NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

ESTIMATING THE FULLY BURDENED COST OF FUEL USING AN INPUT-OUPUT MODEL – A MICRO-LEVEL ANALYSIS

by

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September 2011

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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** September 2011	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE Estimating the Fully Burdened Cost of Fuel Using an Input-Output Model – A Micro-Level Analysis			**5. FUNDING NUMBERS**
6. AUTHOR(S) Sean R. Dubbs			
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) N/A			**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 ______N/A__________.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

In 2010, the Department of Defense (DoD) spent $13.2 billion on fuel purchases, with over 3,000 lives lost in fuel delivery operations between 2003 and 2007. To reduce both of these figures, the DoD is investing in technology to reduce fuel consumption, especially in expeditionary and forward operations. These reductions will cause cascading effects throughout the supply chain.

The tools of Input-Output Analysis appear to be a natural fit for determining fuel costs throughout the supply chain and identifying the best ways to improve the efficiency of providing war-fighting capability. A model of the existing portion of the United States Marine Corps supply chain in Afghanistan was built as a proof of concept, along with six scenarios that explore different methods of reducing fuel consumption, to estimate the fuel multiplier for each component in the supply chain. This model was useful in providing insight and a lower bound on the fully burdened cost of fuel within the Afghanistan supply chain. The results of this analysis show that the impact of force protection fuel usage is not as large as previously believed. In some situations, fuel resupply through an airdrop could be a more efficient delivery method than ground transportation. Different methods of achieving reduced fuel consumption have different impacts on the fuel multiplier in the supply chain, thus affecting the short-term planning ability of the operational commander.

14. SUBJECT TERMS Fully Burdened Cost of Fuel, Input-Output Analysis, Afghanistan, Force Protection, Convoy			**15. NUMBER OF PAGES** 80
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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ESTIMATING THE FULLY BURDENED COST OF FUEL USING AN INPUT-OUPUT MODEL – A MICRO-LEVEL ANALYSIS

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MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

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ABSTRACT

In 2010, the Department of Defense (DoD) spent $13.2 billion on fuel purchases, with over 3,000 lives lost in fuel delivery operations between 2003 and 2007. To reduce both of these figures, the DoD is investing in technology to reduce fuel consumption, especially in expeditionary and forward operations. These reductions will cause cascading effects throughout the supply chain.

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LIST OF ACRONYMS AND ABBREVIATIONS

AOA	Analysis of Alternatives
AOR	Area of Responsibility
COP	Combat Outpost
DAG	Defense Acquisition Guide
DAU	Defense Acquisition University
DESC	Defense Energy Support Center
DLA-E	Defense Logistics Agency-Energy
DoD	Department of Defense
DON	Department of the Navy
DSB	Defense Science Board
DHNDAA	Duncan Hunter National Defense Authorization Act
FBCE	Fully Burdened Cost of Energy
FBCF	Fully Burdened Cost of Fuel
FOB	Forward Operating Base
FP	Force Protection
FY	Fiscal Year
Gal	Gallons
hrs	Hours
IO	Input-Output
KGal	Thousand gallons
KPP	Key Performance Parameters

MATV	MRAP All-Terrain Vehicle
MDA	Milestone Decision Authority
MOB	Main Operating Base
mpg	Miles Per Gallon
MORS	Military Operations Research Society
MRAP	Mine Resistant Ambush Protected
MTVR	Medium Tactical Vehicle Replacement
O&S	Operation and Support
OUSD	Office of the Under Secretary of Defense
OUSD (AT&L)	Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics)
QDR	Quadrennial Defense Review
Req.	Requirements
SECDEF	Secretary of Defense
Trans.	Transportation
USN	United States Navy
USMC	United States Marine Corps
USTRANSCOM	United States Transportation Command
VAMOSC	Visibility and Management of Operating and Support Costs

EXECUTIVE SUMMARY

With substantial budget cuts on the horizon for the Department of Defense (DoD), one area where significant savings could be found is in the area of energy consumption, on which the DoD spent $13.2 billion in 2010. The field of Input-Output (IO) Analysis appeared to be a natural fit for determining fuel costs and areas in which fuel could be used more efficiently. An IO model predicts the effects of a change in one part of an economy, on the other parts of the economy. While IO is usually used to model inputs and outputs to production in a national economy, it can be tailored to model a more focused area such as DoD energy usage.

A model of the existing portion of the United States Marine Corps (USMC) supply chain in Afghanistan was built as a proof of concept and was used to estimate the fuel multiplier for each component in the supply chain. The model includes air and ground fuel transport and force protection, and is based on information provided by a supply chain officer recently returned from Afghanistan.

Once the baseline scenario was modeled based on historical data, six scenarios were developed to explore the IO model by changing specific aspects of the supply chain to determine the effects those changes had on the model and fuel multiplier at each component. Additionally, these scenarios were generated in such a way as to create an understanding of the fuel drivers within a supply chain, so that this model and its results could be used to understand supply chains in future Areas of Responsibility (AORs). Each scenario was a modification of the historical scenario, and all findings were related back to this historical case.

The main advantage of the IO model is that it can be used to calculate the fuel multiplier. In this case, the fuel multiplier for a given component is the amount of fuel required for delivery to Kandahar, per gallon consumed in each component in the supply chain. A one-gallon increase of fuel usage by the end user does not translate to a one-gallon fuel increase in total demand for fuel entering the supply chain, but it

increases total fuel demand by a factor greater than one. The multiplier is different at each component, due to the means by which the fuel is delivered to that location. Quantifying the fuel multiplier is the primary reason for using IO in determining the fully burdened cost of fuel (FBCF). The importance of this effect in the fuel supply chain cannot be overstated and is one normally overlooked by other models that are used to calculate the FBCF. Impacts directly associated with fuel usage (direct purchase costs, greenhouse gas emissions, and convoy losses) are proportional to the total fuel used in the supply chain, not just end-user fuel consumption. An estimate of the fuel multiplier enables the decision maker to make more informed strategic and operational decisions pertaining to operational fuel usage and logistic constraints on the battlefield.

This analysis produced the following findings:

- The impact of force protection fuel usage on the supply chain is not as large as initially expected.
- Due to geography, fuel resupply through an airdrop could be more efficient than a ground convoy, in some circumstances.
- The method of achieving reduced fuel consumption has a direct impact on the fuel multiplier, which affects the short-term planning ability of the operational commander.

This research has provided important insight into determining FBCF within the DoD using an IO, but it has only scratched the surface of the wealth of benefits this approach could have in the future. Fuel multipliers calculated with this model provide a lower bound for the operational commander, with respect to the fuel requirements within the region. Factors such as manpower and personnel costs, greenhouse gas emissions, and equipment and lives lost associated with fuel consumption, need to be captured in order to produce a more complete estimate of FBCF. Future research should expand on, and tap into, IO's ability to provide a flexible and accurate model for determining FBCF.

ACKNOWLEDGMENTS

First, and foremost, I would like to thank my wife, Melinda, for her support and devotion during this process. Without her sacrifices, I would not have been able to complete this project.

To my children, Ryan, Aidan, and Caitlan, for giving me the motivation and perspective to continue and constantly push myself to achieve results I did not think were possible.

Finally, to my advisors, Dr. Eva Regnier and Dr. Daniel Nussbaum, for their guidance and patience, which allowed me to produce an analysis that I previously thought I was unable to do.

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I. INTRODUCTION

With substantial budget cuts on the horizon for the Department of Defense (DoD), one area where significant savings could be found is in the area of energy consumption. Studies have found that the DoD accounts for 93% of all United States government fuel usage, equating to five billion gallons, placing the DoD as the 34th highest user of oil in the world (Lengyel, 2007).

The field of Input-Output (IO) Analysis appeared to be a natural fit for determining fuel costs and areas in which fuel could be used more efficiently. The IO model predicts the effects of a change in one part of an economy, on the other components of the economy. While IO is usually used to model all inputs and outputs to production in a national economy, it can be tailored to model a more focused area such as the DoD’s energy usage.

While the development of this model would allow the DoD to have a clearer picture of DoD-wide energy usage and prospective savings, the real advantage of this model would be its implementation on a command or unit level. The need for this can be seen in our current combat operations and the measures in-country Marine companies are taking to reduce their fuel usage due to insurgents who are increasingly attacking fuel supply convoys within Afghanistan (Rosenthal, 2010). If an IO model was created for this particular instance, the decision makers could readily see how a savings of a certain number of barrels of fuel per month would translate into a reduction in the force protection requirements for that specific Area of Responsibility (AOR).

A. DOD FUEL CONSUMPTION AND ASSOCIATED PROBLEMS

From remote outposts in the hills of Afghanistan to reserve centers across the United States, the DoD’s footprint and subsequent energy usage are global. The missions in which the DoD participates involve more than just combat operations, but include the humanitarian and disaster relief that has been provided in areas such as Haiti and Japan; training and exercises conducted with other military forces; and routine deployment cycles.

In 2010, all of the United States armed services used more than five billion gallons of fuel, mostly JP-8 or JP-5, while conducting operations, which had an estimated cost of $13.2 billion—a 225% increase from the cost in 1997 (Deputy Secretary of Defense, 2011). The $13.2 billion price tag only accounts for the price of fuel alone and does not consider the associated delivery costs. Depending on the mode of transportation, the delivery price for a gallon of fuel can change tremendously. The cost to deliver fuel in an air-to-air scenario was estimated to be between $20 and $25 per gallon, with the large majority of the cost going to items other than the price for the fuel at the source (Deputy Secretary of Defense, 2011). United States Transportation Command (USTRANSCOM) also estimates that the cost of delivering fuel by air could be as high as 10 times the cost of ground delivery (Deputy Secretary of Defense, 2011). While this may seem prohibitive, the Pentagon's comptroller office, in 2009, examined the cost to the Army for delivering fuel in an operational environment and determined that it was between $100 and $600 per gallon, dependent on the range of the battle space (Dimotakis, Grober, & Lewis, 2006).

Another aspect of fuel cost that must be considered are the security and materiel losses that have been associated with the fuel delivery process. In the campaigns of Iraq and Afghanistan from fiscal year (FY) 2003 to FY 2007, at least 3,000 military personnel and civilians were killed or wounded while conducting fuel delivery operations (Army Environmental Policy Institute, 2009). Even with the lessons learned from these attacks and those that have happened in the subsequent years, the number of attacks on convoys during 2010 was estimated to be around 1,100 (Deputy Secretary of Defense, 2011). The enemy's ability to target these deliveries will continue to improve, which is why it is essential for the DoD to recognize the true costs of today's energy sources, while continuing to find new and improved ways to "fuel" our operations of the future.

B. CALLS FOR CHANGE IN DOD FUEL USAGE

In June 1999, the Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics) (OUSD [AT&L]) reached out to the Defense Science Board (DSB) to "identify technologies that improve fuel efficiency of the full range of weapons platforms (land, sea, and air) and assess their operational, logistics, costs and environmental impacts for a range of practical implementation scenarios" (OUSD [AT&L], 1999, p. 1). The resulting report recommended that decisions be based on the true cost of delivered fuel and to include fuel efficiencies into the acquisition process (DSB, 2001).

The JASON Group (Dimotaki et al., 2006) attempted to determine how to decrease the DoD's reliance on fossil fuels. While the JASON Group found that only 2% to 3% of the overall DoD budget in FY05 went to the procurement of fossil fuels, they identified three main reasons for the importance of reducing reliance:

- Fossil fuels account for a large portion of the life-cycle costs for aircraft and nonnuclear ships.
- Extreme multiplier effects characterize fossil fuel use.
- Fossil fuel use results in logistical and operational restrictions. (Dimotakis et al., 2006).

The report did caution that while there may be time for the DoD to address its fuel issues, the JASON Group strongly encouraged the DoD to begin immediate reduction on fossil fuel dependency due to the unpredictable nature of the industry.

In 2007, LMI Government Consulting was asked by the Office of Force Transformation and Resources to establish a roadmap for the DoD Energy Strategy in which it identified four areas (strategic, operational, fiscal, and environmental) with disconnects between "DoD's current energy consumption practices and the capability requirements of its strategic goals" (LMI Government Consulting, 2007, pp. 1–3).

In the fiscal and operational areas, the Defense Energy Support Center (DESC) estimates for providing fuel in support of Operation Iraqi Freedom was 20,000 soldiers and $1 million per day (Dimotakis et al., 2006). The operational disconnect was further amplified by MajGen Richard Zilmer, United States Marine Corps (USMC), "Reducing energy use at outlying bases reduces the frequency of logistics convoys required to provide their energy needs thereby reducing danger to the Marines, soldiers and sailors" (LMI Government Consulting, 2007, p. E-25).

Moreover, the DoD is unable to adequately account for energy considerations in operational and force development analysis, which affects investment decisions, the real cost of fuel to the DoD should be defined as "more than just the DESC standard price used for programming, budgeting and investment decisions" (LMI Government Consulting, 2007, pp. 2–10). This culminated in the main recommendation of LMI's study, which was to "incorporate energy considerations (energy use and energy logistical support requirements) in all future concept developments, capability developments, and acquisition actions" (LMI Government Consulting, 2007, p. 4).

Due to the overall lack of adherence to the 2001 DSB recommendations, OSD (AT&L) contracted with the DSB to conduct another study, with four main focus areas:

- National benefits of the DoD's usage of alternative energy sources;
- Obstacles within the DoD that are not allowing the recommended changes to be implemented;
- Areas where renewable and alternative energy sources could be deployed; and
- Areas where fuel demand could be minimized.

With this mandate, the DSB found that the DoD was not implementing two key areas from their 2001 report:

- Establishment of key performance parameters (KPP) for battlespace fuel demand; and
- Establishment of the true cost of delivering fuel.

However, as of the end of 2009, the OUSD (AT&L) promulgated seven-step method to calculate the fully burdened cost of fuel (FBCF) which appears to have become the standard for DoD calculations (Military Operations Research Society [MORS], 2009). The seven-step method will be described in more detail in Chapter II.

C. DOD GUIDANCE AND POLICIES

In January 2007, President Bush signed Executive Order 13423, *Strengthening Federal Environmental, Energy, and Transportation Management*. This document outlined the nation's goals for acquisition, energy efficiency, and renewable energy, while also establishing objectives for the DoD to maximize their energy use.

Shortly after the issuance of Executive Order 13423, OUSD (AT&L) issued a new policy concerning FBCF that stated, effective immediately, it is DoD policy to include the fully burdened cost of delivered energy in trade-off analysis conducted for all tactical systems, with end items that create a demand for energy, and to improve the energy efficiency of those systems, consistent with mission requirements and cost effectiveness (OUSD [AT&L], 2007).

After the issuance of the policy statement, Mr. Chris DiPetto (Deputy Under Secretary of Defense) gave testimony to the United States House Committee on Armed Services Readiness Subcommittee, where he stated, "strategic planning and long-term costing should include not only the price of the fuel but all logistical effort to deliver the fuel and that OUSD (AT&L)'s immediate focus was to mature the technology for estimating the fully burdened cost of fuel" (DiPetto, 2008, p. 4).

The issuance of these two policy statements resulted in the update of DoD Instruction 5000.02, *Operation of the Defense Acquisition System*, which now states the new policy established from the OUSD (AT&L) Guidance of 2007 pertaining to using the FBCF. In essence, this forced the use of the FBCF into the analysis of alternatives (AOA) stage of the decision-making process, making it a key hurdle that must be accomplished prior to approval of the Milestone Decision Authority (MDA). In theory, any program that does not include the FBCF in its analysis could face delays or cancelation by the MDA.

Congress enacted federal law with the passage of the Duncan Hunter National Defense Authorization Act (DHNDAA) in October 2008, which authorized the funding of DoD weapon system procurement, but placed a stipulation that logistical fuel costs were to be included during the acquisition process. Specifically, the DHNDAA mandates the Secretary of Defense (SECDEF) "to require life-cycle cost analysis for new capabilities include the fully burdened cost of fuel during analysis of alternatives and evaluation of alternatives and acquisition program design trades" (DHNDA Act, 2008). The DHNDAA further established deadlines that ranged from six months to three years for DoD to implement the act's requirements.

In February 2010, the Quadrennial Defense Review (QDR) was published in response to the 2009 passage of the DHNDAA. The QDR describes how the DoD plans to meet the deadlines set within the DHNDAA, while also meeting the challenges of today, while preparing for future conflicts. To this end, the QDR clearly states that the DoD, "will fully implement the statutory requirement for the energy efficiency Key Performance Parameters and fully burdened cost of fuel set forth in the 2009 NDAA" (Secretary of Defense, 2010, p. 87).

Following the issuance of the 2010 QDR, the DoD published an Operational Energy Strategy in May 2011, which intends to establish a new way forward for the DoD on how energy is consumed during military operations. The DoD identifies three goals in which they intend to reduce the use of energy, make the energy supply chain more secure, and ensure future energy security. To ensure achievement of these objectives, the Operational Energy Strategy will become an annual document produced by the DoD, which will continually update the goals for energy reduction, while also providing metrics on how the DoD and its services are meeting the established objectives (Deputy Secretary of Defense, 2011).

In March 2011, the USMC established a comprehensive energy strategy that is designed to place their forward-deployed units on the leading edge of energy efficiency. This strategy attempts to reverse the trends of the past decade, where infantry companies today are using more energy than an infantry battalion used 10 years ago. Their strategy has set a deadline of 2025 for all expeditionary forces to be self-sustaining, with the only fuel requirements being needed for the vehicles associated with the force. To ensure that the USMC meets this goal, several milestones have been established for 2015 and 2020 that will place them on the glide slope to meet the 50% efficiency gains (Commandant of the Marine Corps, 2011).

In June 2011, The Department of the Navy (DON) also established a policy for evaluating energy factors in the acquisition process that intends to "transform the way the Department of the Navy (DON) uses energy on our installations and in our operational forces" (Assistant Secretary of the Navy, 2011, p. 1). In order to accomplish this, the DON has established the following five goals that will achieve this mandate:

1. Mandatory calculation of the fully burdened cost of energy.
2. Create an energy component of the Affordability target.
3. Energy considerations in acquisition plans.
4. Energy considerations in the Gate Review Process.
5. Energy review of legacy systems. (Assistant Secretary of the Navy, 2011)

D. THESIS OBJECTIVES (BENEFIT OF THE STUDY)

From the evidence presented in previous government studies, it is apparent that the DoD must include the real FBCF in its operations and acquisitions process. The current methods only capture a percentage of the actual cost of fuel and leave out multiplying factors that would significantly increase the cost. Without a precise estimating tool, DoD decision makers will be forced to make budget cuts using an inaccurate picture. There is clearly a need for a way to estimate the impact of fuel demand for use in operations and acquisition analysis decisions, to reduce DoD's financial, operational, and support costs and enhance its capability and security.

This thesis addresses whether a DoD FBCF IO model can be useful to model and predict savings costs for a forward-deployed unit. While a DoD-wide model would provide a good planning tool for top-level decision makers, a tool that can be used on the ground, in theater, would provide a more efficient means of evaluating the financial and operational impact of proposed alternatives for conserving fuel.

To the extent that the IO model provides useful insights unit evaluation of a small unit, a wealth of future research opportunities open up to examine not only DoD entities, but also other organizations within the government. The practical challenges to building an IO model in this context can be applied to other DoD entities to determine if their organization can be mapped using the IO process, and indicate the data collection needed to support a useful IO model for estimating FBCF.

II. FULLY BURDENED COST OF FUEL/INPUT-OUTPUT ANALYSIS

A. FULLY BURDENED COST OF FUEL (FBFC)

1. Definition

There are two generally accepted definitions by the DoD pertaining to the FBCF. The first is from the Defense Acquisition Guide (DAG), which defines FBCF as “the cost of fuel itself plus the apportioned cost of all fuel delivery logistics and related force protection required beyond the DESC point of sale to ensure refueling of the systems” (Defense Acquisition University [DAU]. 2009, p. 1). The other can be found in the DHNDAA, which defines FBCF as “the commodity price for fuel plus the total cost of all personnel and assets required to move and, when necessary, protect the fuel from the point at which the fuel is received from the commercial supplier to the point of use” (DHNDAA, 2008, p. 67).

The FBCF is meant to be another tool in the toolbox for planners when determining which platforms or systems should be purchased. Although it is a key tool, it is not a predictor of future events or scenarios that the platform or system will be placed in during an operating wartime environment. This view is clearly the position of DAG as they conclude that the FBCF compliments the planning process pertaining to capabilities and performance metrics (DAU, 2009).

2. Calculation Steps

Table 1 displays the seven steps necessary to calculate the FBCF, according to the process developed by OUSD (AT&L) for DoD programs to use in the calculation in AOAs.

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. The seven cost elements used by OUSD (AT&L) for estimating FBCF (From: DAU, 2009).

a. Commodity Cost of Fuel

The Defense Logistics Agency-Energy (DLA-E), formerly known as DESC, is the sole provider of fuel to the DoD. Figure 1 represents the wholesale supply chain for DLA-E. Through DLA-E's network, fuel is provided around the globe and the price is set at a standard DLA-E price for all services. Like other DoD corporate organizations, DLA-E sets the standard price, for the current FY, based off of the previous 18-month price history and not the current standard price for fuel. The reasoning for this process is to attempt to shield the DoD from the price fluctuations that occur with the price of fuel on a daily basis. These fluctuations in the market price contribute to either a profit or loss for DLA-E, which is then calculated into the following year's standard price.

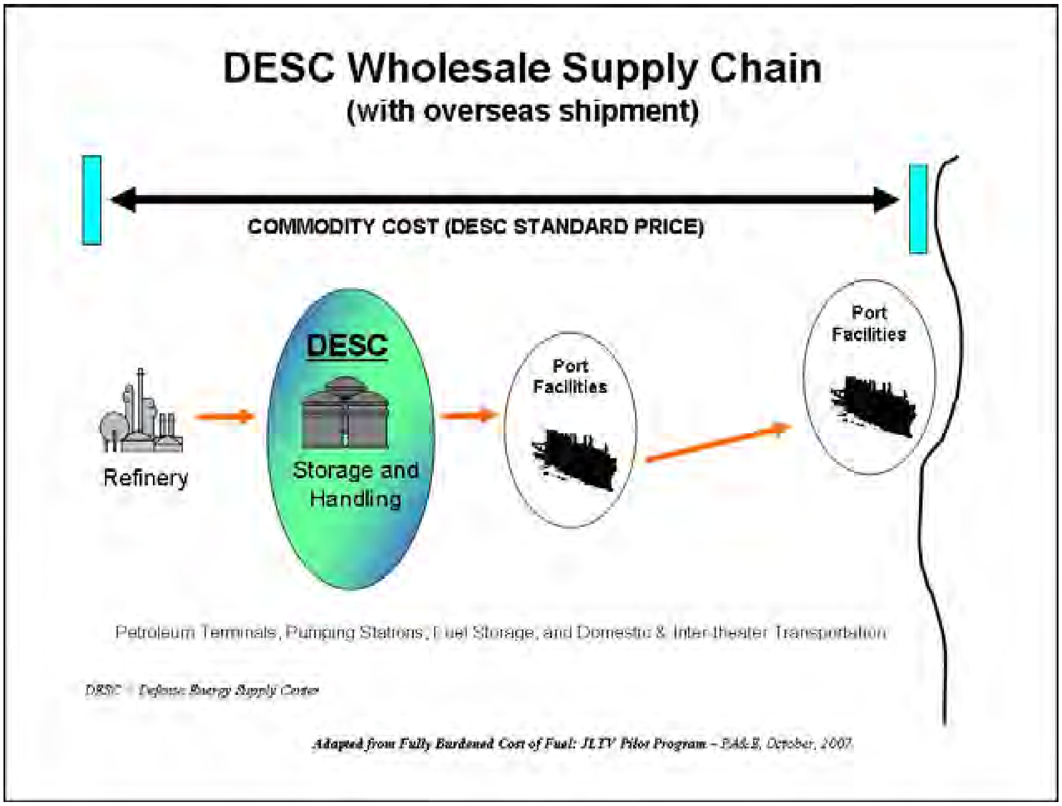

Figure 1. The DESC, now DLA-E, supply chain (From: DAU, 2009).

b. Primary Fuel Delivery Asset Operation and Support Cost

The service-specific assets that are used to transport the fuel from the DLA-E receiving point to the end user generate the operation and support (O&S) costs. The cost associated with O&S consists of the operation and maintenance cost for the fuel delivery assets, in addition to the personnel cost for those individuals who operate and maintain the equipment. Each service tracks these costs through the Visibility and Management of Operating and Support Costs (VAMOSC). The VAMOSC database can be accessed at https:/www.vamosc.navy.mil. The source for this data encompasses over 138 organizations that make up the DON enterprise.

c. Depreciation Cost of Primary Fuel Delivery Assets

These costs are specific to the equipment used to transport the fuel. While there are numerous accounting methods to determine depreciation, OUSD (AT&L) has made the straight-line method the preferred one for DoD calculations.

d. Direct Fuel Infrastructure O&S and Recapitalization Cost

This cost only pertains to the facilities that are used and operated by the services for the purpose of fuel delivery, which are not a part of the DLA-E infrastructure system. These costs are monitored and distributed by the OUSD (Installations and Environment).

e. Indirect Fuel Infrastructure

Per the recommendation of OUSD (AT&L), these costs are allocated on a per capita basis and are only those required to maintain the direct fuel infrastructure.

f. Environmental Cost

While there is no standard calculation for these costs, the Office of the Secretary of Defense (Program, Analysis, and Evaluation) has developed a method to estimate these costs by combining the European carbon emission offset cost with the standard DoD hazardous material and cleanup costs found in the *DoD Financial Management Regulation Vol. 4 Ch. 13* produced by the OUSD (Comptroller) (Office of the Under Secretary of Defense [Comptroller], 2011) (DAU, 2009).

g. Other Service and Platform Delivery Specific Costs

According to OUSD (AT&L) these costs have traditionally exceeded all of the previous six cost factors combined. The justification for this can be found in the factors that make up this area, specifically force protection, depreciation, and manpower costs for non-fuel delivery assets. Of those factors, the force protection aspect has become the major factor, especially in combat areas such as Iraq and Afghanistan.

3. Prior FBCF Studies

Corley (2009) analyzed how using the FBCF would have affected the analyses done by Navy Major Defense Acquisition Programs. In order to determine the effect, Corley used a standard Navy destroyer operating in different environments while using the FBCF calculator developed by the OUSD (AT&L). The results of his analysis showed that between 30% and 50% of the FBCF could be accounted for by using the standard price of the fuel set by DLA-E. Based on his finding that the true cost of fuel consists of 50% to 70% of nonfuel cost, he recommended that using FBCF would be the fiscally responsible way to determine fuel costs during the acquisition process (Corley, 2009).

Truckenbrod (2010) focused on how the FBCF could be applied to the Navy aviation community. Truckenbrod used the OUSD (AT&L) calculator to determine the FBCF for an F/A-18 E/F aircraft and found that the FBCF for the aircraft was twice as much as for the destroyer used in Corley (2009). While certain assumptions that were used in both calculations may have contributed to the large difference between the two figures, Truckenbrod concluded that the main factor affecting the FBCF for the F/A-18 was aerial refueling. Truckenbrod's final recommendation was for the Navy to continue to look at fuel-saving technologies, while also modifying existing aircraft to extend their endurance (Truckenbrod, 2010).

Roscoe (2010) compared the methodologies used by the military services to calculate the FBCF and found there were differences in how each service was calculating FBCF. The United States Navy (USN) and USMC based their calculations on the OUSD (AT&L) model, while the Air Force created its own calculation, with the Army still developing its process. A comparison was made between the Air Force and OUSD (AT&L) models due to the difference in calculation, with the Air Force using a deterministic model, while OUSD (AT&L) uses a stochastic process. After running each model through several scenarios, Roscoe found there was not a statistical difference between the results of the two models, resulting in the following three recommendations:

- The definition for the FBCF should be uniform across the services.
- The use of scenarios should be maintained when calculating the FBCF during AOAs.
- Due to the unpredictability of real world scenarios, a stochastic process should be incorporated into FBCF calculations.

B. INPUT-OUTPUT ANALYSIS

1. History

The theory of IO was developed by Professor Wassily Leontief during the 1930s as a way to capture how the changes in one segment of the economy can be felt and measured in the economy as a whole. As Lin and Polenske (1998) write, IO models have several purposes. They provide the framework for representing flows of goods and services in an economy. Changes in the input matrix can highlight changes in production technology and processes over time. Finally, a national accounts IO model can be adapted to produce an enterprise IO model to support other enterprise-specific analyses.

The model used for IO is a set of linear equations, represented by a matrix with each sector represented by a row and a column. The columns of the matrix represent the inputs for the sector and the rows represent the outputs. Three assumptions are made in order to simplify the problem:

- Only one homogeneous commodity is produced by each sector.
- Each sector uses a fixed input ratio for the production its output.
- Each sector has a constant returns to scale. (Chaing, 1984, p. 116)

Table 2 illustrates the coefficient matrix used in IO. The first subscript corresponds to the input and the second subscript corresponds to the output for the coefficient. The coefficient is equal to the amount of output from the row sector required per unit of output from the column sector.

Input	Output				
	1	2	3	$\cdots$	N
1	a_{11}	a_{12}	a_{13}	$\cdots$	a_{1n}
2	a_{21}	a_{22}	a_{23}	$\cdots$	a_{2n}
3	a_{31}	a_{32}	a_{33}	$\cdots$	a_{3n}
$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$
N	a_{n1}	a_{n2}	a_{n3}	$\cdots$	a_{nn}

Table 2. The input-coefficient matrix used as the basis for IO (After: Chaing, 1984).

From this matrix, flow-balance requires the following:

$$x_i = a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n + d_i \forall i \, , \tag{2.1}$$

where x_i is the output level of the sector to meet the requirement for the other n industries and d_i is the final demand for the output (Chaing, 1984). This set of equations can be solved using the matrix equation below:

$$\begin{pmatrix} (1-a_{11}) & -a_{12} & \cdots & -a_{1n} \\ -a_{21} & (1-a_{22}) & \cdots & -a_{2n} \\ \vdots & \vdots & & \vdots \\ -a_{n1} & -a_{n2} & \cdots & (1-a_{nn}) \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix} = \begin{pmatrix} d_1 \\ d_2 \\ \vdots \\ d_n \end{pmatrix} .$$

(Chaing, 1984)

2. Previous Research

Wu and Chen (1990) use IO to analyze short-run energy problems because the IO model is well suited to capture the relationships among and multiplier effects of all entities in the economy and energy usage in terms of output.

The results of their analysis show that a static IO model can be applied to energy issues, but there are considerations that must be taken into account. By using the static model, the accuracy of the results may diminish, but it does provide a lower bound cost and shorter time frame for those results. Additionally, they were able to find a solution to the double counting problem that exists due to the multiplier effect in the static model, making the model a more efficient tool for energy calculations.

Albino, Izzo, and Kuhtz (2002) attempted to create IO models that can be used to examine both a local and global supply chain. In order to do so, they define the supply chain as "a network of production processes which can be localized within and outside a given geographic area. Each process can be defined as a system that produces output flows in consequence of input flows" (Albino et al., 2002, p. 119). They created two models, one based on the materials and the other on energy flows for the supply chains.

The model can determine the output, material, and waste created during the process. Additionally, these models can reflect changes in the production process or location, which will give both positive and negative results for the changes in the supply chain. Their analysis did show that these models "can be effective to negotiate at supply chain level as well as at local level a common policy for the management of resources and wastes" (Albino et al., 2002, p. 130).

Albino, Dietzenbacher, and Kuhtz (2003) applied their earlier research to industrial districts to determine the amount of resources, energy, and pollution for those areas. This model can be used for both accounting and forecasting. As an accounting tool, the model can use current data to investigate materials and energy flows (Albino et al., 2003). As described in Albino et al. (2002), this model is adaptive and can reflect the changes that occur over time within the district to include the environmental impact. One additional aspect of this model is its consideration of areas that do not produce the energy needed for production, by factoring in different energy suppliers and considering them as a network.

Lu and Rencheng (2007) modified the IO model to evaluate an international supply chain specifically for a multilocation production system. Figure 2 illustrates such a system.

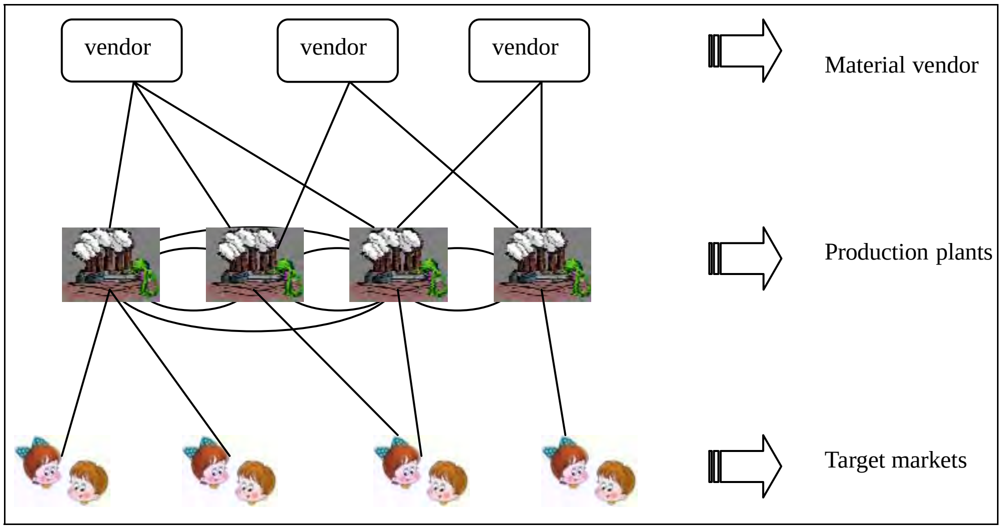

Figure 2. The multilocation distribution model used by Lu and Rencheng to evaluate an international supply chain (From: Lu & Rencheng, 2007).

This paper breaks new ground in the area of IO analysis by modeling a dispersed production system and the resulting increase in transportation costs due to dispersion in energy and material consumption during the process. Additionally, this model has helped resolve some of the linear programming issues in solving supply chain problems by introducing the IO coefficients into the equation, which account for the relationship and multiplier effect in system, therefore allowing linear programming models to solve for problems with a large number of constraints and variables (Lu & Rencheng, 2007).

These recent uses of an IO model on an organization, rather than on an economy, open the door for this type of research to be used in the DoD. This thesis captures the fuel flows and associated costs in a regional operation of the DoD and apply those to the

IO model. By doing so, it will demonstrate how the current methods of calculating the FBCF are not accurately estimating those costs, while also demonstrating this approach to other parts of the DoD.

III. METHODOLOGY

A model of the existing portion of the USMC supply chain in Afghanistan was built as a proof of concept and was used to estimate the fuel multiplier for each component in the supply chain. The fuel multiplier is the amount of fuel required to be delivered to Kandahar, per gallon consumed in a given component in the supply chain. The model includes air and ground fuel transport and force protection.

A. AFGHANISTAN SUPPLY CHAIN

Figure 3 shows the flow of fuel from Kandahar to the Forward Operating Bases (FOBs) and Combat Outposts (COPs), based on information provided by Jeffrey Kausek (a former USMC Captain who separated from active service on May 30, 2011, as Battalion Logistics Officer for 3rd Battalion, 4th Marines, 7th Marine Regiment, 1st Marine Division). Mr. Kausek recently served two tours in Afghanistan as a supply officer for the USMC. While there are real-world distinctions between COPs and FOBs, in this model the COPs are pure consumers in the supply chain. The FOBs consume fuel, but they also serve the role of a supplier to the COPs, so their overall demand signal in the supply chain is greater than their on-site consumption. This distinction is illustrated in Figure 3, which shows the flow of fuel through Deleram and Now Zad supply chain.

Most of the fuel transportation is by ground convoys. Now Zad and Golistan receive fuel via an airdrop. Now Zad receives fuel via ground about 90% of the time, while an airdrop delivers the remaining 10%.

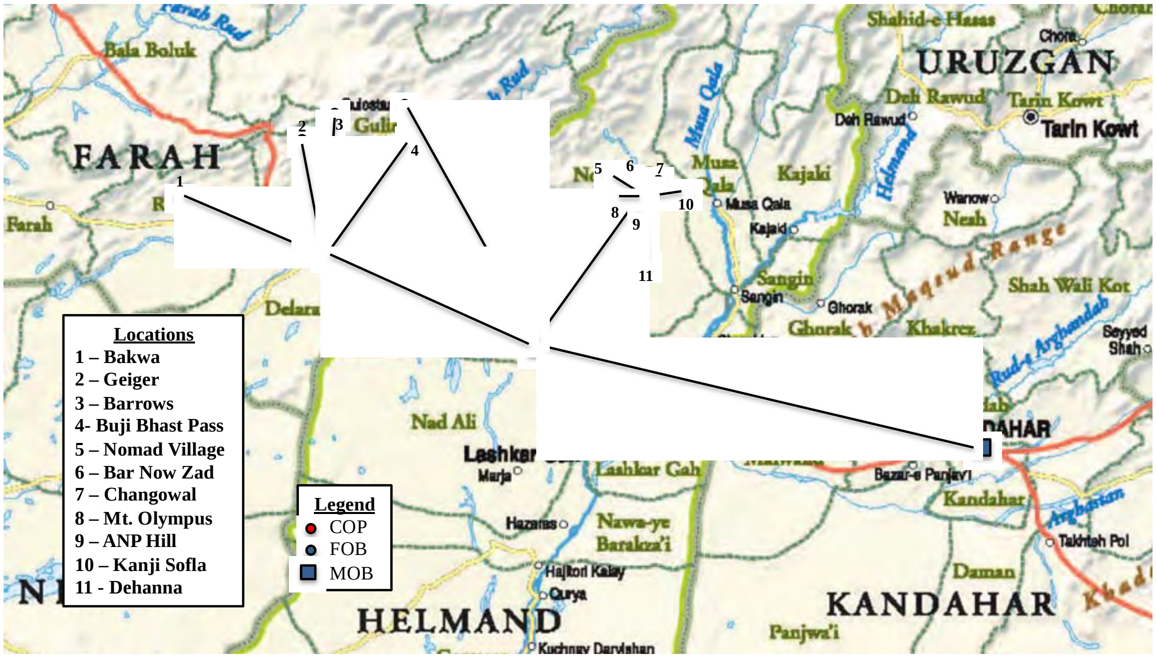

Figure 3. Map of the Deleram and Now Zad supply chain.

The estimated usage rates, transportation method, and travel time for each of the FOBs and COPs in the region provided by Mr. Kausek are given in Table 3 (J. Kausek, personal communication, May 24, 2011).

Origin (i)	**Destination** (j)	**Transport Method** (m)	**Distance (miles)** (d_{ij})	**Transport Time (hrs)** (t_{ij}^m)	**Fuel Consumption on Site (thousands of gallons per week)** (c_j)
Kandahar	Camp Leatherneck	Convoy	110	5	30
Camp Leatherneck	Now Zad	Air	40	0.36	0.8
Camp Leatherneck	Golistan	Air	90	0.81	2
Camp Leatherneck	Now Zad	Convoy	40	18	7.2
Camp Leatherneck	Deleram	Convoy	60	3	10
Now Zad	ANP Hill	Convoy	0.5	0.5	1
Now Zad	Mt. Olympus	Convoy	1.5	0.75	1
Now Zad	Kanji Sofla	Convoy	6	2	1
Now Zad	Changowal	Convoy	2	1.25	1
Now Zad	Bar Now Zad	Convoy	13	4	1
Now Zad	Dehanna	Convoy	5	1.25	1
Now Zad	Nomad Village	Convoy	6	2	1
Deleram	Buji Bhast Pass	Convoy	25	8	2
Deleram	Bakwa	Convoy	50	7	3
Deleram	Barrows	Convoy	40	5.5	2
Deleram	Geiger	Convoy	30	4	1

Table 3. This table shows the transportation method, distance, transportation time, fuel usage, and transport for the Deleram and Now Zad supply chain.

Based on the information from Mr. Kausek, Medium Tactical Vehicle Replacements (MTVRs), better known as 7-ton trucks, are used to move the fuel over the ground. Each MTVR can carry two 900-gallon fuel pods. The MTVRs have an estimated fuel usage of 4.5 miles per gallon (mpg) or 13.3 gallons an hour (Headquarters, United States Marine Corps, 2007). For air transport, the CH-53 is used and has a payload capacity of 36,000 pounds and a fuel usage rating of 600 gallons an hour (Thoms, 2007).

Force protection assets are also required to protect the convoy during ground transport. The two main vehicles used for force protection are the Mine Resistant Ambush Protected (MRAP) and the MRAP All-Terrain Vehicle (MATV). The MRAP has an estimated fuel usage rating of 5.5 mpg or 10.2 gallons an hour, (Deputy Chief of Staff of the Army, 2009), while the MATV achieves an improved fuel usage rate of 6.6 mpg or 6.9 gallons an hour (1 Marine Expeditionary Force [MEF], 2010).

Several policies pertaining to force protection also affect the number of vehicles required to operate in a convoy. At a minimum, four vehicles are required to make up the convoy during operations. Of these four vehicles, two must be force protection vehicles, with an additional force protection vehicle added for every five transport trucks in the convoy. Since the MATVs are more fuel efficient, they are used in preference to MRAPs at about a 2:1 ratio.

Based on the data available, the following variables and indices were used in the model for computation purposes:

1. Notation

a. Indices

i = Source component.

j = Destination component.

m = Transportation method from the source component i to the destination component j. $m \in$ {Air, Convoy}

b. Data Variables

d_{ij} = The distance between source component i and the destination component j in miles.

t_{ij}^{m} = The time to travel between source component i to the destination component j using transportation method m, in hours.

c_j = The amount of fuel required (thousand gallons per week) at destination component j for war-fighting operations.

x_j = The output quantity of component j (thousand gallons of fuel per week) for supplying components.

tv_{ij} = The transportation vehicle used between source component i and destination component j. $tv \in$ {MTVR, CH-53}

fv_{ij} = The fuel transportation vehicle used between source component i and destination component j. $fv \in$ {MRAP, MATV}

g_{tv} = Fuel consumption for transportation vehicle tv in gallons per hour.

g_{fv} = Fuel consumption for force protection vehicle fv in gallons per hour.

vc_{tv} = The payload capacity of vehicle tv in gallons.

c. *Fuel Requirements Variables by Component and Equations*

q_{ij}^{m} = The total fuel required at destination component j by transportation method m from source component i.

For each component j, q_{ij}^{m} is the total amount of fuel that needs to be pushed to the component from component i by mode m to meet its war-fighting requirement (c_j) plus any requirements it incurs from downstream components it supports, (x_j). These additional requirements would include the downstream component's war-fighting requirements in addition to any transportation and force protection fuel requirements.

For consuming components,

$$\sum_{m}\sum_{i} q_{ij}^{m} = c_j \, . \tag{3.1}$$

For supply chain components, the following equation calculates their fuel requirement:

$$\sum_{m}\sum_{i} q_{ij}^{m} = x_j + c_j \, . \tag{3.2}$$

d. *Transportation and Force Protection Requirements Variables and Equations*

F_{ij}^{m} = The fuel required for force protection per unit of fuel transported from i to j by mode m in thousand gallons per week.

T_{ij}^{m} = The fuel required for transportation per unit of fuel transported from i to j by mode m in thousand gallons per week.

n_{ij}^{m} = The number of transportation vehicles of type tv_{ij} per week required to transport fuel from i to j by mode m, as calculated in Equation (3.3):

$$n_{ij}^{m} = \left\lceil \frac{q_{ij}^{m}}{vc_{tv_{ij}^{m}}} \right\rceil . \tag{3.3}$$

fn_{ij}^{m} = The number of number of vehicles per week required to provide force protection from i to j by mode j, as determined in Equation (3.4):

$$fn_{ij}^{m} = 2 + \left\lceil \frac{n_{ij}^{m}}{5} \right\rceil . \tag{3.4}$$

From these formulas F_{ij}^{m} and T_{ij}^{m} can be calculated:

$$F_{ij}^{m} = \frac{fn_{ij}^{m}(g_{fv_{ij}^{m}} \times t_{ij}^{m})}{1000} . \tag{3.5}$$

$$T_{ij}^{m} = \frac{n_{ij}^{m}(g_{tv_{ij}^{m}} \times t_{ij}^{m})}{1000} . \tag{3.6}$$

B. THE FBCF/IO MODEL

From the historical data provided by Mr. Kausek, an IO model was created. A screenshot of the Excel implementation of the model can be found in the Appendix.

Equation (3.7) captures the consumption of the transport and force protection vehicles required to transport the required fuel from i to j. The values of C_{ij}^{m} are found in Table 2, in the spreadsheet, of the Appendix.

$$C_{ij}^{m} = F_{ij}^{m} + T_{ij}^{m} . \tag{3.7}$$

Equation (3.8) calculates the IO coefficient, a_{ij}^{m} for supply components, while Equation (3.9) is for consuming components. The values of a_{ij}^{m} in the historical scenario are found in Table 3, in the spreadsheet, of the Appendix.

a_{ij}^{m} = the amount of output of component i delivered by mode m required per unit of output from component j

$$a_{ij}^{m} = \left(\frac{q_{ij}^{m}}{\sum_{i} \sum_{m} q_{ij}^{m}} \right) \left(1 + \frac{C_{ij}^{m}}{q_{ij}^{m}} \right) \left(\frac{c_{j} + x_{j}}{x_{j}} \right) \text{ for supply components,} \tag{3.8}$$

$$a_{ij}^{m} = \left(1 + \frac{C_{ij}^{m}}{q_{ij}^{m}} \right) \text{ for consuming components.} \tag{3.9}$$

These computations can then be used in Equation (3.10) to calculate the total fuel required at Kandahar.

$$X = \sum_{j} a_{ij} x_{j} \text{ , where } i = \text{ Kandahar} \tag{3.10}$$

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IV. ANALYSIS AND FINDINGS

This analysis focuses on the fuel multiplier, which is one of the main benefits of using an IO model. This fuel multiplier was determined in two separate ways—a marginal and average for each component—with each providing distinct insights into the dynamics of the supply chain in Afghanistan. The multipliers were considered in conjunction with distance and time between locations to determine how these factors contributed to the differences across components seen in the multiplier.

In order to explore the effect of various features of the model of the Afghanistan supply chain, six scenarios were created that altered different variables of the system. Each scenario was compared against the baseline (historical) scenario, comparing fuel multiplier and the total amount of fuel required for warfighting at the bases of operations, transportation fuel, and force protection fuel requirements. These comparisons provide some insight on which areas of the supply chain have the largest effect on fuel usage through the system. These comparisons resulted in new insights into the Afghanistan supply chain, while also confirming several findings in previous research.

A. FUEL MULTIPLIERS

A one-gallon increase in fuel usage by the end user does not translate to a one-gallon increase in total demand for fuel entering the supply chain, but increases total fuel demand by a factor greater than one. The multiplier is different at each component, due to the means by which the fuel is delivered to that location. As stated previously, quantifying the fuel multiplier is the primary reason for using IO analysis in determining the FBCF. The importance of this effect in the fuel supply chain cannot be overstated and is normally overlooked by other models that are used to calculate the FBCF. An estimate of the fuel multiplier enables the decision maker to make more informed strategic and operational decisions pertaining to logistic constraints on the battlefield.

Average and marginal fuel multipliers reflect how much X, the total fuel entering the supply chain at Kandahar, changes with a change in the fuel demanded, c_j, at component j.

1. Average Fuel Multiplier

The average fuel multiplier shows the overall amount of fuel required to be sent into the supply chain per gallon consumed at a given component. If a component has a multiplier of 2, that means a one-gallon increase in demand at the consuming component results in two-gallon increase from the original source component, X, to be sent through the supply chain to meet the demand, assuming transport and force protection requirements are a constant factor of fuel flowing from each i to each j in the supply chain. To calculate the average fuel multiplier for a given j, we look at the reduction in X when we set c_j equal to zero. Letting $\bar{X}(c_j)$ represent X as a function of c_j, while holding all a_{ij}^m constant, the average fuel multiplier $\bar{M}_j$ for component j is calculated as shown in Equation (4.1).

$$\bar{M}_j = \frac{\bar{X}(c_j) - \bar{X}(0)}{c_j} . \tag{4.1}$$

2. Marginal Fuel Multiplier

The marginal fuel multiplier for a given j, M_j', is the change in the total fuel demanded at Kandahar associated with a 1,000-gallon-per-week increase in c_j. This multiplier looks at the capacity of the supply chain at current levels, and can result in a multiplier of 1 if the supply chain is not at maximum capacity. The marginal fuel multiplier is calculated as shown in Equation (4.2).

$$M_j' = X(c_j + 1) - X(c_j) . \tag{4.2}$$

The marginal fuel multiplier in each scenario assumes there may be transportation vehicles in a convoy that are not filled to maximum capacity. This does not accurately capture the real world actions found in Afghanistan where fuel convoys are only sent when at maximum capacity. In many circumstances, these convoys are carrying other supplies, such as water, food, or batteries, so the fuel portion of the convoy would be considered a partial load.

B. SCENARIOS

Due to the limited data available concerning fuel usage in the Afghanistan theater of operation, it was determined that the best way to validate the IO model was to create scenarios that would change specific aspects of the supply chain to determine the effects those changes had on the model and fuel multiplier at each component. Additionally, these scenarios were generated in such a way as to reveal the fuel drivers within a supply chain, so this model and its results could provide insight about supply chains in future AORs. Each scenario was a modification of the historical scenario that was provided by Mr. Kausek, using his in-theater experience, and all findings were related back to this historical case. This section describes each scenario, how it affects the supply chain, and the justification for its inclusion in the analysis. Table 4 provides an overview of the scenarios and highlights the changes that occur in each, compared to the historical scenario.

Scenario	Fuel Req. per Week (Kgal)	Ground to Air Trans.	Transport					
			MTVR		Force Protection Vehicle Composition		Force Protection Requirement	
			Gal/Hr	Pods (#)	MATV	MRAP	Rear	Per Transport
Historical	65	14:2	13.3	2	0.67	0.33	1	5
(1) Payload Increase	65	14:2	13.3	**3**	0.67	0.33	1	5
(2) Efficiency Increase	65	14:2	**8**	2	0.67	0.33	1	5
(3) Transit Limit	65	**9:7**	13.3	2	0.67	0.33	1	5
(4) Reduced Consumption	**32.5**	14:2	13.3	2	0.67	0.33	1	5
(5) Reduced Force Protection	65	14:2	13.3	2	0.67	0.33	**0**	**10**
(6) MATV Only	65	14:2	13.3	2	**1**	**0**	1	5

Table 4. An overview of each scenario used in the IO model, highlighting the changes made from the historical scenario.

1. Scenario 1 – Transport Payload Increase

The current transportation vehicle, MTVR, has been modified by extending the bed of the truck to allow for extra capacity. This modification allows the MTVR to carry three pods of fuel instead of the two pods the previous vehicle was limited to, thus increasing the amount of fuel carried per MTVR and reducing the total number of transport vehicles needed on each leg of the supply chain. An increase of the pod limit appeared to be a logical, and rather simple, modification that could easily be incorporated in theater, which would have a substantial impact. This modification also had the potential to affect the force protection requirements of the supply chain by reducing the number of MTVRs needed during the operation, thus reducing the total number of force protection vehicles need to protect the convoy.

2. Scenario 2 – Transport Fuel Efficiency Increase

A new transportation vehicle has been introduced to replace the MTVR for operations in Afghanistan. While the capacity of the new vehicle remains identical to the current MTVR, an improved engine and drive train have been used in the new vehicle, allowing it to consume less fuel during operations, thereby reducing the overall fuel demand in the supply chain. The new fuel consumption rating for this vehicle is 8 gallons an hour—a five-gallon-an-hour improvement over the MTVR. An introduction of a new vehicle type onto the battlefield is well within the realm of possibility. This type of event has already occurred with the force protection vehicles used in theater, which are in our current model. The MRAP was a new vehicle at the beginning of operations in Iraq and Afghanistan, but a constant complaint concerning the vehicle was its fuel efficiency. In order to address this issue, the MATV was introduced, providing increased fuel efficiency and the USMC has now begun to phase out the MRAP. With the DoD-wide push to increase fuel efficiency, the introduction of a new, more fuel-efficient transport vehicle is well within the realm of possibility.

3. Scenario 3 – Increase Use of Air Assets

Following a change of command in Afghanistan, in this scenario, a new policy has been put in place restricting the number of hours that a convoy is allowed to operate consecutively, which is a maximum of 10 hours. Due to this restriction, all fuel replenishments that have a time greater than 10 hours must now be conducted by airdrop. This change in policy affects five bases of operation, increasing the use of air transport within the supply chain from 16% to 45% of the number of deliveries. While there is not a precedent for this type of policy change occurring during current operations, this policy shift was a means to test the question of whether using air assets during fuel deliveries significantly increases the use and cost of fuel in the supply chain.

4. Scenario 4 – Reduced Base Consumption

A new supply of generators and front-line vehicles has been sent to Afghanistan to be used at all of the FOBs and COPs in country. This new equipment increases fuel efficiency over the previous units, resulting in a reduction in fuel in the supply chain from 65,000 gallons per week to 32,500 gallons per week. The main emphasis in efforts to reduce the DoD's fuel dependency has been to focus on improvements that can be made down range, particularly with the end user. Creating a scenario modeling improvement in end-user efficiency enables an analysis to determine, under this supply chain, the level of cost savings achievable.

5. Scenario 5 – Improved In-Country Security (Force Protection Reductions)

With increased cooperation between local Afghans and United States troops, the routes convoys use to transport fuel have become safer due to the lower risk of attack and improved explosive device incidents. This increased security has decreased the number of force protection vehicles necessary to escort the convoy. The new force protection policy for convoys is one force protection vehicle in the lead of the convoy and one force protection vehicle for every 10 transport trucks in the convoy, thus reducing the previous fuel burden placed on the supply chain by force protection vehicles. Changes to the force protection posture are dynamic. This scenario captures that dynamic nature, while also demonstrating the flexibility of the IO model, thereby demonstrating its relevance for capturing the fuel multipliers within the supply chain.

6. Scenario 6 – Force Protection Vehicle Change

Due to the favorable feedback and success of the MATV in combat operations, the USMC has decided to use this vehicle exclusively for all force protection operations. This decision causes the overall efficiency of the convoy operations to increase due to the MATV's 6.6-gallon per hour rating, replacing the MRAP's 10.24-gallon per hour rating. As discussed with respect to Scenario 2, a shift in vehicle usage of this nature has already been occurring in the Afghanistan theater of operations. This scenario provides a clearer picture of what fuel usage would look like for this supply chain once the transition from MRAP to MATV is complete.

C. RESULTS AND FINDINGS

The analysis explores three key features of the supply chain: the relative efficiencies of ground convoy versus airdrop; the impact of transportation and force protection efficiencies; and which modifications have the greatest impact on fuel usage throughout the supply chain.

The data provided by Mr. Kausek were used to define the historical scenario against which the other scenarios were compared. The results for the historical scenario are shown in Figures 4 through 6.

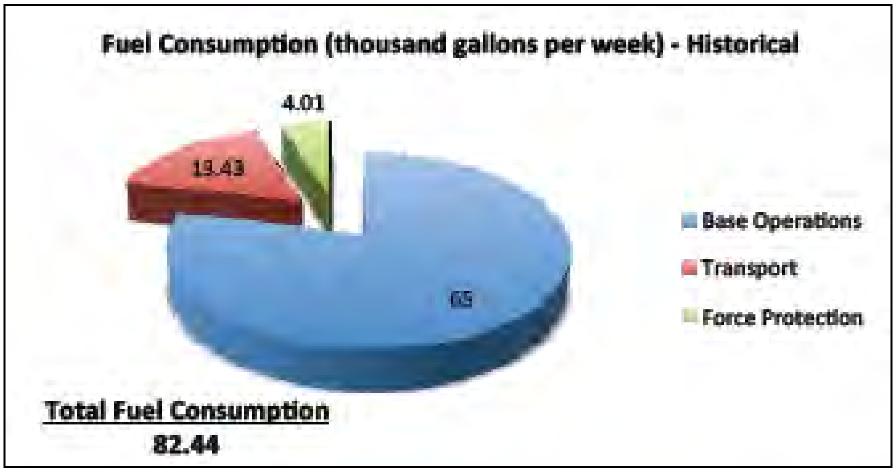

Figure 4. Total supply chain fuel consumption for the historical scenario, by base operations, fuel transportation, and force protection.

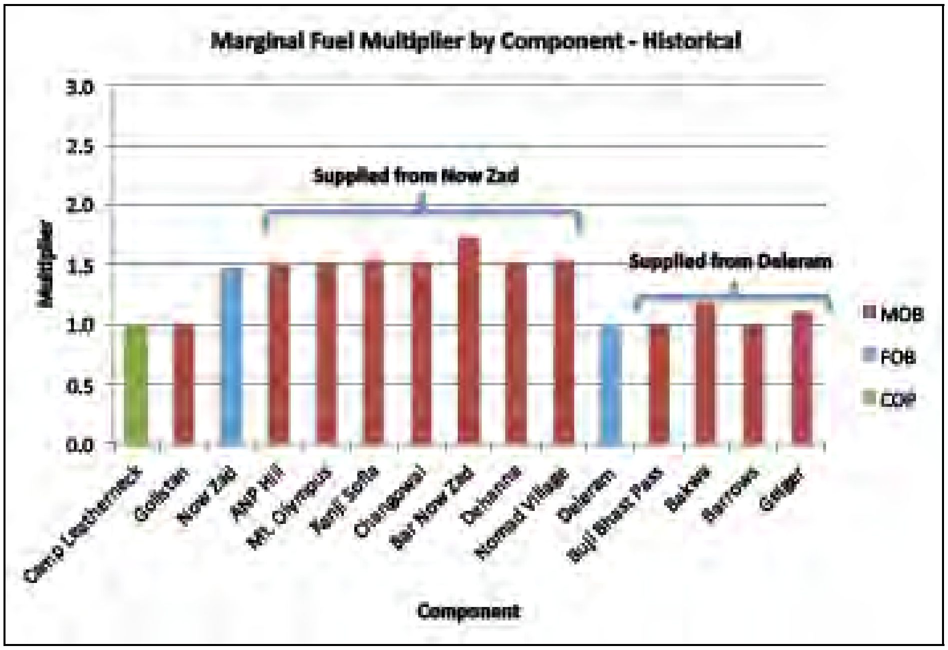

Figure 5. Marginal fuel multiplier for the historical scenario by supply chain component.

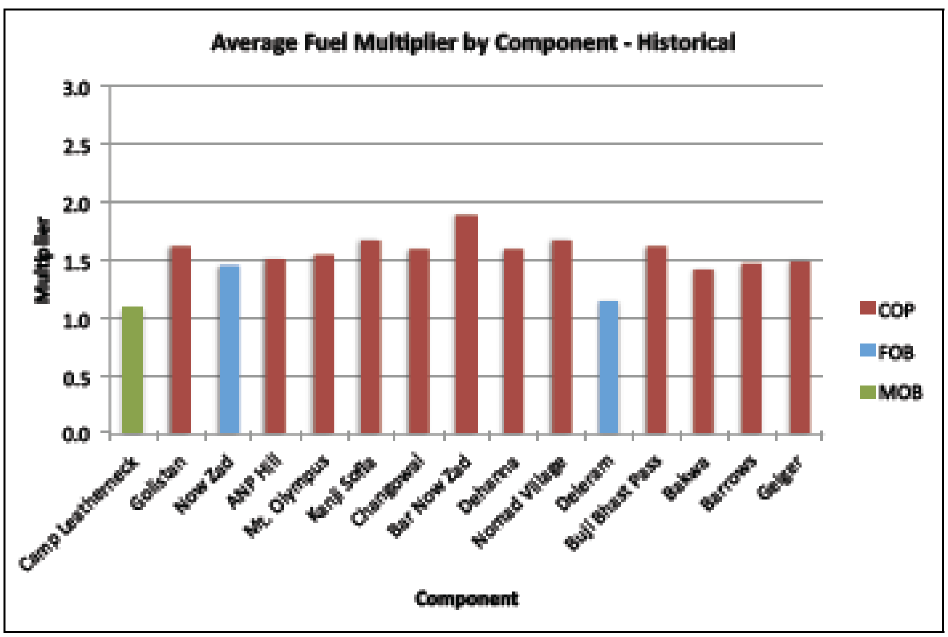

Figure 6. Average fuel multiplier for the historical scenario by supply chain component.

The larger marginal fuel multiplier at Now Zad FOB, relative to other FOBs, can be attributed to the method by which it receives fuel from Camp Leatherneck. Although it receives 10% of its fuel requirement by air transportation, the driving factor in the multiplier is the time required to deliver the fuel by ground convoy. This observation is further strengthened by looking at the COPs that Now Zad supplies. Of the seven COPs supported by Now Zad, Bar Now Zad has the longest travel time and the largest multiplier. For ground convoys, the fuel multiplier is largely driven by the overall travel time. The multiplier informs the decision maker that, under these circumstances, an increase in demand of 1,000 gallons at Bar Now Zad requires an additional 1,720 gallons to be pushed into the supply chain.

As seen in Figure 6, the multipliers for Golistan and Now Zad are larger than the multiplier for Deleram (the other component that receives fuel directly from Camp Leatherneck), which receive all, or part, of their fuel requirement from an airdrop rather than a ground convoy. This factor appears to make the multiplier higher at these locations than those receiving fuel solely through ground convoy. There is a threshold for the total travel time to conduct a ground convoy, where it becomes more costly on a per gallon basis than using an airdrop to support the component. The route between Deleram and Buji Bhast Pass appears to be longer than this threshold. This supply route requires a total travel time of 16 hours to complete the round trip; therefore, this resupply would be more efficient to conduct by another means. The verification of this insight is the theme of the following section of this chapter.

1. Ground Convoy and Airdrop Methods of Delivery

Scenarios 1 through 3 were used to analyze the effects of changes in the delivery methods on the supply chain. Figures 7 through 9 illustrate the impact each scenario had on the overall fuel usage within the supply chain, while Table 5 provides the changes seen in the fuel requirement, relative to the historical scenario.

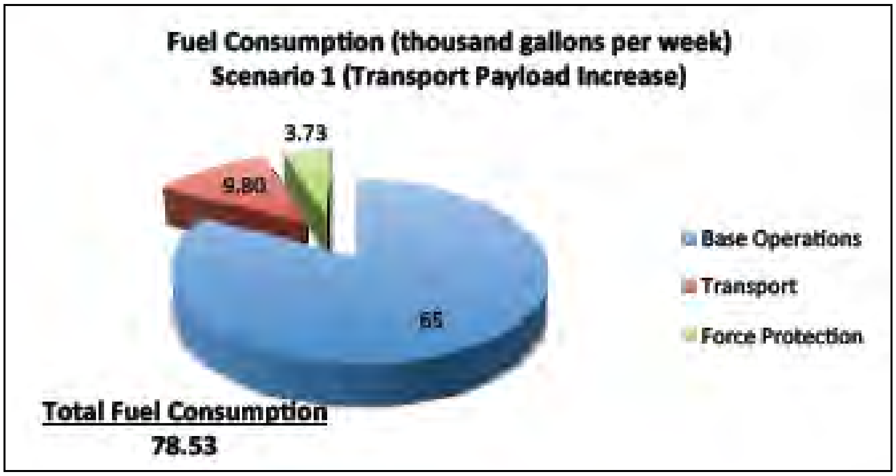

Figure 7. Total supply chain fuel consumption for Scenario 1, which increases the number of pods the MTVR transports base operations, fuel transportation, and force protection.

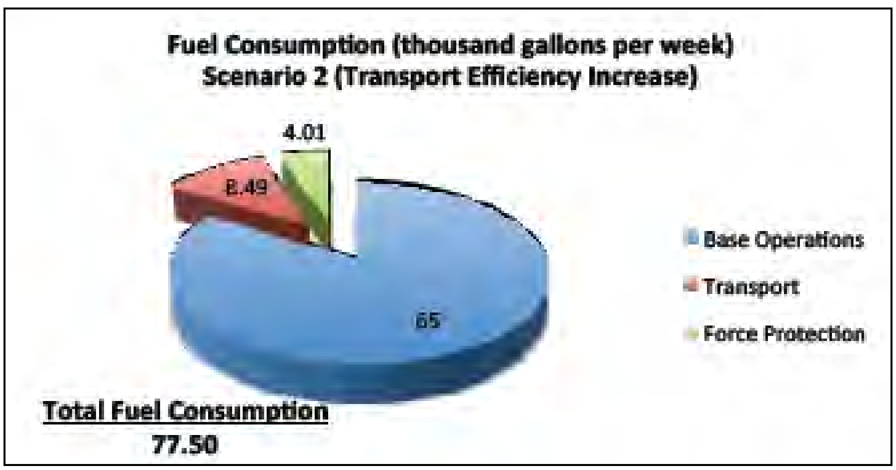

Figure 8. Total supply chain fuel consumption for Scenario 2, which decreases the gallons per hour used by the MTVR by base operations, fuel transportation, and force protection.

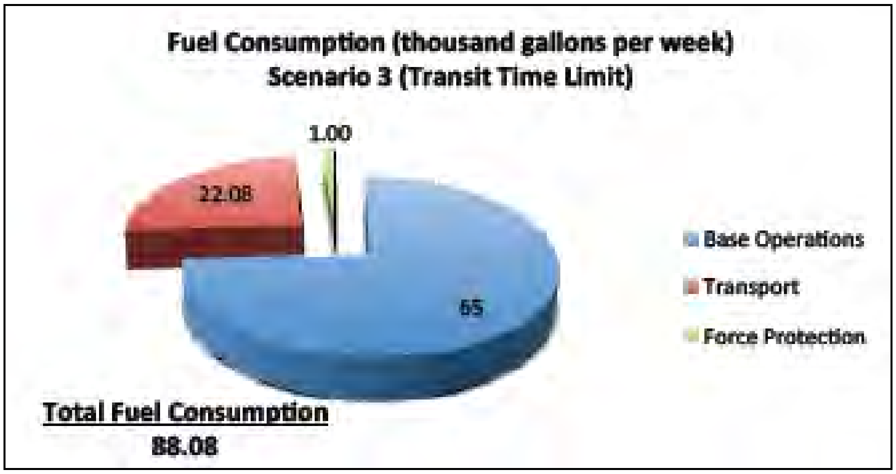

Figure 9. Total supply chain fuel consumption for Scenario 3, which limits the total time a ground convoy can operate by base operations, fuel transportation, and force protection.

Change in Fuel Requirements from Historical Scenario			
Scenario	**Overall**	**Transport**	**Force Protection**
(1) Payload Increase	–4.74%	–27.03%	–6.98%
(2) Efficiency Increase	–5.99%	–36.78%	0.00%
(3) Transit Limit	6.84%	64.41%	–75.06%

Table 5. The change in the overall, transport, and force protection fuel requirement from the historical scenario for Scenarios 1 through 3.

It is interesting to observe the reduction in force protection fuel requirements that is seen in Table 5 due to the increase in payload capacity of the MTVR. A benefit of this impact is it will allow decision makers, with limited budgets, to evaluate improvements within the supply chain that will increase efficiencies not only at the point of improvement, but also throughout the supply chain.

The transit limit scenario resulted in a significant decrease in the force protection fuel requirement in the supply chain. This reduction is attributed to the assumption, consistent with historical operations, that no force protection assets are used during air transports. While this assumption could be invalid, the impact that force protection fuel use has on the supply chain is small, so the effects of reducing this use is negligible.

While the raw fuel requirement numbers might indicate that air transportation is more costly than ground transportation, a look at the average fuel multipliers, seen in Figures 10 through 12, provide a better insight on this issue. These fuel multipliers also help answer the question raised while analyzing the historical scenario, i.e., whether there is a threshold at which ground transports become more costly than airdrops in the Afghanistan supply chain. While it would initially appear that these scenarios undermine the hypothesis that air transportation could be more cost effective than ground convoy transportation, a deeper analysis of the consumption numbers of each component leads to a mixed conclusion.

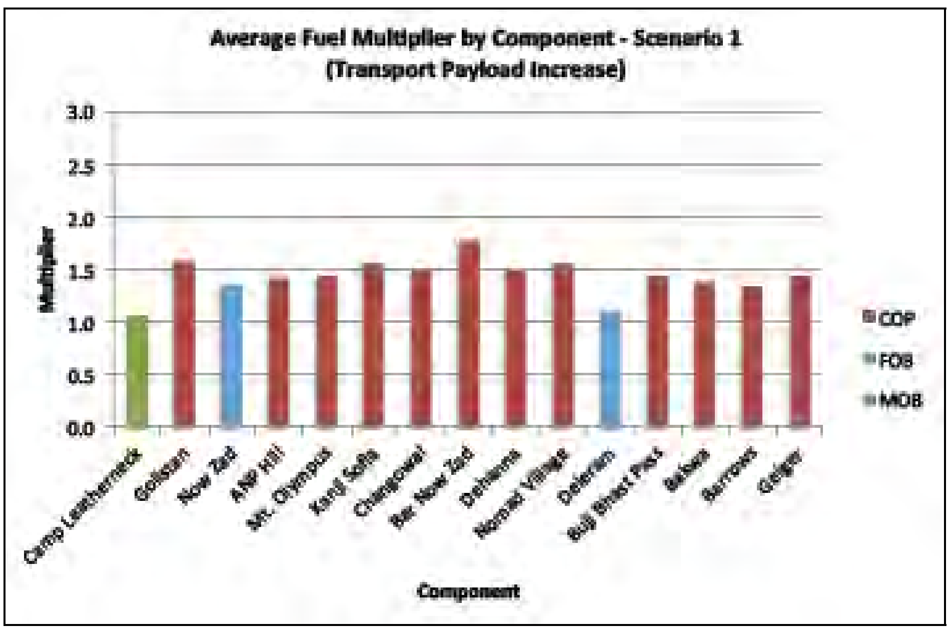

Figure 10. Average fuel multiplier for Scenario 1, which increases the number of pods the MTVR transports, by supply chain component.

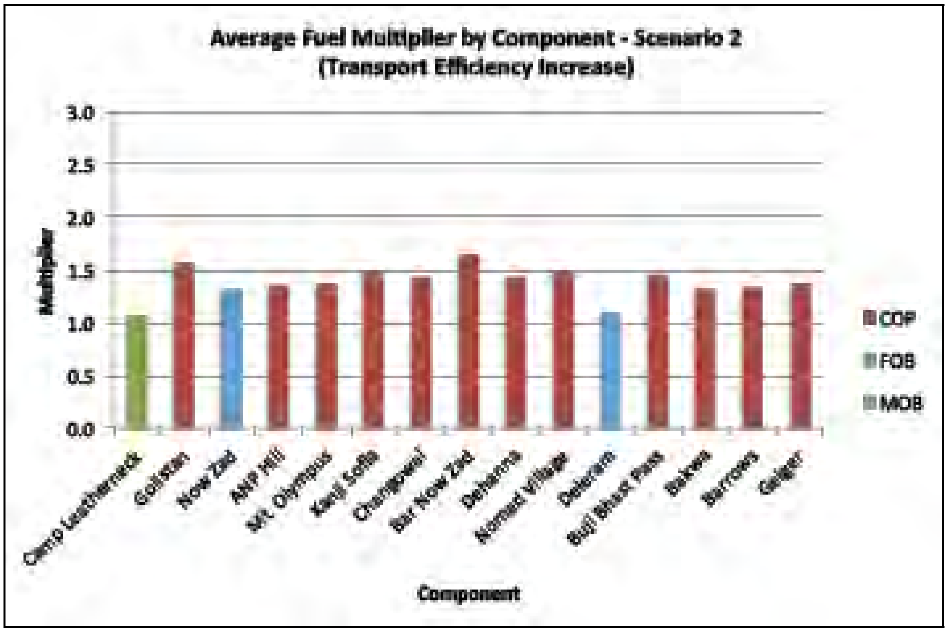

Figure 11. Average fuel multiplier for Scenario 2, which decreases the gallons per hour used by the MTVR, by supply chain component.

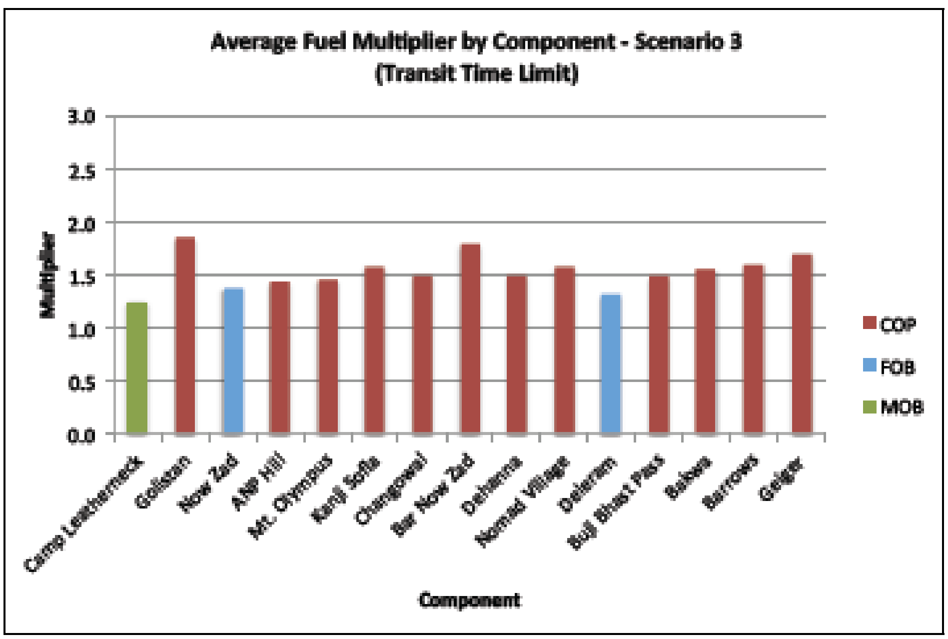

Figure 12. Average fuel multiplier for Scenario 3, which limits the total time a ground convoy can operate, by supply chain component.

One aspect that needs to be highlighted in each of these scenarios is the dependency that each component multiplier has on its supply component's multiplier. This can clearly be seen in the case of Golistan. During each of these scenarios, its method of receiving fuel remained constant, but in Scenario 3, which restricted the total transit time for ground convoys, Golistan's average multiplier increased from 1.6 to 1.8. The reason for the increase is because of the change in transportation methods between Kandahar and Camp Leatherneck in this last scenario. While the total number of assets required to transport the fuel between these locations decreased from 54 ground vehicles to 14 helicopters, the total fuel consumed during the transportation phase increased from roughly 6,500 gallons to 16,800 gallons. This resulting increase was then passed on to all of Camp Leatherneck's supported bases, with the increase being more apparent at Golistan due its direct relationship with Camp Leatherneck.

These same observations cannot be made for the Deleram-supported COPs. With the exception of Geiger, the Deleram COPs' method of transportation shifted from ground to air transportation due to the new policy put in place in Scenario 3. While the fuel multiplier, seen in Figure 12, at each of these COPs increased during this scenario, all of the increase could be attributed to the higher transportation fuel usage seen at Camp Leatherneck, described previously. Again, there was a decrease in the total number of vehicles required between this scenario and the historical scenario, but unlike the Camp Leatherneck to Golistan transport, the fuel consumed during transportation from Deleram to its supported COPs actually decreased by as much as 75%.

The decrease in transportation fuel consumption between Camp Leatherneck and Now Zad was large enough to counter the increase between Kandahar and Camp Leatherneck, to allow the multiplier at Now Zad to decrease. This can be attributed to the need for only one helicopter being used in these parts of the supply chain instead of the 14 required between Kandahar and Camp Leatherneck. These results appear to point to the fact that the mode of transportation that should be used between specific portions of the supply chain should be based not only on the total transit time of that particular leg, but also on the amount of fuel being transported.

The marginal fuel multipliers from these scenarios are best illustrated by Figure 13, showing the results from Scenario 1. In this scenario, the increase of 1,000 gallons of fuel required at Buji Bhast Pass and Geiger caused the number of MTVRs required to transport the fuel between Deleram and these COPs to increase by one. This increase triggered the fuel multiplier of the IO model, resulting in a higher multiplier at these locations. For the purpose of analyzing the effects of ground versus air transports, the use of the marginal multiplier is not revealing because the marginal effects are determined by whether transportation assets are operating at capacity.

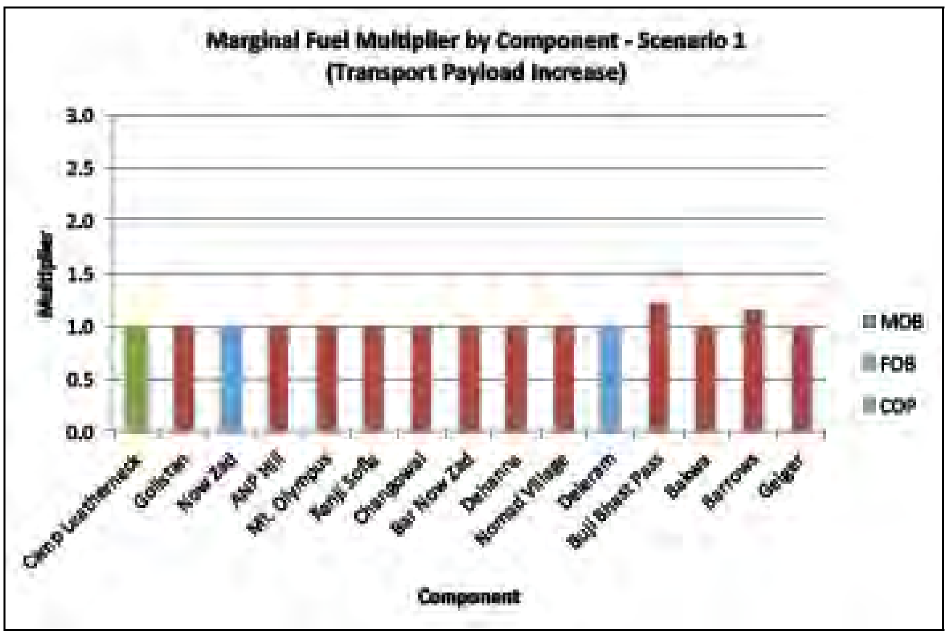

Figure 13. Marginal fuel multiplier for Scenario 1, which increases the number of pods the MTVR transports, by supply chain component.

2. Impact of Transportation and Force Protection Efficiency Improvements

Scenarios 1, 2, 5, and 6 show the impact of transportation and force protection efficiencies on the demand for fuel within the supply chain. Figures 7, 8, 14, and 15 illustrate the impact each scenario had on the overall fuel usage within the supply chain, with Table 6 providing the change in the fuel requirement relative to the historical scenario.

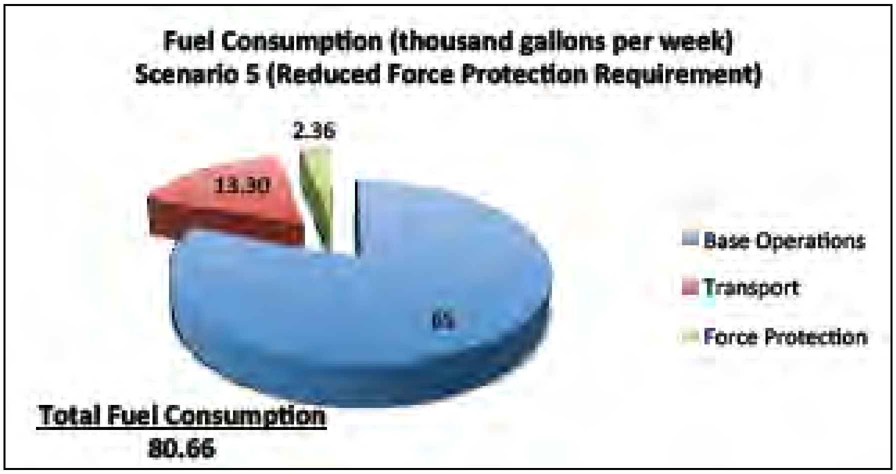

Figure 14. Total supply chain fuel consumption for Scenario 5, which reduces the number of force protection vehicles required during ground convoys by base operations, fuel transportation, and force protection.

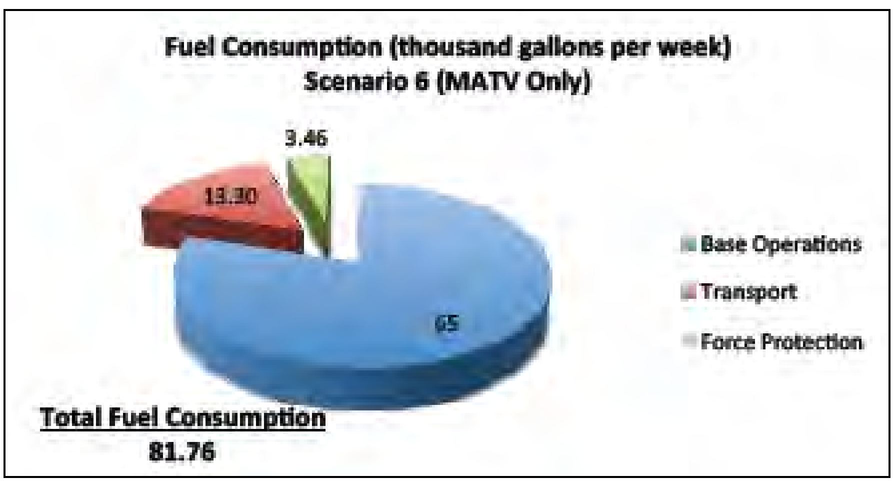

Figure 15. Total supply chain fuel consumption for Scenario 6, which uses the MATV as the only force protection vehicle during ground convoys by base operations, fuel transportation, and force protection.

Change in Fuel Requirements from Historical Scenario			
Scenario	**Overall**	**Transport**	**Force Protection**
(1) Payload Increase	–4.74%	–27.03%	–6.98%
(2) Efficiency Increase	–5.99%	–36.78%	0.00%
(5) Reduced FP	–2.16%	–0.97%	–41.15%
(6) MATV Only	–0.82%	–0.97%	–13.72%

Table 6. The change in the overall, transport, and force protection fuel requirement from the historical scenario for Scenarios 1, 2, 5, and 6.

While each of these scenarios does provide a reduction in the overall fuel requirement of the Afghanistan supply chain, it appears that the more significant reductions occur while improving the transportation aspect of the system. During the course of this research, many reports pointed to the force protection requirement as being one of the driving factors for higher fuel costs in the theater of operations (Commandant of the Marine Corps, 2011). The most significant force protection fuel requirement reductions can be seen by merely reducing the number of vehicles required during convoy operations, instead of switching all vehicles to the more efficient MATV. Again, the decision maker can use this insight to determine if limited funds should be allocated to the production of a new vehicle or focus more effort on improving the security within a region. The dynamic nature of the IO model is illustrated by the reduction in force protection usage resulting in a decrease in the transportation portion of the supply chain.

The average fuel multipliers for each of the scenarios must be reviewed to determine if there are any underlying reasons, not apparent in the overall fuel requirement numbers, for the changes seen in each scenario. Figures 10, 11, 16, and 17 show the average multiplier fuel multipliers in these scenarios.

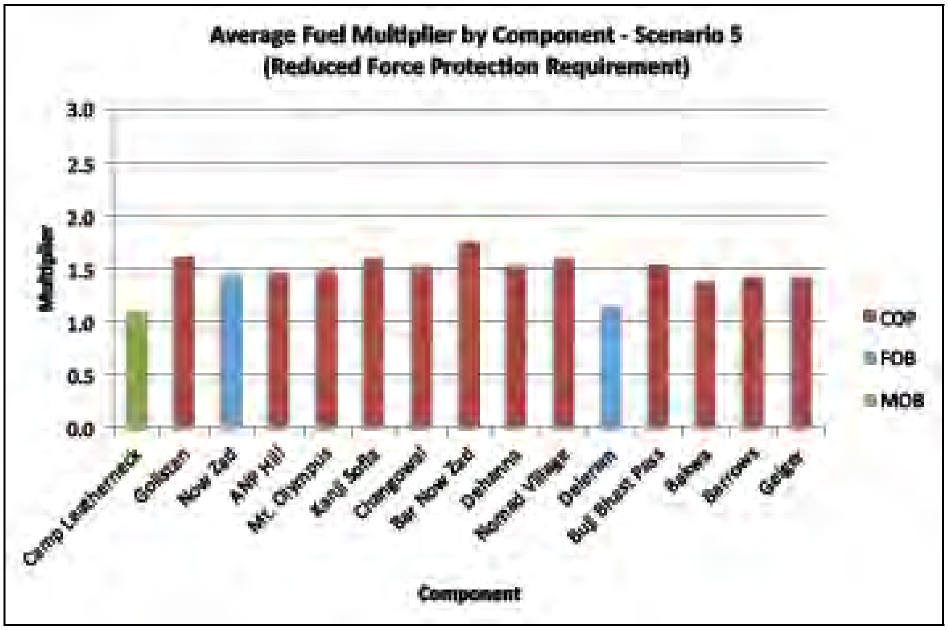

Figure 16. Average fuel multiplier for Scenario 5, which reduces the number of force protection vehicles required during ground convoys, by supply chain component.

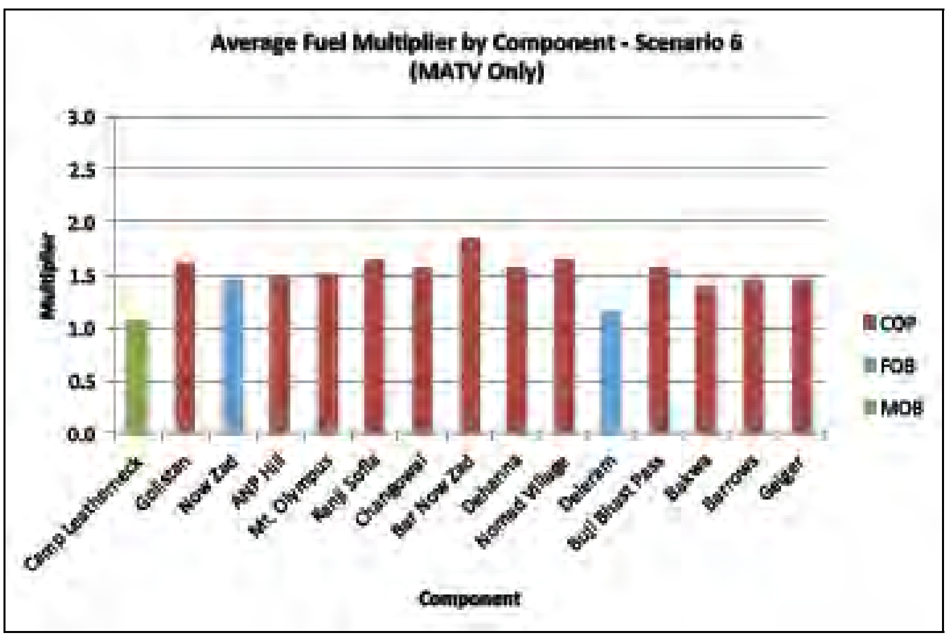

Figure 17. Average fuel multiplier for Scenario 6, which uses the MATV as the only force protection vehicle during ground convoys, by supply chain component.

The reductions seen in the multipliers for each component in Scenarios 5 and 6 can be attributed to the lower overall fuel requirement in the supply chain. These same conclusions apply when analyzing the marginal multipliers. With this particular supply chain, the force protection requirements are minimal, so at no time do they cause an increase in the overall fuel requirements that can be seen in the transportation scenarios.

3. Factors Providing the Largest Impact on Efficiencies

Since the six scenarios capture almost all of the major types of improvements or changes that could realistically occur in the Afghanistan theater of operations, it is worth asking whether a particular course of action results in a bigger decrease in fuel requirements. This analysis will provide insight into whether the concerted effort to reduce the fuel requirements by the end users results in the best reduction of fuel usage in a supply system. Figures 7–9, 14, 15, and 18 illustrate the impact each scenario had on the overall fuel usage within the supply chain, with Table 7 providing the change in the fuel requirement from the historical scenario.

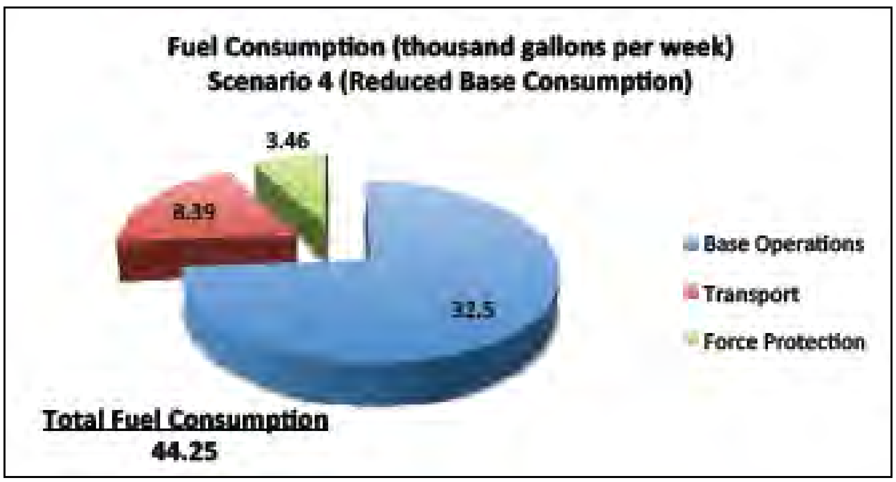

Figure 18. Total supply chain fuel consumption for Scenario 4, which reduces the amount of fuel used at each base by 50% by base operations, fuel transportation, and force protection.

Change in Fuel Requirements from Historical Scenario			
Scenario	**Overall**	**Transport**	**Force Protection**
(1) Payload Increase	–4.74%	–27.03%	–6.98%
(2) Efficiency Increase	–5.99%	–36.78%	0.00%
(3) Transit Limit	6.84%	64.41%	–75.06%
(4) Reduced Consumption	–46.32%	–37.53%	–16.21%
(5) Reduced FP	–2.16%	–0.97%	–41.15%
(6) MATV Only	–0.82%	–0.97%	–13.72%

Table 7. The change in the overall, transport, and force protection fuel requirement from the historical scenario for Scenarios 1 through 6.

This analysis suggests that reducing the consumption at the end user has the greatest impact on the overall fuel requirement. While this is true, even obvious, an interesting effect can be seen when looking only at the transportation fuel requirements. Based on the scenario, it would be reasonable to assume a 50% reduction in demand would result in a 50% reduction in transportation requirements; this, however, is not the case. Rather, reducing the overall fuel requirements by 50% causes a similar reduction on transportation fuel requirements as improving the transport vehicles themselves. This can be explained by the fact that in components such as Bar Now Zad and ANP Hill, their historical fuel requirement was 1,000 gallons, which, in Scenario 4, was reduced to 500 gallons. Each of these requirements is fulfilled by one transport vehicle, so the reduction in demand is not passed along to the transportation part of the supply chain.

Figure 19 shows the average fuel multiplier of Scenario 4. The impact of reducing base consumption on the fuel multiplier appears different than the pure requirement numbers would suggest. The increase of COPs’ multipliers ranges from 25% to 75% over the historical multipliers. Although the overall fuel requirement of the supply chain was reduced, the higher multipliers seen at every component would contribute to short-term impacts to the planning process of the operational command. The supply officers would be making fuel purchase projections based on the new demand model within the supply chain. These projections would remain accurate until there was a change in demand within the system. Using the COP of Bar Now Zad demonstrates a good example of this. Under this scenario, Bar Now Zad has a multiplier of around 2.5. For every change in 1 gallon of demand at Bar Now Zad, it has a ripple effect of 2.5 gallons through the supply chain. Now, if the area around Bar Now Zad becomes a hotbed of activity, resulting in a spike for fuel on the order of several thousand gallons, the result will be either an immediate shortfall in other COPs to meet the demand at Bar Now Zad or Bar Now Zad's inability to meet its assigned objectives.

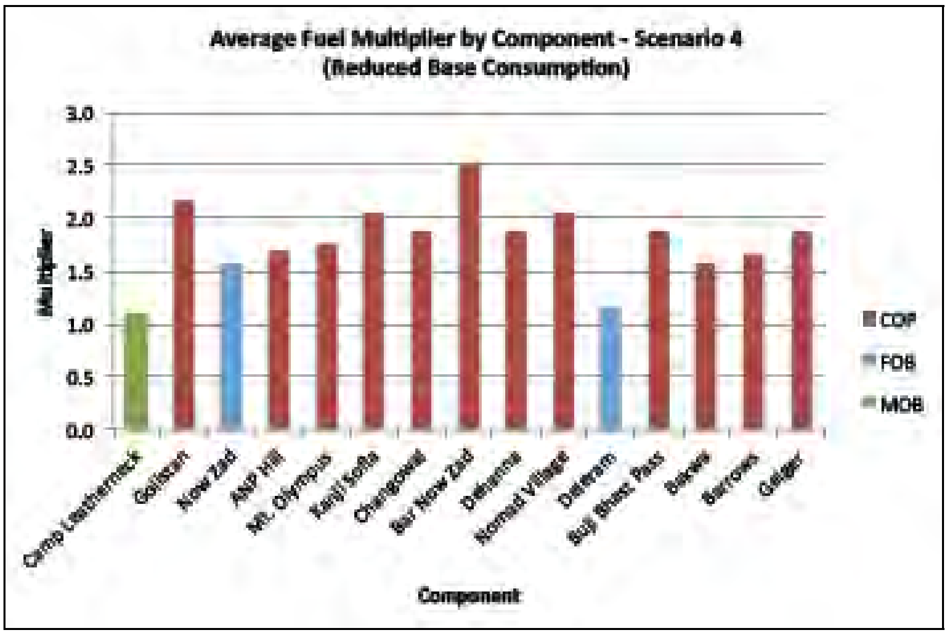

Figure 19. Average fuel multiplier for Scenario 4, which reduces the amount of fuel used at each base by 50%, by supply chain component.

The marginal fuel multiplier for the base requirement reduction scenario can be seen in Figure 20. In the previous scenarios, the marginal multiplier does not appear to provide much insight into the overall behavior of the supply chain seen in Afghanistan.

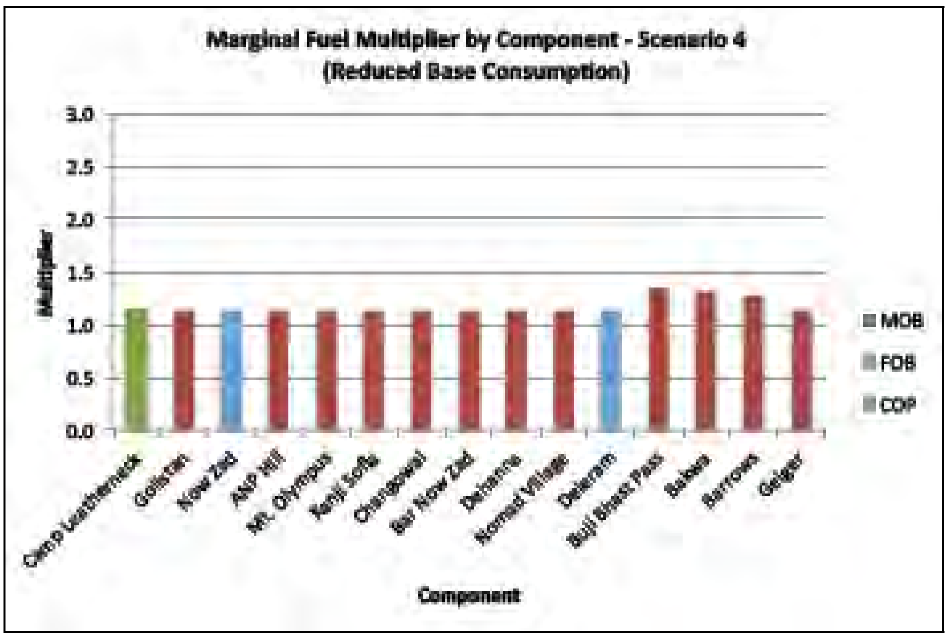

Figure 20. Marginal fuel multiplier for Scenario 4, which reduces the amount of fuel used at each base by 50%, by supply chain component.

V. CONCLUSIONS AND FUTURE RESEARCH

Although IO has traditionally been used for analysis of economies, the qualities that made it ideal for this also could be exploited to understand DoD's fuel requirement. The user or decision maker can customize the model, which allows for a more robust model to be created for a particular scenario. While this makes IO extremely useful, as with any model, it is only as good as the data that are used to build it.

Getting appropriate data was a major issue, which resulted in numerous difficulties in building the model. The data needed to feed the model appeared to be of the type that should have been readily available, but this was not the case. Systematic tracking of fuel in Afghanistan stopped once the fuel reached the point of entry—in this case, Kandahar. For this type of model to be successfully implemented throughout the DoD, the tracking of fuel flows needs to be more comprehensive and the data more readily available, so that those responsible for making acquisition and operational decisions have the complete picture.

The lack of data limited the model, which does not incorporate several cost elements that are found in other FBCF estimates. These cost elements include asset depreciation, manpower and personnel costs, and asset casualties during operation. While these are not captured in this IO model, the other FBCF models fall short by not capturing the fuel multiplier within the entire supply chain. This model is the first to capture the fuel multiplier in such a way that those individual parts of the chain can be evaluated. Impacts of fuel consumption, such as greenhouse gases produced during fuel consumption, should be multiplied by the fuel multiplier and then attributed to the consuming component, thus allowing for a revised estimate to be calculated for emissions.

Additionally, the fuel multipliers calculated by the current model, multiplied by the commodity cost of fuel, provide a lower bound for FBCF calculations, which again gives the decision maker valuable information. The IO approach can uncover the true root cause of inefficiencies and help identify changes with the biggest impact. These insights were found by running the model through various scenarios and determining the average and marginal fuel multiplier at each component.

One of the first observations pertained to the belief that force protection fuel usage was a major contributing factor to the overall fuel consumption of units and commands located in Iraq and Afghanistan (Rosenthal, 2010). In the historical scenario, the impact that force protection had on the overall fuel requirements was small. The previously held beliefs were the impetus for creating two distinct scenarios of varying force protection. These scenarios not only provided further evidence concerning the effect force protection has on fuel usage, but it also provided insight that efficiencies gained in the area did not result in significant savings to the overall supply chain.

Another area this research was able to provide more insight into was the most efficient use of ground and air assets within a particular supply chain. Prior studies have claimed the use of air assets is at least twice as expensive as ground assets to transport fuel (Deputy Secretary of Defense, 2011). While the model did support this in providing evidence for some circumstances, it also demonstrated that air assets could be more efficient than ground convoys in other circumstances.

The battlespace of Afghanistan is a prime example of such a supply chain, where careful consideration needs to be given to the methods of transportation of fuel. This is due to the lack of efficient roadways that connect the different bases of operation, resulting in relatively short distances requiring numerous hours being spent driving in a convoy, when an air asset could complete the resupply operation in less than an hour. These results lend themselves to useful for the foreseeable future due to the areas of the world in which we are likely to fight future conflicts.

A final insight from this analysis concerns the proper allocation of resources to improve efficiency of a fuel supply chain. Across the DoD, a majority of the attention for gaining efficiency has focused on improving the fuel use of the end users (Commandant of the Marine Corps, 2011). While reducing the overall demand does have a direct impact on the amount of fuel transported, the model revealed an underlying issue that should cause decision makers to reconsider making the end user the focus of efficiency programs.

When the scenario of reduced fuel consumption was introduced, the average fuel multipliers at each base of operation increased significantly, from 25% to 75%. Although the overall fuel requirement of the supply chain was reduced, the higher multipliers seen at every component would contribute to short-term impacts to the planning process of the operational command. The supply officers would be making fuel purchase projections based on the new demand model within the supply chain. These projections would remain accurate until there was a change in demand within the system. The change in demand would be subject to the fuel multiplier, which, for Bar Now Zad, results in a 2.5-gallon increase at the source component for every 1-gallon increase of demand. These fluctuations could result in shortages throughout the supply chain, reducing the mission effectiveness of the components. While efficiency improvements in every aspect of the supply chain should be considered, the impact they will have on the planning process must be evaluated. In a combat environment, the demands of the forward components are constantly changing and directly impact the fuel requirements within the supply chain. While the reduction of the overall fuel consumption is the goal, these findings illustrate there will be unintended consequences in the short-term planning process that could result in a loss of mission effectiveness.

This research has provided important insight into determining FBCF within the DoD using an IO, but it has only scratched the surface of the wealth of benefits this approach will have in the future. Future research must be conducted to expand on and tap into IO's ability to provide the most flexible and accurate model for FBCF. To do this, a follow-on study should incorporate the other cost factors described earlier, so the model can capture all aspects of the supply chain costs, instead of establishing the lower bound for the FBCF. Additionally, other supply chains should be modeled using the same method as the Afghanistan supply chain was, in order to determine whether the same insights apply across the DoD, or are a special circumstance found only in this particular supply chain. By looking at diverse supply chains, other improvements or efficiencies could be found that apply widely to the DoD, and general rules for a consistent approach to using IO in the DoD could be developed. Finally, research focusing on how the fuel usage data are captured would provide a way for more commands and organizations to take advantage of the benefits IO provides. By unraveling the data collection issue, it would create a triad of efficiency (data, model, and implementation) that would help the DoD lead the way in reducing the United States' dependence on fossil fuels.

APPENDIX. SPREADSHEET IMPLEMENTATION OF AFGHANISTAN FBCF/IO MODEL

The implementation of the FBCF/IO model in Excel calculating the fuel requirements, fuel consumption during transportation, and the per unit output by component to determine the total fuel required to be purchased at Kandahar.

Table 1

	Supply Chain Components						Consuming Components											
Fuel Requirement (q_{ij}^m)	Kandahar	Leatherneck	Leatherneck Air	Leatherneck Ground	Delerem	Nowzad	Golistan	Buji	Bakwa	MT Olympus	ANP Hill	Kanji Sofla	Changowal	Bar Now Zad	Dehanna	Nomad Village	Barrows	Geiger
Kandahar	0	75.8485931	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leatherneck	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leatherneck Air	0	0	0	0	0	1.58767051	2	0	0	0	0	0	0	0	0	0	0	0
Leatherneck Ground	0	0	0	0	20.3733234	14.2890346	0	0	0	0	0	0	0	0	0	0	0	0
Delerem	0	0	0	0	0	0	0	2	3	0	0	0	0	0	0	0	2	1
Nowzad	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0
Golistan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buji	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bakwa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MT Olympus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ANP Hill	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kanji Sofla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Changowal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bar Now Zad	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dehanna	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nomad Village	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barrows	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geiger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
External	82.4478351	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2

Consumption en route (C_{ij})	Kandahar	Leatherneck	Leatherneck Air	Leatherneck Ground	Delerem	Nowzad	Golistan	Buji	Bakwa	MT Olympus	ANP Hill	Kanji Sofla	Changowal	Bar Now Zad	Dehanna	Nomad Village	Barrows	Geiger
Kandahar	0	6.599242	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leatherneck	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leatherneck Air	0	0	0	0	0	0.43636364	0.98181818	0	0	0	0	0	0	0	0	0	0	0
Leatherneck Ground	0	0	0	0	1.197666	4.9827168	0	0	0	0	0	0	0	0	0	0	0	0
Delerem	0	0	0	0	0	0	0	0.8097056	0.7084924	0	0	0	0	0	0	0	0.5566726	0.2984528
Nowzad	0	0	0	0	0	0	0	0	0	0.0559599	0.0373066	0.1492264	0.0932665	0.2984528	0.0932665	0.1492264	0	0
Golistan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buji	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bakwa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MT Olympus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ANP Hill	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kanji Sofla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Changowal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bar Now Zad	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dehanna	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nomad Village	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barrows	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geiger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
External	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3

Per Unit Output (a_{ij})	Kandahar	Leatherneck	Leatherneck Air	Leatherneck Ground	Delerem	Nowzad	Golistan	Buji	Bakwa	MT Olympus	ANP Hill	Kanji Sofla	Changowal	Bar Now Zad	Dehanna	Nomad Village	Barrows	Geiger
Kandahar	0	1.79826314	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leatherneck	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leatherneck Air	0	0	0	0	0	0.25696457	2.98181818	0	0	0	0	0	0	0	0	0	0	0
Leatherneck Ground	0	0	0	0	2.07946755	2.44667677	0	0	0	0	0	0	0	0	0	0	0	0
Delerem	0	0	0	0	0	0	0	2.8097056	3.7084924	0	0	0	0	0	0	0	2.5566726	1.2984528
Nowzad	0	0	0	0	0	0	0	0	0	1.0559599	1.0373066	1.1492264	1.0932665	1.2984528	1.0932665	1.1492264	0	0
Golistan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buji	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bakwa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MT Olympus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ANP Hill	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kanji Sofla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Changowal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bar Now Zad	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dehanna	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nomad Village	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barrows	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geiger	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
External	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Purchase from External (X)	82.4478351																	
Consumption on site (c_j)	0	30	0	0	10	8	2	2	3	1	1	1	1	1	1	1	2	1
Output (x_j)	82.4478351	45.8485931	5.00585233	40.8427408	10.3733234	7.8767051	1	1	1	1	1	1	1	1	1	1	1	1

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