for quantifying and monetizing the demands placed upon the logistics force created by the fuel demands of the systems we are designing and fielding. By quantifying the logistics burden, this logistics information is now part of the acquisition trade space; along with cost, schedule and performance. The FBCF will be calculated as part of the larger total ownership cost of major systems in the Analyses of Alternatives (AoAs) for all notional combat platforms, combat support platforms and major equipment programs where the system is expected to create a demand for delivered energy in the battlespace.

This calculator contains parameters for all transportation modes (air, land, and sea). However, depending on the mode, certain parameters will not be necessary. Mode specific versions of the calculator have been developed to ease computations. The concept of the FBCF is to help differentiate the merits of the alternatives in an AoA. As such, it must not be taken out of context, and should always be referenced to the scenario and platform under investigation.

General Assumptions:

- The FBCF is determined from a scenario-based analytic process.
- The operations tempo (OPTEMPO) sets the pace of equipment usage, and the selection of the scenarios used directly affects the magnitude of the FBCF.
- FBCF cannot be calculated without representing surge, wartime activities. These higher OPTEMPO scenarios incur greater wear and tear on equipment, and the higher fuel logistics demands require protection from threats.
- FBCF is different for every platform because demand varies among systems.

- Because FBCF is to be used for future systems' AoAs, a DoD Component must use derivatives of Defense Planning Scenarios (a future look at a time when planned developmental systems will be in the US inventory) to work from a common analytic baseline and to present a common set of assumptions by which to oversee and assess its application in those AoAs.

Calculator Methodology Assumptions:

- Fuel deliveries are made by logistics vehicles traveling along a route that forms a closed-loop circuit. Fuel is loaded out at a Defense Energy Support Center (DESC) port/terminal, the deliveries are made out to the systems, and the delivery vehicles return to the originating port/terminal.
- The fuel delivered out to the battlespace is not used exclusively by the system under investigation, but rather is used by a number of other systems. Defining how much fuel is used by the system under investigation versus how much is demanded by other systems in the battlespace is termed *Apportionment*.
- "Peacetime" operations are based upon scenarios involving foundational activities as defined in the Analytic Agenda (AA), while surge activities are conducted at a higher OPTEMPO in AA scenarios. Defining the ratio of the amount of time spent at the higher surge OPTEMPO versus the total useful life of the platform is termed *Allocation* and must be in line with standing Service planning OPTEMPO assumptions provided to OSD.
- The parameters associated with delivery are based upon scenarios that reflect a Service's logistics operational concept that are consistent with the Defense Planning Scenarios.
- An average FBCF is computed amongst the scenarios in both surge and foundational activities. The higher intensity surge activities and the lower intensity foundational activities comprise two broad OPTEMPO end-points. The final FBCF is a weighted average of these two broad OPTEMPO intensities based upon the OPTEMPO Ratio established during *Allocation*.

- The Assured Delivery Price (ADP) is the sum of the 7 price elements that together account for purchase of the fuel from DESC, plus the tactical delivery costs of transporting and protecting that fuel out to the point of consumption by the systems. It is measured in units of $/gal.
- The number of delivery assets needed to deliver the quantity of fuel demanded is balanced through the Service MSFD data.
- The calculator includes provisions for force protection forces to the logistics forces, as a lesson learned from current operations that have not yet been factored into Defense Planning Scenarios.
- The amount of fuel loaded out at the port/terminal is equal to the fuel demanded by the destination systems, plus the fuel that will be consumed by the delivery and escort vehicles. The delivery and escort vehicles are consuming the fuel they are carrying. Also loaded out is the additional proportion of fuel expected to be lost due to enemy attack.
- No external re-fueling of the delivery convoy occurs during their passage along the delivery circuit.
- All fuel loaded out is either consumed or delivered by the end of the circuit. Only the small additional amounts loaded to account for interdiction are stockpiled at the final receiving location. However, this amount is consumed over time as interdictions occur and this small stockpile does not incur any additional costs in this model.
- There is no equipment failure of any of the vehicles used in the delivery process. However, attrition of delivery vehicles due to interdiction during enemy attack is accounted for.
- The FBCF is based upon the ADP to deliver the fuel out to the system and the amount of fuel demanded by the system/platform type in question over the course of one day (or other set period of time). Typically, the FBCF is measured in $/day for ground and sea platforms and in $/Flight Hour for air platforms.

- To account for higher wear and tear on systems functioning at surge OPTEMPO, an LCC multiplier (*LM*) parameter is included to compensate for the accelerated usage of a system.
- The *LM* parameter is not used in procurement cost computations. The procurement cost in surge scenarios is assumed equal to the cost in foundational activity scenarios.

Basic Definitions:

A distinction is made between the terms *Price* and *Cost*. *Price* is the value of a specified volume of a commodity. It is typically measured in units of \$/gal or \$/bbl for liquid fuels. Conversely, *cost* is the total amount spent to purchase a commodity over a period of time. It is typically measured in \$/day or \$/Flying Hour. Occasionally, it may be measured in units of \$/sortie or \$/mission for operations that do not conveniently fit into shorter time units. By combining the *Price* with the Demand, the *Cost* may be computed:

$$Price\ (\$/gal) * Demand\ (gal/day) = Cost\ (\$/day) \qquad \text{(eq. 1.1)}$$

As per the DAG guidance, the seven Price Elements are defined below. The FBCF can only be calculated when based upon fuel demand in different specified scenarios. Two broad OPTEMPO-related scenario categories were chosen: Surge (S) and Foundational (F). Surge scenarios include higher intensity wartime activities, deployed forces in support of major combat operations and irregular campaigns, operating out of temporary locations. Foundational activity scenarios primarily include lower intensity operations, deterrence, conflict prevention, and smaller-scale contingency activities, operating out of permanent, OCONUS installations. Each Price Element is measured in \$/gal for each of the Surge and Foundational scenarios, for a total of 14 Price Elements.

1. *Commodity Price of Fuel.* Defense Energy Support Center (DESC) standard price for the appropriate type of fuel.
2. *Primary Fuel Delivery Asset O&S Price.* Cost of operating and support of service-owned fuel delivery assets including the cost of military and civilian personnel dedicated to the fuel delivery mission (measured with respect to the volume of fuel delivered).
3. *Depreciation Price of Primary Fuel Delivery Assets.* Measures the decline in value of fuel delivery assets with finite service lives using straight-line depreciation over total service life. This element also includes the cost of delivery vehicle losses (measured with respect to the volume of fuel delivered) due to interdiction by writing off the entire remaining procurement value of a delivery vehicle at the time of its destruction.
4. *Direct Fuel Infrastructure O&S and Recapitalization Price.* Cost of fuel infrastructure (measured with respect to the volume of fuel handled) that is not operated by DESC and directly tied to energy delivery.

5. *Indirect Fuel Infrastructure O&S Price.* Cost of base infrastructure (measured with respect to the volume of fuel handled) that is shared proportionally among all base tenants.
6. *Environmental Price.* Price of carbon trading credits, hazardous waste control and related subjects.
7. *Other Service & Platform Delivery Specific Prices.* Includes potential costs associated with delivering fuel such as force protection, regulatory compliance, contracting and other costs as appropriate (measured with respect to the volume of fuel protected or handled).

Price Element Computations:

Numerical estimates of some of the 14 Price Elements may be adequately determined through traditional cost estimating techniques. In some cases, contract prices may be used to define either the surge or foundational price elements. However, for most surge scenarios, these figures are typically not computed. The three, most significant, surge price elements are related to *Surge Price Element 2, Delivery Asset O&S Price* (SP_2)*;* *Surge Price Element 3, Depreciation Price of Primary Fuel Delivery Assets* (SP_3)*;* and *Surge Price Element 7, Other Prices* (SP_7)*.* Element SP_2 reflects the operational and support costs of the delivery vehicles (including the manpower to operate them) to transport the fuel from the DESC delivery port/terminal out to the operational area where it is finally loaded into the combat vehicle. Price Element SP_3 includes the cost of procuring the delivery vehicles and the value lost, if they are destroyed during an attack. Price Element SP_7 largely reflects the costs incurred by the force protection assets and personnel used to assure the safe transport and return of the delivery vehicles from the DESC port/terminal out to the operational delivery point and back. These three Price Elements have the greatest influence on the magnitude of the ADP and hence the FBCF. The following method defines how these three critical Price Elements are computed in the FBCF Calculator.

The following table lists the parameters used to compute Price Elements SP_2, SP_3, and SP_7. All these parameters are on a single platform basis.

Parameter	Symbol	Units
Fuel Consumption Rate by 1 delivery Vehicle	CR_V	gal/day
Fuel Consumption Rate by 1 Escort vehicle	CR_E	gal/day
Fuel Consumption Rate by 1 escort Aircraft	CR_A	gal/day
Number of days to deliver fuel (round-trip)	T	days
Multiplier to keep convoy fuel flowing	A	#
Capacity of one delivery vehicle	Q	gal
Total Life-Cycle Cost (LCC) of 1 delivery Vehicle (Peacetime estimate)	TC_V	$
Procurement Cost fraction of delivery Vehicle LCC	PC_V	#
O&S cost fraction of delivery Vehicle LCC	OS_V	#
Probability of an interdiction event during a delivery	P	#
Number of delivery vehicles Lost during the interdiction	□	#
LCC Multiplier to account for accelerated surge usage of delivery Vehicle	LM_V	#
Average age of a delivery vehicle	M_μ	days
Number of days 1 delivery Vehicle will be used during its lifetime	M_V	days
Total life-cycle Cost of 1 Escort vehicle	TC_E	$
LCC Multiplier to account for surge usage of Escort vehicle	LM_E	#
Escort Ratio (delivery vehicles per Escort vehicle)	ER_E	#

Table 1. Input Parameters for SP_2, SP_3, and SP_7 (continues on next page)

Parameter	Symbol	Units
Number of days 1 Escort vehicle will be used in its lifetime	M_E	days
Total life-cycle Cost of 1 escort Aircraft	TC_A	$
LCC Multiplier to account for surge usage of escort Aircraft	LM_A	#
Aircraft Escort Ratio (delivery vehicles per escort aircraft)	ER_A	#
Number of days 1 escort Aircraft will operate during its lifetime	M_A	days

Table 1. (cont.) Input Parameters for SP_2, SP_3, and SP_7

To begin computing SP_2, SP_3, and SP_7, it must first be determined how much fuel needs to be loaded out at the DESC port/terminal. This load-out quantity (L) includes all fuel demands (for one day of operation) at the final delivery location, plus the total amount of fuel required by the delivery and force protection assets needed to get the fuel safely out to the war fighter. L also includes the proportional amount that must be loaded to account for the loss of fuel due to interdiction. It is assumed that the delivery, and force protection escort vehicles and aircraft all draw their fuel out of this initial load-out quantity that is obtained from the DESC port/terminal.

$$L = D_S + \alpha + \sum_i C_i \qquad \text{(eq. 1.2)}$$

Where:

$L =$ Load-out quantity of fuel from the DESC port/terminal for one delivery trip (gal)
$D_S =$ Quantity of fuel Demanded during Surge per day by all users at the final location (gal)
$\alpha =$ Additional quantity of fuel loaded-out due to interdiction losses (gal)
$C_i =$ Total quantity of fuel Consumed by vehicle type *i* during the delivery trip (gal)
$i =$ index for vehicle type: V=delivery Vehicle, E=Escort vehicle, A= escort Aircraft

The loss due to interdiction (□) is determined by the Probability of an interdiction event (*P*) and by how many delivery vehicles are expected to be destroyed (□) during that interdiction event. The quantity of fuel lost due to interdiction is computed as follows:

$$\alpha = P * \lambda * Q \qquad \text{(eq. 1.3)}$$

Where:

$\alpha =$ Additional fuel load-out to account for interdiction loss (gal)
$P =$ Probability of an interdiction event during a delivery mission
$\lambda =$ Expected number of delivery vehicles that will be destroyed during the interdiction
$Q =$ Capacity of one delivery vehicle (gal)

To determine how much fuel each vehicle type consumes during the delivery trip, the number of vehicles must first be determined. These computations assume there is no equipment breakdown. However, attrition is accounted for by the □-term above. Using the same subscripts from index *i* above, the total number of vehicles needed are as follows:

$$N_V = \frac{L * A}{Q} \qquad \text{(eq. 1.4)}$$

$$N_E = \frac{N_V}{ER_E} \qquad \text{(eq. 1.5)}$$

$$N_A = \frac{N_V}{ER_A} \qquad \text{(eq. 1.6)}$$

Where:

N_V = Number of delivery Vehicles needed to transport L amount of fuel
N_E = Number of Escort vehicles needed to protect N_V vehicles
N_A = Number of escort Aircraft needed to protect N_V vehicles
L = Load-out quantity of fuel from the DESC port/terminal for one delivery trip (gal)
A = Convoy continuity multiplier factor
Q = Capacity of one delivery vehicle (gal)
ER_E = Escort Ratio, number of delivery vehicles per Escort vehicle
ER_A = Aircraft Escort Ratio, number of delivery vehicles per escort Aircraft

The convoy (composed of N_V delivery vehicles) continuity multiplier factor (A) is a number greater than or equal to 1.0 that measures the number of convoys simultaneously deployed from the DESC port/terminal that are en-route to the final delivery location and/or still returning to the DESC port/terminal. On shorter runs, this factor is equal to 1.0. Particularly on longer delivery runs, several convoys will be needed to keep the deliveries evenly and regularly spaced. The continuity factor A accounts for the multiple sets of delivery assets that are simultaneously in use to support one location.

Using the formulae for the number of vehicles needed (eqs. 1.4, 1.5, and 1.6); along with the given values for CR_i and T, the total quantities of fuel consumed by the three vehicle types, during a delivery trip, are computed as follows:

$$C_V = N_V * CR_V * T \qquad \text{(eq. 1.7)}$$
$$C_E = N_E * CR_E * T \qquad \text{(eq. 1.8)}$$
$$C_A = N_A * CR_A * T \qquad \text{(eq. 1.9)}$$

Where:

C_i = Total quantity of fuel Consumed by vehicle type i during the delivery trip (gal)
N_i = Number of Vehicles of type i needed during the delivery trip
CR_i = Fuel Consumption Rate of vehicle type i (gal/day)
T = Number of days to deliver fuel (round-trip) (days)
i = index for vehicle type: V=delivery Vehicle, E=Escort vehicle, A= escort Aircraft

Remembering that the purpose of all the computations above is to compute the load-out quantity of fuel L, the above equations may be rearranged and substituted into one another to finally compute L as follows:

Rearrange eq. 1.2: $D_S = L - \sum_i C_i - \alpha$

(eq. 1.10)

Substituting:

$$D_S = L - \left[\left(\frac{L * A}{Q} * CR_V * T\right) + \left(\frac{L * A}{ER_E * Q} * CR_E * T\right) + \left(\frac{L * A}{ER_A * Q} * CR_A * T\right)\right] - \alpha \quad \text{(eq. 1.11)}$$

Factor out L and common terms: $D_S = L - L * \left[\frac{A * T}{Q} * \left(CR_V + \frac{CR_E}{ER_E} + \frac{CR_A}{ER_A}\right)\right] - \alpha$

(eq. 1.12)

Define common terms as β: $\beta = \left[\frac{A * T}{Q} * \left(CR_V + \frac{CR_E}{ER_E} + \frac{CR_A}{ER_A}\right)\right]$

(eq. 1.13)

Substitute β into eq. 1.12: $D_S = L - (L * \beta) - \alpha$

(eq. 1.14)

Factor out L: $D_S = L * (1 - \beta) - \alpha$

(eq. 1.15)

Solve for L: $L = \frac{D_S + \alpha}{1 - \beta}$

(eq. 1.16)

With the total load-out fuel quantity L computed, the total number of vehicles required for a delivery mission may be calculated using equations 1.4, 1.5, and 1.6. The number of different types of vehicles will be used in the following calculations.

Price Elements SP_2 and SP_3 are related to the Life-Cycle Cost (LCC) of the delivery vehicles. SP_2 reflects the operating and support (O&S) costs, while SP_3 captures the procurement costs.

The SP_2 Price Element, the O&S fraction of the Total LCC used each day of a delivery mission, is based upon the Total LCC, TC_V. However, because the LCC is typically estimated for peacetime usage, and surge usage generally incurs O&S costs several times the peacetime estimate; the O&S portion needs to be multiplied by the LCC multiplier factor, LM_V. Also, since SP_2 only accounts for the O&S portion of the LLC, the entire TC_V is not used. The OS_V factor represents the O&S cost portion of the LLC and is used to ensure only the O&S portion of the LLC is included in the SP_2 calculation.

To finally compute the SP_2 Price Element, the TC_V is adjusted as follows to arrive at the *Primary Fuel Delivery Asset O&S Price*, in units of $/gal for one delivery trip:

$$SP_2 = \frac{\left(T * N_V * \dfrac{OS_V * LM_V * TC_V}{M_V}\right)}{D_S} \qquad \text{(eq. 1.17)}$$

Where:

$T =$ Number of days to deliver fuel (round-trip) (days)
$N_V =$ Number of delivery Vehicles needed to transport L amount of fuel
$OS_V =$ O&S cost fraction of delivery Vehicle's LCC
$LM_V =$ LCC Multiplier to account for surge usage of delivery Vehicle
$TC_V =$ Total Life Cycle Cost (LCC) of delivery Vehicle determined in peacetime ($)
$M_V =$ Number of days a delivery Vehicle will be used in its lifetime (days)
$D_S =$ Quantity of fuel Demanded during Surge per day by all users at the final location (gal)

Price Element SP_3 measures the value of the fuel delivery assets during the time period they are used in one fuel delivery mission. Using the Total LCC as a start, it is multiplied by the Procurement Cost Factor PC_V, which is the proportion of the LCC that is composed of the procurement costs, to arrive at an estimate of the procurement cost alone. This procurement cost is divided by the number of days in the life of this asset to arrive at a value for the delivery asset on a per-day of use basis.

During delivery, there is a distinct possibility that the enemy will attack the fuel delivery vehicles. This model only accounts for losses to the delivery vehicles. Any losses to the escorting vehicles are not included. Services may wish to include these additional costs, but must be aware of properly apportioning the value of the escorts related purely to fuel delivery operations.

The probability of such an attack is defined as P. Given that such an attack occurs, the number of delivery vehicles destroyed is measured by the parameter lambda (λ). The value of the vehicles destroyed is based on the remaining life of the vehicle ($1-M_\lambda/M_V$). The value lost due to attack is thus the product of P, λ, the life remaining factor, and the procurement cost.

To finally compute the SP_3 Price Element, the fraction of the procurement cost used each day of a delivery mission (from above) is combined with the number of delivery assets used (N_V) and the number of days they are used (T), plus the value of the loss due to interdiction, all divided by the amount of fuel demanded, to arrive at the *Depreciation Price of Primary Fuel Delivery Assets*, in units of $/gal for one delivery trip:

$$SP_3 = \frac{\left(T * N_V * \frac{PC_V * TC_V}{M_V}\right) + \left[P * \lambda * \left(1 - \frac{M_\mu}{M_V}\right) * PC_V * TC_V\right]}{D_S} \quad \text{(eq. 1.18)}$$

Where:

$T =$ Number of days to deliver fuel (round-trip) (days)
$N_V =$ Number of delivery Vehicles needed to transport L amount of fuel
$PC_V =$ Procurement Cost fraction of delivery Vehicle LCC
$TC_V =$ Total Life Cycle Cost (LCC) of delivery Vehicle determined in peacetime ($)
$M_V =$ Number of days a delivery Vehicle will be used in its lifetime (days)
$P =$ Probability of an interdiction event during a delivery mission
$\lambda =$ Expected number of delivery vehicles that will be destroyed during the interdiction
$M_\mu =$ Average age of a delivery vehicle (days)
$D_S =$ Quantity of fuel Demanded during Surge per day by all users at the final location (gal)

The *Other Prices* Price Element, SP_7, is largely composed of the costs associated with force protection of the delivery assets. It is assumed that the force protection contingent is directly proportional to the size of the delivery fleet (N_V). A greater number of delivery vehicles (N_V) will require a greater number of imbedded escort vehicles (N_E) and overhead protection aircraft (N_A). The issue of force protection may merit a complete sub-model to address the complexities of defending the delivery vehicles. This calculator model uses simple proportions in equations 1.5 and 1.6 to indicate where this issue plays a role in the FBCF calculation to compute the value for SP_7.

The appropriate LCC Multipliers (LM_x) for the escort vehicles and aircraft are used to adjust the peacetime derived LCCs. All other variables are as defined in Table 1. The following equation shows how the parameters are combined to produce the SP_7 cost, in units of $/gal for one delivery trip:

$$SP_7 = \frac{T * \left\{\left[N_E * \left(\frac{LM_E * TC_E}{M_E}\right)\right] + \left[N_A * \frac{(LM_A * TC_A)}{M_A}\right]\right\}}{D_S} \quad \text{(eq. 1.19)}$$

Where:

$T =$ Number of days to deliver fuel (round-trip) (days)
$N_E =$ Number of Escort vehicles needed to protect delivery vehicles
$LM_E =$ LCC Multiplier to account for surge usage of Escort vehicle
$TC_E =$ Total life-cycle Cost of 1 Escort vehicle ($)
$M_E =$ Number of escort days 1 Escort vehicle will be used in its lifetime (days)

$N_A =$ Number of escort Aircraft needed to protect delivery vehicles
$LM_A =$ LCC Multiplier to account for surge usage of escort Aircraft
$TC_A =$ Total life-cycle Cost of 1 escort Aircraft ($)
$M_A =$ Number of days 1 escort Aircraft will perform escorts during its lifetime (days)
$D_S =$ Quantity of fuel Demanded during Surge per day by all users at the final location (gal)

The sum of the seven Price Elements within each scenario, determines the Assured Delivery Price (ADP). The ADP reflects the true price of assuring delivery of the fuel from the DESC point of sale out to the location where the fuel will be consumed by the military platform. The ADP is measured in units of $/gal, for each scenario OPTEMPO class:

$$ADP_S = \sum_{e=1}^{7} SP_e \qquad \text{(eq. 1.20)}$$

$$ADP_F = \sum_{e=1}^{7} FP_e \qquad \text{(eq. 1.21)}$$

Where:

$ADP_S =$ Assured Delivery Price in Surge scenarios ($/gal)
$SP_e =$ Price of element e in Surge activity scenarios ($/gal)
$ADP_F =$ Assured Delivery Price in Foundational activity scenarios ($/gal)
$FP_e =$ Price of element e in Foundational activity scenarios ($/gal)
$e =$ index of the Price Element that accounts for part of fuel delivery price (Element numbers 1, 2, 3, 4, 5, 6, and 7)

To compute a single, OPTEMPO-averaged value for the ADP, the individual, scenario-based values of the ADP are weighted according to the relative amount of time the system operates in each of the two basic OPTEMPOs. The ratio of Operating Hours within the surge scenarios divided by the total planned Operating Hours of the system in its full, life-cycle lifetime (derived from the surge activity scenarios plus foundational activity scenarios) provides the proper proportional estimate of OPTEMPO usage. The ratio R, reflects the OPTEMPO ratio and provides the weighting factor needed to compute the ADP:

$$ADP = \left[ADP_S * R\right] + \left[ADP_F * (1 - R)\right] \qquad \text{(eq. 1.22)}$$

Where:

$ADP =$ Assured Delivery Price, OPTEMPO averaged ($/gal)

$$R = \frac{OH_S}{OH_{Tot}} \qquad \text{(defined as the OPTEMPO Ratio)} \qquad \text{(eq. 1.23)}$$

Where:

OH_S = Number of Operating Hours vehicle powered on in Surge scenarios
OH_{Tot} = Total number of Operating Hours vehicle powered on during its lifetime (all scenarios, surge and foundational activities)

Fully Burdened Cost of Fuel Computation:

Recall the distinction made between "Price" and "Cost". Price is the value of a specified amount of a commodity. Price is measured in units of $/gal or $/bbl. The ADP reflects the value of a gallon of fuel as delivered into the combat area. Cost, on the other hand, is the total amount spent to purchase a commodity. Cost is measured in units of $/day, $/Flying Hour or $/mission task. A general form for the calculation of FBCF is thus:

$$ADP * Demand = FBCF \qquad \text{(eq. 2.1)}$$

To compute the FBCF, additional parameters are required that relate the price of assured delivery of the fuel out to the combat vehicle (ADP), to the quantity of fuel demanded by each vehicle. The following calculations assume the following two additional quantities are known: 1) the proportion of the fuel logistics "tail" attributable to the platform or system in question (P_x), and 2) the number of systems consuming the fuel (N_x). It is assumed that the total quantity of fuel delivered is completely consumed. This model does not account for any stockpiling of fuel; it treats the delivery as a continuously flowing process. The FBCF is measured in units of $/day per platform, for each scenario OPTEMPO class:

$$FBCF_S = ADP_S * \left(\frac{P_S * D_S}{N_S} \right) \qquad \text{(eq. 2.2)}$$

$$FBCF_F = ADP_F * \left(\frac{P_F * D_F}{N_F} \right) \qquad \text{(eq. 2.3)}$$

Where:

$FBCF_S$ = Fully Burdened Cost of Fuel in Surge scenarios ($/day)
ADP_S = Assured Delivery Price in Surge scenarios ($/gal)
P_S = Proportion of all fuel delivered in Surge scenarios to the final location that is consumed by the platform of interest
D_S = total amount of fuel Demanded (consumed) by all systems at the final delivery location on a daily basis while in Surge scenarios (gal/day)
N_S = Number of platforms of interest demanding fuel in Surge scenarios
$FBCF_F$ = Fully Burdened Cost of Fuel in Foundational activity scenarios ($/day)
ADP_F = Assured Delivery Price in Foundational activity scenarios ($/gal)

$P_F =$ Proportion of all fuel delivered in Foundational activity scenarios to the final location that is consumed by the platform of interest
$D_F =$ total amount of fuel Demanded (consumed) by all systems at the final delivery location on a daily basis while in Foundational activity scenarios (gal/day)
$N_F =$ Number of platforms of interest demanding fuel in Foundational activity scenarios

Finally, to compute a single, OPTEMPO-averaged value for the FBCF, the individual, scenario-based values of the FBCF are weighted according to the relative amount of time the system operates in each of the two OPTEMPO classes. The same OPTEMPO Ratio (R), as defined above in eq. 1.23, is used again:

$$FBCF = [FBCF_S * R] + [FBCF_F * (1 - R)] \qquad \text{(eq. 2.4)}$$

Where:

$FBCF =$ Fully Burdened Cost of Fuel, OPTEMPO averaged (\$/day)
$R =$ OPTEMPO Ratio (eq. 1.23)

C. OUTPUT FOR ONE HUNDRED OSD (AT&L) CALCULATOR RESULTS

Steady State		Operational		Duty-Cycle Weighted	
ADP	FBCF	ADP	FBCF	ADP	FBCF
$5.28	**$18,836.49**	**$29.15**	**$204,959.69**	**$19.60**	**$130,533.89**
$0.00	**$33.26**	**$13.20**	**$96,703.26**	**$7.93**	**$58,121.71**
$5.28	$18,781.37	$25.74	$182,370.20	$17.56	$117,015.38
$5.28	$18,820.33	$54.84	$368,476.47	$35.08	$229,020.71
$5.27	$18,814.14	$30.68	$216,045.03	$20.52	$137,159.33
$5.28	$18,805.69	$42.76	$292,260.75	$27.80	$183,090.02
$5.27	$18,827.85	$22.35	$153,878.58	$15.52	$99,882.81
$5.27	$18,818.97	$30.45	$216,408.12	$20.36	$137,194.32
$5.28	$18,778.26	$26.40	$185,143.35	$17.94	$118,538.57
$5.28	$18,791.38	$39.74	$279,639.56	$25.93	$175,024.90
$5.27	$18,836.57	$33.07	$232,391.45	$21.93	$146,781.73
$5.28	$18,793.74	$9.29	$64,834.97	$7.57	$45,749.64
$5.28	$18,849.56	$33.22	$229,696.34	$21.97	$144,887.61
$5.28	$18,882.05	$21.26	$147,265.66	$14.77	$95,318.63
$5.28	$18,819.85	$29.14	$205,814.38	$19.61	$131,147.35

$5.27	$18,854.06	$6.87	$21,606.56	$6.53	$22,772.59
$5.27	$18,795.87	$36.12	$251,618.12	$23.90	$159,330.48
$5.28	$18,872.47	$19.72	$141,102.56	$13.98	$92,445.60
$5.28	$18,892.41	$27.92	$196,360.34	$18.94	$125,888.04
$5.27	$18,848.25	$34.31	$247,995.29	$22.81	$157,155.42
$5.27	$18,836.60	$31.12	$222,177.82	$20.88	$141,521.73
$5.27	$18,808.89	$32.71	$235,086.56	$21.84	$149,338.58
$5.27	$18,787.97	$30.73	$216,347.98	$20.55	$137,352.60
$5.28	$18,843.53	$32.35	$214,708.34	$21.40	$135,572.86
$5.27	$18,823.12	$17.53	$128,796.92	$12.65	$84,841.98
$5.27	$18,902.49	$15.03	$55,298.46	$10.82	$38,488.34
$5.28	$18,882.29	$16.28	$92,047.69	$11.73	$61,665.16
$5.27	$18,814.13	$53.86	$335,957.18	$34.62	$210,222.97
$5.27	$18,839.06	$34.35	$247,901.53	$22.68	$155,977.02
$5.28	$18,855.21	$31.98	$218,663.59	$21.37	$139,197.42
$5.27	$18,804.24	$27.15	$196,850.11	$18.24	$124,559.84
$5.28	$18,844.11	$24.94	$182,533.03	$17.05	$116,900.89
$5.27	$18,832.69	$26.05	$189,691.57	$17.64	$120,730.36
$5.27	$18,870.12	$36.46	$237,596.87	$23.79	$148,954.97
$5.28	$18,886.32	$28.55	$229,704.63	$19.48	$147,101.60
$5.28	$18,821.23	$19.87	$138,638.52	$13.96	$90,227.18
$5.27	$18,787.72	$19.02	$135,044.10	$13.57	$88,944.13
$5.28	$18,916.18	$19.45	$130,951.71	$13.79	$86,208.33
$5.28	$18,788.82	$18.11	$117,195.93	$13.06	$78,498.79
$5.27	$18,806.85	$18.78	$124,073.82	$13.42	$82,353.56
$5.27	$18,881.80	$17.69	$125,430.25	$12.71	$82,740.33
$5.28	$18,858.51	$18.23	$124,752.03	$13.07	$82,546.94
$5.27	$18,807.46	$17.96	$125,091.14	$12.89	$82,643.64
$5.27	$18,837.77	$32.48	$232,584.19	$21.63	$147,380.12
$5.28	$18,843.37	$25.93	$206,917.65	$17.68	$131,892.63
$5.28	$18,870.18	$19.88	$133,331.71	$14.03	$87,445.56
$5.27	$18,849.86	$20.83	$144,319.52	$14.66	$94,475.83
$5.27	$18,871.60	$44.64	$314,003.42	$28.98	$196,505.91
$5.27	$18,853.31	$17.81	$120,168.55	$12.82	$79,786.57
$5.28	$18,870.71	$16.13	$109,127.14	$11.85	$73,526.90
$5.27	$18,861.53	$31.13	$218,517.26	$20.88	$139,247.28
$5.28	$18,899.10	$27.27	$211,082.29	$18.38	$133,525.48
$5.28	$18,810.26	$51.12	$360,036.61	$33.06	$225,568.04
$5.27	$18,794.37	$32.42	$227,533.86	$21.58	$144,155.35

$5.28	$18,830.24	$41.77	$293,785.23	$27.32	$184,861.70
$5.27	$18,826.38	$30.25	$211,717.93	$20.30	$134,882.49
$5.27	$18,831.17	$36.01	$252,751.58	$23.81	$159,872.09
$5.28	$18,852.73	$22.46	$158,113.14	$15.60	$102,531.11
$5.27	$18,888.71	$78.36	$645,320.44	$49.14	$394,773.41
$5.28	$18,807.43	$24.49	$160,254.57	$16.79	$103,607.97
$5.28	$18,800.52	$21.82	$153,832.73	$15.31	$100,571.71
$5.28	$18,833.82	$22.27	$112,328.84	$15.29	$73,264.95
$5.28	$18,851.58	$23.88	$180,335.37	$16.46	$115,829.29
$5.28	$18,830.21	$37.20	$263,776.15	$24.44	$165,874.49
$5.28	$18,808.14	$30.54	$222,055.76	$20.45	$140,851.89
$5.27	$18,829.46	$14.40	$106,863.59	$10.73	$71,499.07
$5.28	$18,857.89	$22.47	$164,459.67	$15.59	$106,175.48
$5.28	$18,826.19	$9.49	$62,442.23	$7.75	$44,575.20
$5.28	$18,752.50	$13.94	$89,556.32	$10.40	$60,653.25
$5.28	$18,834.08	$32.22	$224,248.87	$21.47	$142,313.67
$5.28	$18,885.77	$13.01	$91,617.66	$9.87	$62,078.03
$5.28	$18,798.13	$49.00	$354,945.26	$31.50	$220,383.65
$5.27	$18,875.03	$17.43	$125,140.66	$12.57	$82,673.40
$5.27	$18,834.01	$30.73	$216,347.98	$20.55	$137,352.60
$5.28	$18,771.68	$28.62	$194,073.51	$19.10	$122,703.50
$5.27	$18,844.98	$48.58	$331,348.60	$31.25	$206,298.64
$5.28	$18,779.94	$38.60	$262,711.06	$25.18	$164,501.07
$5.27	$18,798.35	$16.87	$127,951.95	$12.26	$84,318.07
$5.28	$18,845.57	$71.81	$504,013.22	$44.91	$308,019.96
$5.28	$18,792.20	$24.50	$178,455.10	$16.75	$114,202.65
$5.28	$18,806.65	$5.36	$54,901.65	$5.38	$40,775.75
$5.27	$18,841.71	$40.04	$280,671.15	$26.12	$175,852.09
$5.27	$18,836.29	$22.70	$167,786.40	$15.75	$108,313.92
$5.28	$18,827.58	$31.37	$224,228.78	$20.94	$142,083.00
$5.27	$18,846.37	$57.21	$387,511.59	$36.50	$240,461.09
$5.28	$18,839.02	$36.44	$271,855.82	$23.95	$170,498.49
$5.28	$18,817.33	$10.42	$72,425.04	$8.19	$49,790.93
$5.27	$18,835.81	$23.09	$169,012.68	$16.01	$109,295.59
$5.28	$18,907.65	$20.88	$167,096.26	$14.53	$107,264.18
$5.27	$18,815.06	$21.99	$168,054.47	$15.27	$108,279.88
$5.28	$18,880.41	$39.24	$287,957.04	$25.69	$180,563.96
$5.28	$18,851.22	$30.61	$228,005.76	$20.48	$144,421.92
$5.27	$18,866.93	$39.36	$278,178.79	$25.78	$174,855.46

$5.28	$18,860.74	$31.61	$229,159.10	$21.07	$145,006.54
$5.27	$18,816.43	$18.46	$134,376.39	$13.16	$87,960.85
$5.28	$18,854.27	$32.69	$222,455.29	$21.72	$141,106.35
$5.27	$18,818.63	$25.57	$178,415.84	$17.44	$114,533.60
$5.27	$18,856.93	$18.05	$135,068.71	$12.98	$88,834.14
$5.27	$18,854.97	$49.90	$335,195.75	$32.04	$208,619.07
$5.27	$18,879.59	$66.55	$467,384.36	$42.11	$288,545.79
$5.28	$18,874.03	$18.68	$119,345.83	$13.33	$79,254.89
$5.27	$18,830.54	$42.61	$293,365.09	$27.72	$183,900.34

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