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Estimating Logistics Burdens in Support of Acquisition Decisions

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Naval Postgraduate School

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Preface & Acknowledgements

Welcome to our Ninth Annual Acquisition Research Symposium! This event is the highlight of the year for the Acquisition Research Program (ARP) here at the Naval Postgraduate School (NPS) because it showcases the findings of recently completed research projects—and that research activity has been prolific! Since the ARP's founding in 2003, over 800 original research reports have been added to the acquisition body of knowledge. We continue to add to that library, located online at www.acquisitionresearch.net, at a rate of roughly 140 reports per year. This activity has engaged researchers at over 60 universities and other institutions, greatly enhancing the diversity of thought brought to bear on the business activities of the DoD.

We generate this level of activity in three ways. First, we solicit research topics from academia and other institutions through an annual Broad Agency Announcement, sponsored by the USD(AT&L). Second, we issue an annual internal call for proposals to seek NPS faculty research supporting the interests of our program sponsors. Finally, we serve as a "broker" to market specific research topics identified by our sponsors to NPS graduate students. This three-pronged approach provides for a rich and broad diversity of scholarly rigor mixed with a good blend of practitioner experience in the field of acquisition. We are grateful to those of you who have contributed to our research program in the past and hope this symposium will spark even more participation.

We encourage you to be active participants at the symposium. Indeed, active participation has been the hallmark of previous symposia. We purposely limit attendance to 350 people to encourage just that. In addition, this forum is unique in its effort to bring scholars and practitioners together around acquisition research that is both relevant in application and rigorous in method. Seldom will you get the opportunity to interact with so many top DoD acquisition officials and acquisition researchers. We encourage dialogue both in the formal panel sessions and in the many opportunities we make available at meals, breaks, and the day-ending socials. Many of our researchers use these occasions to establish new teaming arrangements for future research work. In the words of one senior government official, "I would not miss this symposium for the world as it is the best forum I've found for catching up on acquisition issues and learning from the great presenters."

We expect affordability to be a major focus at this year's event. It is a central tenet of the DoD's Better Buying Power initiatives, and budget projections indicate it will continue to be important as the nation works its way out of the recession. This suggests that research with a focus on affordability will be of great interest to the DoD leadership in the year to come. Whether you're a practitioner or scholar, we invite you to participate in that research.

We gratefully acknowledge the ongoing support and leadership of our sponsors, whose foresight and vision have assured the continuing success of the ARP:

- Office of the Under Secretary of Defense (Acquisition, Technology, & Logistics)
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We also thank the Naval Postgraduate School Foundation and acknowledge its generous contributions in support of this symposium.

James B. Greene Jr. Rear Admiral, U.S. Navy (Ret.)	Keith F. Snider, PhD Associate Professor

Panel 24. Understanding the Cost/Capabilities of Humanitarian Assistance and Supply Operations

Thursday, May 17, 2012	
3:30 p.m. – 5:00 p.m.	**Chair: Rear Admiral Kathleen Dussault,** USN, Director, Logistics Programs and Corporate Operations Division (OPNAV N41) ***Estimating Logistics Burdens in Support of Acquisition Decisions*** Eva Regnier, Jay Simon, and Daniel Nussbaum *Naval Postgraduate School* ***Financing Humanitarian Assistance and Disaster Response: The Case of the Tōhoku Earthquake and Tsunami*** Keenan Yoho, *Naval Postgraduate School* ***Capabilities and Competencies in Humanitarian Operations*** Aruna Apte and Keenan Yoho *Naval Postgraduate School*

Kathleen Dussault—Rear Admiral Dussault is the director of Supply, Ordnance and Logistics Operations Division (OPNAV N41). She assumed duties as the director of Supply, Ordnance and Logistics Operations in the Office of Chief of Naval Operations (OPNAV N41) in March 2009. Dussault comes to OPNAV from her most recent assignment as commander of the Joint Contracting Command Iraq/Afghanistan, headquartered in Baghdad, Iraq, with 18 regional offices throughout both theaters.

Dussault graduated from the University of Virginia in 1977 with a Bachelor of Arts in American government, received her commission through Officer Candidate School in Newport, RI, in November 1979, and graduated from Navy Supply Corps School in May 1980. Dussault has served in USS *Point Loma* (AGDS-2) in the Pacific Area Launch Support Ship for the Trident missile program as supply officer, USS *Concord* (AFS-5) as the assistant supply officer during Operations Desert Shield and Desert Storm, and as supply officer aboard USS *Seattle* (AOE-3), where she served as Afloat Logistics coordinator while deployed to the 5th Fleet operating area.

Dussault's shore tours include assistant supply officer and disbursing officer to the Navy Communications Station, Nea Makri, Greece; Defense Contract Administration Services Region (DCASR), Los Angeles; a negotiator and contracting officer at Naval Supply Center, Oakland, CA; procuring contracting officer for the Sidewinder and deputy for Missile Systems Acquisition at Naval Air Systems Command (NAVAIR); business and financial manager for programs managed by the Space and Naval Warfare Command; and executive assistant to the Deputy Assistant Secretary of the Navy for Acquisition Management within the office of the Assistant Secretary of the Navy for Research Development and Acquisition. In May 2001, Dussault assumed command of Defense Distribution Depot San Diego, and in April 2003 she assumed command of the Office of Special Projects, Arlington, VA. She then served as deputy director of Acquisition Management at Defense Logistics Agency, Fort Belvoir, VA. Prior to her combat assignment, she was assigned as deputy assistant secretary of the Navy for Acquisition and Logistics Management in Washington.

Dussault has earned a master's degree (with honors) in procurement management from Saint Mary's College in Moraga, CA, and a master's degree in national resource strategy from the Industrial College of the Armed Forces. She has achieved the highest levels of accreditation in Acquisition, Financial and Supply Chain Management and Joint Professional Military Education. Dussault is certified in production and inventory management through APICS, the educational society for resource management. She has completed the Executive Education Program at Columbia Business School.

Her decorations include the Defense Superior Service Medal, Legion of Merit, Bronze Star, Navy Meritorious Service Medal with two gold stars, Joint Service Commendation Medal, Navy Commendation Medal, Navy Achievement Medal with gold star and various unit citations, campaign medals and service medals.

Estimating Logistics Burdens in Support of Acquisition Decisions

Eva Regnier—Dr. Regnier is an associate professor of decision science at the Defense Resources Management Institute (DRMI) and a visiting associate professor in the Operations Research Department at NPS. She received a PhD in industrial engineering and an MS in operations research from the Georgia Institute of Technology, and a BS in environmental engineering science from the Massachusetts Institute of Technology. Dr. Regnier teaches decision analysis and management of defense resources. Her research is in decisions under uncertainty, including both optimization and characterizing uncertainty for decision-makers, with a focus on applications with sources of uncertainty in the natural environment. [eregnier@nps.edu]

Jay Simon—Dr. Simon is an assistant professor of decision science at the Defense Resources Management Institute (DRMI) at NPS. Dr. Simon's main research focus is multiattribute preference modeling. His current and recent work includes a prostate cancer decision model, preference models for health decisions, preferences over geographic outcomes, altruistic utility modeling, and time discounting anomalies. He is a member of the Institute for Operations Research and the Management Sciences (INFORMS) and the Decision Analysis Society of INFORMS. Dr. Simon joined the DRMI faculty in August 2009. [jrsimon@nps.edu]

Daniel Nussbaum—Dr. Nussbaum is a professor of operations research at the Naval Postgraduate School. His expertise is in cost/benefit analyses, life cycle cost estimating and modeling, budget preparation and justification, performance measurement and earned value management (EVM), activity-based costing (ABC) and total cost of ownership (TCO) analyses. From December 1999 through June 2004 he was a principal with Booz Allen Hamilton, providing estimating and analysis services to senior levels of the U.S. federal government. He has been the chief advisor to the Secretary of Navy on all aspects of cost estimating and analysis throughout the Navy, and has held other management and analysis positions with the U.S. Army and Navy, in this country and in Europe. In a prior life, he was a tenured university faculty member. [danussba@nps.edu]

Abstract

Department of Defense policy and federal statute call for using the fully burdened cost of energy in cost estimates that support acquisition decision-making, so that decisions reflect all the costs throughout the organization that will be incurred (or saved) by a given acquisition decision. This work explores methods to estimate the fully burdened cost of supply for fuel, batteries, water, and other consumables as a function of variables that may be modeled during early (up to and including Milestone A) acquisition decisions, such as the geographic location at which supply is demanded.

Introduction

Sustaining the warfighter has been a critical challenge throughout history. Modern warfare has not overcome this challenge. On the contrary, modern military technology requires military-specific supply, including fuels meeting military specifications. Maintaining and defending supply lines that stretch thousands or even tens of thousands of miles, is a critical current challenge to the U.S. Department of Defense (DoD). Supply, and in particular fuel, requirements, have been a source of constant and intense conversation as one of the key vulnerabilities of U.S. and NATO forces in Afghanistan.

Until recently, DoD practice called for using the Defense Logistic Agency's standard fuel in cost analyses for candidate platforms and weapons systems. This price captures the purchase price and transportation and handling to the point of acceptance by the Services, smoothed over a period of 18 months to shield the Services from market price volatility.

DoD leadership has noted that the standard price dramatically underestimates the total costs imposed by the use of fuel. It excludes any cost for organic transport beyond the

Services' acceptance point, as well as many indirect costs, such as force protection. The Army Environmental Policy Institute (AEPI) estimates that there were over 3,000 resupply convoy casualties, mostly attributable to fuel and water supply, during the five-year period of 2003–2007 in Iraq and Afghanistan (AEPI, 2009). Every gallon of fuel consumed incurs not just dollar costs but also puts convoy personnel at risk.

The fully burdened cost of fuel (now the fully burdened cost of energy, and hereafter referred to as FBCF/E) is a concept intended to estimate and monetize all the costs incurred in order to assure supply of fuel or energy to its point of consumption. The idea is that a dollar value per unit of fuel/energy can be used as an estimate for the total costs (the burden) imposed on the DoD by its consumption.

DoD policy and federal statute call for using the FBCE in cost estimates in acquisition decisions and analyses of alternatives, so that decisions reflect all the costs throughout the DoD organization that will be incurred (or saved) by a given acquisition decision. In particular, legislation, directives and policy guidance—including the 2009 National Defense Authorization Act, the 2010 Quadrennial Defense Review, defense acquisition directives, and Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics policy makers—specifically call for the use of FBCF/E by DoD analysts.[1]

Each Service and the Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics) have all developed methods and tools, which are coalescing around a seven-step process outlined in Roscoe (2010). Each method requires at least one scenario, and usually two or more, reflecting operation of the platform or weapon system in different contexts, including at least one peacetime and one wartime scenario. Each scenario must be detailed enough that the cost of operating Service-owned fuel-delivery assets can be estimated. Usually this means actually specifying the type of fuel-delivery asset used in each transport leg, as well as details about fuel-handling infrastructure, and many other details (Truckenbrod, 2010; Corley, 2009).

The FBCF/E is required to be used in estimating life cycle costs for weapons systems and platforms during their acquisition process; these scenarios are specified at least years and often decades before the bulk of the system's operation. The DoD supply chain stretches around the globe, and is a complex, frequently changing system. Therefore it is very unlikely that most of the details of the scenario will ever be reproduced during the system's actual operation. This raises at least two questions: (1) How much detail about the logistics network should cost analysts be required to specify in estimating the FBCF/E? and (2) Which elements are the biggest drivers of FBCF/E and therefore are most important to predict, estimate, and specify?

As discussed in Regnier and Nussbaum (2011), two challenges are generally not met by FBCE estimates: (1) capturing the multiplier effect and (2) estimating the appropriate path-weighted FBCE when supply to a given part of the organization (hereafter, component) may travel multiple paths through the supply chain.

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[1] The discussion about the importance of fuel/energy consumption and the importance of reducing this consumption, reveals that many would like the FBCF/E to capture two distinct categories of costs:

1. resource demands, that is, all the resources including infrastructure, equipment, and material as well as personnel and attrition, required to assure the supply; and
2. the tether, that is, the reduction in capability associated with the need to establish, maintain, and protect the supply line.

To our knowledge, there are no studies that attempt to quantify, let alone monetize, capability reductions associated with the tether. Like all other studies on the burden associated with F/E, this work addresses only resource requirements.

The Regnier and Nussbaum approach, which uses an input–output (IO) framework, automatically assigns costs associated with each stage of the logistics network proportionally to all supply that the stage handles. This effect is illustrated in Dubbs (2011), who modeled a portion of the U.S. Marine Corps logistics network in Afghanistan. In that model several bases supplied multiple downstream bases or outposts. The fuel required for downstream stages was reflected in the total requirement for each upstream base, and the fuel consumption associated with operation of the base was proportionally attributed to the downstream consumers. Although Dubbs did not estimate costs, the same allocation and attribution of costs can be accomplished with the input–output approach.

Perhaps more important, to our knowledge, none of the existing FBCF/E methods and tools captures the multiplier effect highlighted in Regnier and Nussbaum (2011) and Dubbs (2011). The multiplier effect is potentially highly important and its importance increases—exponentially—the more stages are involved in the logistics network. Since it is also universally overlooked, we refer to the example offered in Regnier and Nussbaum (2011). In that three-stage example, failing to account for the fuel multiplier effect understates the FBCF by 16%.

Dubbs (2011) estimates only the fuel multiplier, and only for a portion of the logistics network, from Kandahar to a set of forward operating bases and combat outposts, a maximum of three transportation legs. The fuel multiplier for one combat outpost was 1.72, implying that 1.72 gallons of fuel were required at Kandahar merely to transport, protect, and supply the needs of the warfighter at the combat outpost. This analysis excluded any indirect costs other than fuel, for example, the cost of other supplies to sustain the personnel involved in this portion of the logistics network, as well as any costs upstream of Kandahar. Therefore, the 1.72 factor times the commodity price of fuel is clearly a distant lower bound on the FBCF at this combat outpost. It should be noted that the multiplier for a given stage is multiplied by the multipliers at other stages that supply must travel to reach the warfighter. Therefore its importance increases exponentially with the number of stages in the logistics network.

Our approach has two parts:

1. Network construction: Using a limited amount of user-specified scenario data, a novel optimization algorithm is used to construct a logistics network, consisting of depots (nodes) and transportation legs (arcs) that can provide organic transportation and handling of supply from origin to destination(s).
2. Input–output modeling and cost estimation: Based on the logistics network, an input–output model of the transportation network is constructed and used to calculate the total organization-wide requirements for fuel, water, and other resources, as well as monetary costs associated with the consumption of supply at any point in the logistics network.

First conceived and most often applied to the analysis of national economies (Dietzenbacher & Lahr, 2004; Leontief, 1986), using industries and subindustries as the units of analysis (components), IO is a simple but powerful tool.

In recent years, input–output analysis has been extended to model greater detail in the material and economic relationships in the economy, and to trace the resource and environmental impacts through economic systems. The research literature is rich with applications to life cycle assessment (LCA), which is the estimation of the environmental impacts of consumption of products and services, traced back through the economy (Hendrickson et al., 2006). Physical input–output analyses represent the transformation of materials through production processes to trace resource requirements and environmental impacts throughout a system (Hoekstra & van den Bergh, 2006).

The input–output framework has been used previously to estimate the system-wide implications of fuel consumption in one part of the DoD, representing either material requirements (in particular, fuel; Dubbs, 2011) or monetary implications (Hills, 2011).

Approach

In the current work, we are designing a practical tool that acquisition professionals can use that will capture requirements for multiple resources (including fuel, water, labor, and force protection) as well as monetary impacts. In addition, our tool seeks to capture the interacting effects of multiple types of supply, including both fuel and water, each of which is consumed in the provision of the other. The tool is based on an input–output model of a logistics network together with supporting organizations, and will therefore capture the resource demands of support including force protection and personnel, as well as the logistics associated with providing those resources to their points of consumption.

In addition, we are developing a method to construct, automatically, the necessary details about a logistics network based on scenario information that acquisition professionals may anticipate years before a system is eventually deployed.

Our approach addresses the following shortcomings of other FBCF/E estimation approaches:

- allocation of costs and resource requirements to multiple types of supply handled and/or to multiple downstream stages in the logistics network;
- the requirement to specify details such as the specific transportation or force-protection platform to be used in the scenario, details which are unlikely to be accurate when the system is actually operated years or decades later; and
- the lack of an input–output framework allowing the model to automatically allocate costs of the logistics network to different categories of supply and to fully capture higher-order resource demands.

In our approach, the user would be asked to specify scenario parameters that are likely to be anticipated during early-milestone acquisition analyses and that are the most important drivers of the FBCS.

In particular, the user will be required to specify the distance between the origin and destination(s), which are the locations of consuming or warfighting organizations, and something about the terrain separating them. The user can specify something as simple as what portion of the route will be over land and over sea, and predetermined planning factors will be used to specify the resource requirements associated with supply in each type of terrain. The user will also have the ability to adjust these planning factors to reflect potential scenario changes, such as increased efficiency of supply vehicles, or increased force-protection requirements.

Constructing the Network

A network-construction module takes inputs describing the origin and destinations of supply as well as parameters that determine the cost to transport supply along the route, and determines a network of depots and transport legs, as well as the distances and costs on each leg.

We are developing optimization-based algorithms to determine the network, assuming a self-sufficient organic logistics network. Depot and transport costs and fuel consumption and labor hours as a function of terrain are set according to standard planning factors or may be adjusted by the user.

The inputs are the (unique) origin and destination locations (i.e., the consuming organizations) and the amount per unit time of supply demanded at each, and they produce a network consisting of nodes (which represent depots) and arcs (which represent transport legs). Since the network structure of the logistics network is not exploited in later stages of the calculation, we will refer to both depots and legs as stages, and index them with s. Each stage has a fuel requirement and a cost (which excludes fuel) per unit of supply that passes through it.

Since we assume a single source of supply, the network construction algorithm produces a directed tree. This implies that each stage (except the origin) has a unique preceding stage, that is, each depot is preceded by its incoming leg, and each leg is preceded by its originating node. We denote stage s's preceding stage as $r(s)$.

In the simplest case, we consider a single source and a single destination, and determine the optimal locations for intermediate depots, in terms of minimizing the overall cost of meeting the demand. This set of optimal locations will always satisfy certain properties, which can be extended to the scenario in which there are multiple destinations. The solution to the single-destination scenario can also be extended to cases in which there are multiple terrains, or in which costs of force protection must be included.

The optimal network for a particular scenario will depend on the transportation vehicle(s) used. Two properties of the vehicle are especially relevant: its capacity, and its rate of fuel consumption. While small changes in these parameters are unlikely to lead to major changes in the optimal network, the choice of an entirely different type of vehicle (e.g., helicopters instead of trucks), may result in an extremely different network. In addition, operating, maintenance, and personnel costs may differ significantly between vehicle types.

Input–Output Analysis

Once the transportation network has been constructed, the tool will build an input–output model of the logistics network. An input–output model can be used to estimate the marginal system-wide resource (or monetary) requirements associated with fuel (or other supply) consumption anywhere in the logistics network.

An input–output model has the following features:

- sectors, indexed j, which transform a set of inputs into a single output[2];
- input (resource) requirements, i.e., a matrix of coefficient a_{ij} describing the amount of input from sector i required to produce a unit of input from j;
- proportionality assumption, i.e., the amount of input each input required per unit output is constant regardless of the amount of output from a sector, as reflected in the coefficient matrix;
- consuming sectors, that require inputs (described by a vector of a_{ij}'s) whose output is not used by other sectors;
- mass-balance assumption, i.e., the amount of output x_i required from (non-consuming) sector i is exactly sufficient to supply the other sectors, and

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[2] Note that in some formulations, multiple outputs from a sector are allowed, but an equivalent model can be built by defining a separate sector for each output.

$$x_i = \sum_{j=1}^{n} a_{ij} x_j, \forall i \in \{\text{non-consuming sectors}\} \qquad (1)$$

Building an input–output model requires first, defining the sectors, or unit of analysis, which determines the level of data that will be required to populate the model. Second, the model requires a populated matrix of the type shown in Table 1.

Table 1. General Input-Coefficient Matrix

			destination			
			sector			
			1	2	3	n
source	sector	1	a_{11}	a_{11}	…	a_{1n}
		2	a_{21}	a_{22}	…	a_{2n}
		…	…	…	…	…
		n	a_{n1}	a_{n2}	…	a_{nn}
		external	a_{X1}	a_{X2}	…	a_{Xn}

Depots and Transportation Legs

Each stage (whether depot or transportation leg) can handle different types of supply. Therefore, each stage s will be modeled as multiple sectors, each producing one output. The types of output are indexed c for commodity, for example, $c =$ fuel, $c =$ water, $c =$ other supply. We will denote a transportation-network sector either by the general sector index j, or by the pair (s, c).

Each stage has an input mix, where $\lambda_s^c =$ the amount of commodity c required by stage s per standardized unit of supply (in volume or weight), for all c. All supply is measured in standard units, and all supply vehicles can transport any type of supply, subject to a fixed capacity. Note that for $c =$ fuel, λ_s^{fuel} is determined by the network construction algorithm. If sectors $i = (s_i, c_i)$ and $j = (s_j, c_j)$, and $s_i = r(s_j)$, then

$$a_{ij} = \begin{cases} \lambda_{s_j}^{c_i} + 1 \text{ if } c_j = c_i \\ \lambda_{s_j}^{c_i} \text{if } c_j \neq c_i \end{cases} \qquad (2)$$

In addition to supply requirements, each stage will have associated operational resource requirements including personnel, and may include force protection. Therefore, additional sectors must be defined.

Consuming and Support Sectors

In addition to supply, sectors of any type (including consuming sectors) may require other inputs, such as force protection and personnel. Therefore, support sectors are defined whose outputs are in units of force protection (units reflecting intensity and duration will be defined) and personnel (in units of people × time), and others as needed.

Each depot has its own associated sectors for each type of support input. The modeling of a separate sector to provide each input to each depot reflects the fact that the system-wide costs associated with providing the same level of support differs by location (hence by depot). For example, the system-wide incurred costs associated with sustaining personnel will differ according to where the personnel are based; the differences may reflect both different direct support requirements (for example, housing in tents versus barracks, hot meals versus pre-packaged rations) as well as the logistics burden incurred to provide the supply.

The purpose of the logistics network is to sustain the warfighter, and the warfighting portion of the organization produces the DoD's final output, which is not an input into any other part of the organization. Each warfighting component that has a distinct input mix is modeled as a consuming sector. There are many consuming sectors for two reasons: (1) to allow for different input mixes for different warfighting components and (2) because of the different system-wide implications of inputs demanded at different locations in the logistics network.

A consuming sector j has an input mix, represented by a vector $\left[a_{ij}\right]$, and an output level x_j. The output level for consuming sectors is exogenous and is determined by warfighting demands; this is distinct from all other sectors, whose output levels are determined by the mass-balance equations that satisfy the input requirements of the rest of the sectors in the model.

Let the following denote a partition of the sectors: D= sectors representing depots; L= sectors representing transportation legs; S= sectors representing support organizations; and C= consuming sectors.

Each transportation leg receives its support inputs from the preceding depot, and each support sector gets its commodities from its corresponding depot. Supporting sectors associated with the same depot take their support inputs from each other. We will use the notation $s = r(j)$ to indicate that depot s is associated with sector j, for $j \notin D$. For $j \in D$, $s = r(j)$ is j's inbound transportation leg. Only depots take inputs from transportation legs. This means $a_{ij} = 0$ unless

$$\begin{gathered} i \in \{D, L\} \text{ and } s_i = r(j) \\ \text{OR} \\ i, j \in \{S\}, \text{ and } r(i) = r(j) \end{gathered} \qquad (3)$$

$$\text{if } i \in \{D, L\} \text{ and } s_i = r(j). \qquad (4)$$

Other features can readily be added to the IO portion model, including the possibility of acquiring supply from external sources at each depot.

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