NPS-LM-13-C10P05R01-059

EXCERPT FROM THE

PROCEEDINGS

OF THE

TENTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM LOGISTICS MANAGEMENT

Fully-Burdened Cost of Supply in Self-Sustaining Logistics Networks

Eva Regnier, Jay Simon, Daniel Nussbaum, Aruna Apte, and John Khawam
Naval Postgraduate School

Published April 1, 2013

The research presented in this report was supported by the Acquisition Research Program of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

To request defense acquisition research, to become a research sponsor, or to print additional copies of reports, please contact any of the staff listed on the Acquisition Research Program website (www.acquisitionresearch.net).

ACQUISITION RESEARCH PROGRAM
GRADUATE SCHOOL OF BUSINESS & PUBLIC POLICY
NAVAL POSTGRADUATE SCHOOL

Preface & Acknowledgements

Welcome to our Tenth Annual Acquisition Research Symposium! We regret that this year it will be a “paper only” event. The double whammy of sequestration and a continuing resolution, with the attendant restrictions on travel and conferences, created too much uncertainty to properly stage the event. We will miss the dialogue with our acquisition colleagues and the opportunity for all our researchers to present their work. However, we intend to simulate the symposium as best we can, and these *Proceedings* present an opportunity for the papers to be published just as if they had been delivered. In any case, we will have a rich store of papers to draw from for next year’s event scheduled for May 14–15, 2014!

Despite these temporary setbacks, our Acquisition Research Program (ARP) here at the Naval Postgraduate School (NPS) continues at a normal pace. Since the ARP’s founding in 2003, over 1,200 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 70 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 encourage your future participation.

Unfortunately, what will be missing this year is the active participation and networking that has been the hallmark of previous symposia. By purposely limiting attendance to 350 people, we encourage just that. This forum remains unique in its effort to bring scholars and practitioners together around acquisition research that is both relevant in application and rigorous in method. It provides the opportunity to interact with 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. Despite the fact that we will not be gathered together to reap the above-listed benefits, the ARP will endeavor to stimulate this dialogue through various means throughout the year as we interact with our researchers and DoD officials.

Affordability remains a major focus in the DoD acquisition world and will no doubt get even more attention as the sequestration outcomes unfold. It is a central tenet of the DoD’s Better Buying Power initiatives, which continue to evolve as the DoD finds which of them work and which do not. 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)
- Director, Acquisition Career Management, ASN (RD&A)
- Program Executive Officer, SHIPS
- Commander, Naval Sea Systems Command
- Program Executive Officer, Integrated Warfare Systems
- Army Contracting Command, U.S. Army Materiel Command
- Office of the Assistant Secretary of the Air Force (Acquisition)
- Office of the Assistant Secretary of the Army (Acquisition, Logistics, & Technology)
- Deputy Director, Acquisition Career Management, U.S. Army
- Office of Procurement and Assistance Management Headquarters, Department of Energy
- Director, Defense Security Cooperation Agency
- Deputy Assistant Secretary of the Navy, Research, Development, Test, & Evaluation
- Program Executive Officer, Tactical Aircraft
- Director, Office of Small Business Programs, Department of the Navy
- Director, Office of Acquisition Resources and Analysis (ARA)
- Deputy Assistant Secretary of the Navy, Acquisition & Procurement
- Director of Open Architecture, DASN (RDT&E)
- Program Executive Officer, Littoral Combat Ships

James B. Greene Jr.
Rear Admiral, U.S. Navy (Ret.)

Keith F. Snider, PhD
Associate Professor

Logistics Management

Fully-Burdened Cost of Supply in Self-Sustaining Logistics Networks

Eva Regnier, Jay Simon, Daniel Nussbaum, Aruna Apte, and John Khawam
Naval Postgraduate School

Platform Design for Fleet-Level Efficiency: Application for Air Mobility Command (AMC)

Jung Hoon Choi, Parithi Govindaraju, Navindran Davendralingam, and William A. Crossley
Purdue University

Improving DoD Energy Efficiency: Combining MMOWGLI Social-Media Brainstorming With Lexical Link Analysis (LLA) to Strengthen the Defense Acquisition Process

Ying Zhao, Don Brutzman, and Douglas J. MacKinnon
Naval Postgraduate School

Addressing Counterfeit Parts in the DoD Supply Chain

Jacques S. Gansler, William Lucyshyn, and John Rigilano
University of Maryland

Wave Release Strategies to Improve Service in Order Fulfillment Systems

Erdem Çeven and Kevin Gue
Auburn University

Issues and Challenges in Self-Sustaining Response Supply Chains

Aruna Apte, John Khawam, Eva Regnier, Jay Simon, and Daniel Nussbaum
Naval Postgraduate School

Lead Time Demand Modeling in Continuous Review Supply Chain Models

Barry R. Cobb, *Virginia Military Institute*
Alan W. Johnson, *Air Force Institute of Technology*

Improving Multi-Component Maintenance Acquisition With a Greedy Heuristic Local Algorithm

Sifat Kalam and Kash Barker, *University of Oklahoma*
Jose Emmanuel Ramirez-Marquez, *Stevens Institute of Technology*

An Internal, Demand-Side Approach Toward Implementing Strategic Sourcing:

Political, Legal, and Economic Considerations

John Fallon, *University of Maryland, University College*
Timothy Reed, *Beyond Optimal Strategic Solutions*

Optimizing Causes of Procurement Cost Through Strategic Sourcing: The Impact of Rate, Process, and Demand

Timothy Reed, *Beyond Optimal Strategic Solutions*
Michael E. Knipper, *United States Air Force*
John Fallon, *University of Maryland, University College*

Fully-Burdened Cost of Supply in Self-Sustaining Logistics Networks

Eva Regnier—Dr. Regnier is an associate professor of decision science at the Defense Resources Management Institute (DRMI) at NPS. 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. His research is in decision analysis. His main research focus is multi-attribute preference modeling, particularly involving outcomes which occur over time, space, or groups of people. His current and recent work includes a prostate cancer decision model, preference models for health decisions, preferences over geographical data, altruistic utility modeling, and multi-attribute procurement. He is an associate editor of the journal *Decision Analysis*. 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]

Aruna Apte—Dr. Apte is an associate professor of operations and logistics management in the Graduate School of Business and Public Policy at NPS. She has over 20 years of experience teaching operations management, operations research, and mathematics courses at the undergraduate and graduate levels. Her research interests can be categorized in three broad areas in the field of operations and logistics management: humanitarian logistics, service operations, and military logistics. She has worked as a consultant at MCI. She has advised emergency planners in preparing for disaster response. She is the founding and current president for a new college (focus group) in Humanitarian Operations and Crisis Management under the flagship of Production and Operations Management Society. [auapte@nps.edu]

John Khawam—Dr. Khawam is an assistant professor at the Naval Postgraduate School GSBPP and received his PhD from the Department of Management Science & Engineering at Stanford University in 2009. His thesis focuses on warranty inventory management in the presence of a reverse supply chain. He spent 2009–2010 as a postdoc at WHU, Otto Beisheim School of Management. He received his master's degree (2001) and BS (2000) from Cornell University's OR&IE Department. He worked at Lord & Taylor as an internal consultant, where he received Six Sigma training. He has also worked at Gap Inc., Eaton Corp., Allied Signal, and End-2-End Analytics. [jhkhawam@nps.edu]

Abstract

Cost estimates and other analyses for acquisition decisions should incorporate fully-burdened costs of the required commodities in the relevant planning scenarios. In addition to other widely recognized challenges associated with estimating fully-burdened costs of supply, standard approaches systematically produce underestimates for self-sustaining logistics networks. The disparity is especially pronounced when multiple commodities consumed by logistics activities are not locally available. This work develops a model for estimating

resource demands and overall cost associated with self-sustaining logistics networks, which can then be applied to specific examples.

Introduction

Analysis supporting acquisition decisions requires the calculation of fully-burdened costs of resources consumed by the systems being considered. This requires an assessment of planning scenarios under which the systems may be operated. In many cases, an important part of a planning scenario is the logistics network that supports the system. However, a Defense Science Board (DSB) task force was “unable to identify any case where the logistics reductions or deployment and sustainment enhancements achievable from improvements in platform efficiency were quantitatively included as capability improvements and factored into trade-off decisions” (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics [OUSD(AT&L)], 2008). This work is part of an effort to allow such factors to be included in a quantitative analysis supporting acquisition decisions.

We describe a logistics network as “self-sustaining” if one or more commodities consumed by the logistics activities are not locally available and must therefore be supplied via the network itself. These types of networks are common for operations in undeveloped or disaster-impacted regions. The costs associated with self-sustaining logistics networks are significantly higher than those of traditional logistics networks. Thus, traditional approaches to cost estimation for acquisition decisions tend to underestimate actual costs of operating systems in such environments. It is likely that the implications of the findings of the DSB task force are even more pronounced when the additional factor of self-sustainment is considered. The purpose of this work is to build a framework for estimating fully-burdened cost of supply (FBCS) in self-sustaining logistics networks.

Previous work has identified the existence of a “multiplier effect” for fuel in multi-stage self-sustaining networks. If the warfighter requires X gallons of fuel, some proportion of X is consumed by the preceding stage of the network, and thus some larger amount $X+\Delta$ is required at the start of this stage. The stage preceding that one will in turn consume some proportion of $X+\Delta$, resulting in an even larger requirement. This process continues all the way back to the beginning of the network, where the fuel requirement may be substantially greater than X gallons, depending on characteristics of the network. For more details on the multiplier effect, see Dubbs (2011); Regnier, Simon, and Nussbaum (2012); and Regnier, Simon, Nussbaum, and Whitney (2013).

The multiplier effect is even more pronounced when multiple resources consumed by the logistics activities are not locally available. For example, consider a network in which both fuel and water must be supplied via the network itself. If an additional 1,000 gallons of fuel are needed at the third stage of the network, this may require an extra convoy on the second stage. The extra convoy will not only consume additional fuel, but the additional personnel involved will consume water as well. Thus, the additional fuel requirement increases the requirements for both fuel and water at earlier stages of the network. A notional illustration of this phenomenon is shown in Figure 1. These interactions are not trivial and become larger and more complex if many different commodities must be transported through the logistics network.

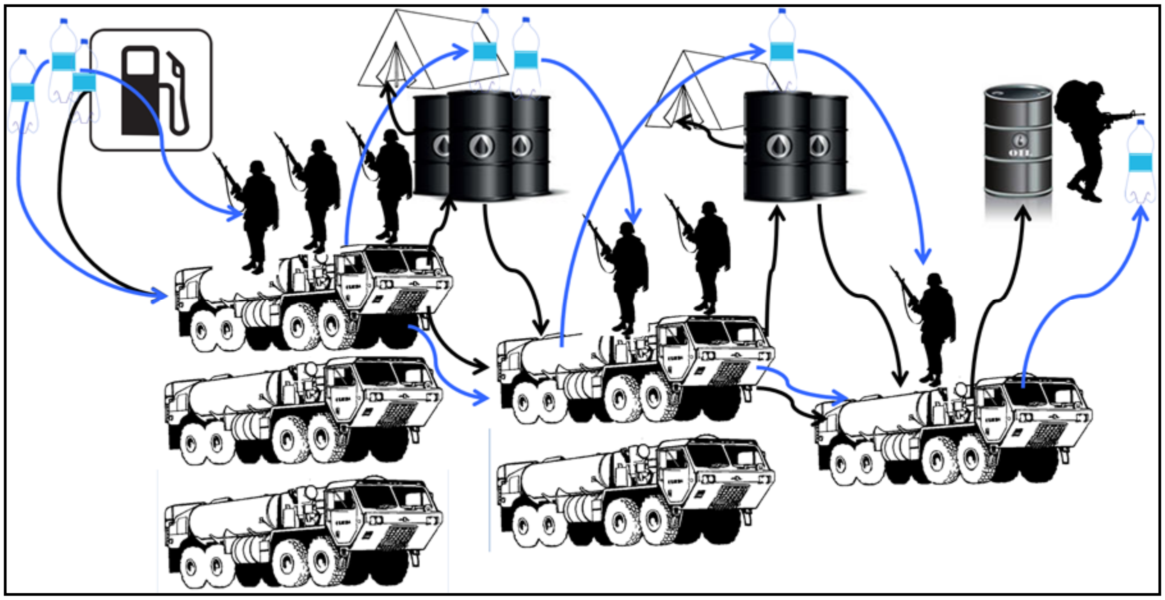

Figure 1. Illustration of the Multiplier Effects and Interactions Between Fuel Demand and Water Demand in a Self-Sustaining Supply Network

Table 1, reproduced from Regnier et al. (2013), illustrates the single-commodity fuel multiplier. In this example, a total of 1,794 gallons of fuel are required at the beginning of Stage 1 in order to transport and deliver 1,000 gallons of fuel to the end of Stage 3. Table 2 shows an example which is similar to that of Table 1, except that it includes two commodities. In this example, a total of 1,000 gallons of supply—fuel and water—are delivered to the end of Stage 3. The fuel requirements of each stage (as a percentage of the supply delivered) are unchanged, and the water requirements (as a percentage of supply delivered) are 90% lower than the fuel requirements. However, transporting either fuel or water requires consumption of both commodities. The total amount of fuel and water required in this example is 1,890 gallons, an increase of 5.4% relative to the Table 1 example, although the per-stage water requirements do not exceed 3%. This demonstrates the impact of multiple commodities on the operating costs of self-sustaining supply networks.

Table 1. Example of a Single-Commodity Self-Sustaining Supply Network
(reproduced from Regnier et al., 2013)

	Fuel Delivered (gal)	Fuel Consumption (% of delivered)	Operating Costs Non-Fuel	Operating Costs Fuel	Operating Costs Total	Total Operating Costs per Gallon Delivered
Stage 1	1560	15%	$3,120	$538	$3,658	$2.35
Stage 2	1200	30%	$2,400	$828	$3,228	$2.69
Stage 3	1000	20%	$2,000	$460	$2,460	$2.46
Total	1794	79%	$7,520	$1,826	$9,346	

Table 2. Example of a Two-Commodity Self-Sustaining Supply Network

	Fuel Delivered (gal)	Fuel Consumption (% of delivered)	Water Delivered (gal)	Water Consumption (% of delivered)	Total Resources Delivered	Operating Costs Non-Resource	Operating Costs Resource	Operating Costs Total	Total Operating Costs per Gallon Delivered
Stage 1	1466	15%	157	1.5%	1,623	$3,732	$616	$4,348	$2.97
Stage 2	1100	30%	120	3%	1,220	$2,806	$926	$3,732	$3.39
Stage 3	900	20%	100	2%	1,000	$2,300	$506	$2,806	$3.12
				Total	1,890	$8,838	$2,048	$10,886	

Note. The model in this example includes consumption of both fuel and water.

As we have noted previously, analyses of costs and requirements should not be conducted independently for each stage, because the resulting quantities are not additive. Similarly, analyses of costs and requirements should not be conducted independently for each commodity, because these resulting quantities are not additive either. Capturing the cross-commodity impacts for many commodities is difficult to do by estimating unit costs of delivery on each stage, especially as the number of commodities supplied via the supply network itself increases.

We have previously used input–output analysis to estimate fully-burdened costs of fuel (FBCF) in single-commodity supply networks, which can be found in the references given earlier in this section. This approach can be extended to include the types of cross-commodity impacts used in the example shown in Table 2. The general input–output approach was developed by Leontief (1970, 1986). Based on the previous application of input–output analysis to FBCF, this work expands the approach to estimate FBCS given any number of commodities in a self-sustaining logistics network.

Model

The multi-commodity FBCS model is presented in this section. Further details and derivations of results were given by Regnier and Simon (2013). The model examines one individual path through the logistics network. Let this path have *n* nodes. We refer to the stage which begins at node *i* and ends at node *i*+1 as stage *i*; the path has *n*-1 stages. We assume there are *m* different commodities transported on it, indexed by *c*. We also assume that all commodities can be expressed in the same units, whether by weight or by volume. The model includes the following parameters:

x_n^c - amount of commodity *c* needed at the destination (exogenously given requirement)

x_i^c - amount of commodity *c* required at node *i*

X_i - total requirement at node *i* . Note $X_i = \sum_{c=1}^{m} x_i^c$

d_i - distance of stage *i* (i.e., from node *i* to node *i*+1)

r_i^c - amount of commodity *c* consumed per unit distance on stage *i*

R_i - total consumption per unit distance on stage *i*. Note $R_i = \sum_{c=1}^{m} r_i^c$

α_i - number of personnel required on convoy in stage *i*

β_i - average speed on stage *i* (includes time spent loading and unloading)

w_i - total convoy capacity on stage *i*, including payload plus internal fuel tanks

a_i^c - amount of commodity *c* consumed at node *i* per hour of labor on stage *i*

A_i - total consumption at node *i* per hour of labor on stage *i*. Note $A_i = \sum_{c=1}^{m} a_i^c$

ϕ_i - operating & support cost per unit of distance for the convoy on stage *i* (i.e., vehicle depreciation, maintenance costs, and any similar costs not explicitly captured in consumption)

y_c - unit cost of purchasing/producing commodity *c* at the start of the supply chain (let y_L represent the cost of labor)

The values of these parameters will, of course, depend on the particular logistics network being analyzed. Many of the parameters are easily obtainable given a familiarity with the network. For example, if the convoy composition for a stage is known, several of the parameters are straightforward to compute.

Analysis

Two intermediate calculations are helpful before presenting any general results. The number of convoy round-trips K_i required on stage *i* can be expressed as

$$K_i \approx \frac{X_{i+1}}{w_i - 2d_i R_i} . \tag{1}$$

The denominator represents the total amount of commodities which can be delivered to node *i*+1 by the convoy on one round-trip. (This expression is an approximation because fractional round-trips are impossible; the size of the error is trivial if the number of round-trips is large.) The model allows for replenishment of logistics assets within a stage—the distance of a stage is not constrained by the internal fuel tank of a transportation asset, for example.

It will also be helpful to compute L_i: the number of labor hours required per convoy round-trip on stage *i*. It can be expressed as

$$L_i = \alpha_i \frac{2d_i}{\beta_i} . \tag{2}$$

Given K_i and L_i, it is possible to compute requirements for each commodity at each node:

$$x_i^c = x_{i+1}^c + \underbrace{2K_i d_i r_i^c}_{\substack{\text{amount of} \\ \text{resource } c \\ \text{consumed} \\ \text{in transport on} \\ \text{stage } i}} + \underbrace{a_i^c L_i K_i}_{\substack{\text{amount of} \\ \text{resource } c \\ \text{consumed to} \\ \text{sustain convoy} \\ \text{personnel} \\ \text{while at node } i}} \tag{3}$$

for $i = 1, \ldots, n-1$. This expression is recursive; the requirements at a given node are a function of the requirements at the following node. Given these relationships between requirements, the total FBCS for this path through the supply network is given by

$$\sum_{c=1}^{m} x_1^c y_c + 2\sum_{i=1}^{n-1} d_i \phi_i K_i + y_L \sum_{i=1}^{n-1} L_i K_i . \tag{4}$$

At the operational planning level, the above calculations are unlikely to be managerially relevant. Many costs included in ϕ_i (e.g., acquisition costs) are sunk. Even variable costs such as labor often cannot be influenced by operational logistics decisions in theater. Labor and other resources may be diverted from other tasks to logistics support, however. More important, at the strategic level, all costs are variable—they may all be influenced by decisions that affect the total end user demand (x_n^c) and efficiency of logistics (a_i^c, r_i^c, and ϕ_i).

The total FBCS estimate is intended to be used in strategic-level assessments of the magnitude of costs of supply to a particular area. However, being able to compute the overall FBCS also allows us to answer more specific questions about the impacts of acquisition decisions on total costs.

To build a framework for answering the types of questions relevant to acquisition decisions, we will introduce several concepts analogous to the fuel multiplier in a single-commodity network. One such concept is a *stage multiplier* Λ_i, which is expressed for any stage *i* as

$$1+\frac{2d_iR_i+L_iA_i}{w_i-2d_iR_i}. \tag{5}$$

The stage multiplier shows the increase in total requirement at node *i* per unit of increase in the total requirement at node *i*+1. Another helpful concept is a *cross-commodity factor* χ_i^c, which is expressed for any commodity *c* and stage *i* as

$$\chi_i^c=\frac{2d_ir_i^c+a_i^cL_i}{w_i-2d_iR_i}. \tag{6}$$

The cross-commodity factor shows the increase in the required amount of commodity *c* at node *i* per unit of increase in the amount of a different commodity required at node *i*+1.

Based on Equations 5 and 6, it is possible to construct a factor which captures such relationships across multiple stages, denoted as χ_{ij}^c. This factor is expressed as

$$\chi_{ij}^c=\sum_{i'=i}^{j-1}\left(\chi_{i'}^c\prod_{j'=i'+1}^{j-1}\Lambda_{j'}\right) \tag{7}$$

for any commodity *c* and nodes *i* and *j*, *i* < *j*. It indicates the increase in the amount of commodity *c* required at node *i* per unit increase in the amount of a different commodity required at node *j*. Note that Equation 7 expresses the relationship between the consumption of a commodity at a given node with the requirement of any other commodity at any other node. In particular, when *i* = 1, Equation 7 shows the additional amount of commodity *c* needed at the beginning of the supply network, which can be used to determine the impact on total cost. Further details and mathematical results were given by Regnier and Simon (2013).

For example, consider a new platform which decreases the warfighter's fuel requirement by Δ gallons. The cost savings resulting from a decrease in the FBCS would be given by

$$\sum_{c=1}^{m} y_c \chi_{1n}^{c} \Delta . \quad (8)$$

These savings are in addition to the savings achieved as a result of not consuming those Δ gallons of fuel themselves, which would be equal to Δ multiplied by the per-gallon market price of fuel at the start of the network.

Discussion and Conclusions

The model given above applies to any mode of transport and can model multi-modal logistics networks—for example, a sea-based stage, followed by ground transportation, followed by air delivery. However, there are some important systematic differences by mode. In Regnier et al. (2013), we provided a model of ground-based transport, in which each stage's resource requirements are determined by the distance and the composition of a logistics convoy. This model is single-commodity but nevertheless highlights the fact that land-based stages are highly sensitive to variations in terrain and infrastructure that are less relevant to air and sea-based stages. Relative to sea-based transport, the assumption of a large number of round-trips is more appropriate. In addition, because the payload of each vehicle is much smaller than the payload of a vessel, convoy composition for land stages is more flexible and can be tailored to specific commodity requirement distribution, which supports treating commodities as interchangeable.

Based on the methods in this work, Hathorn (2013) developed a model for fully burdened costs of supply in a naval supply network under different possible threat scenarios. The complete network is shown in Figure 2, reproduced from Hathorn's paper. The models presented previously can be applied to any individual route through this supply network. In Hathorn's model, force protection is an important consideration; multiplier effects and interactions between commodities are much more significant when force protection vehicles are required in addition to transportation vehicles. In the network being studied, fuel is the commodity that has by far the highest level of consumption—over 95%. However, other commodities such as stores and ordnance are included as well.

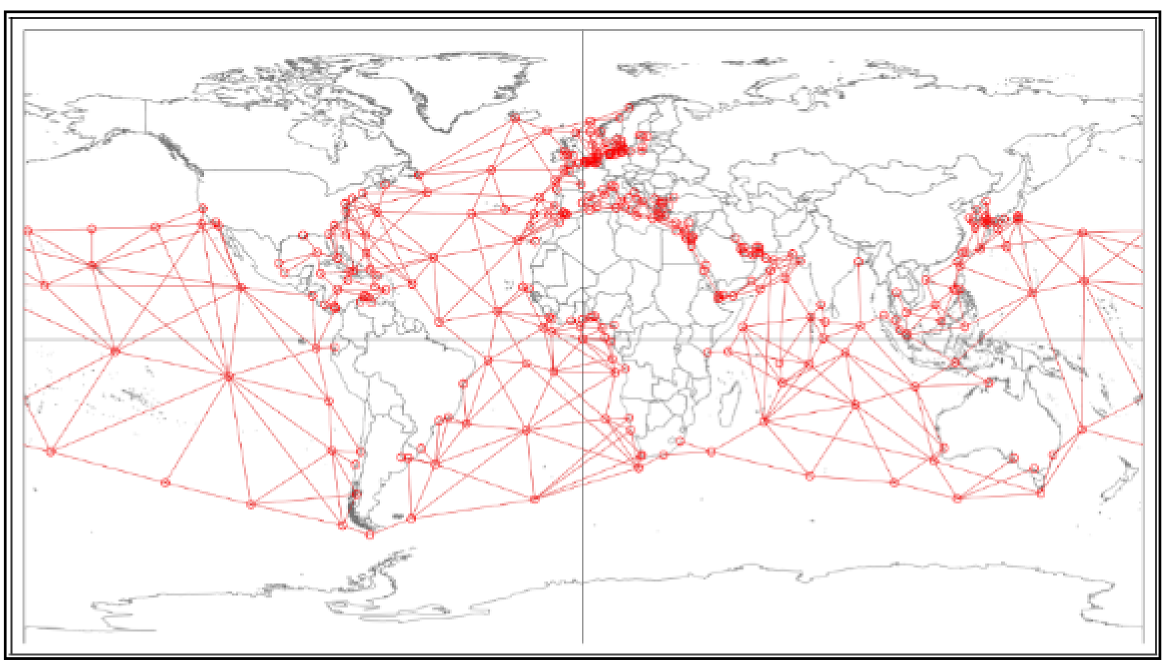

Figure 2. The Nodes and Arcs of a Global Naval Supply Network

(reproduced from Hathorn, 2013)

Hathorn also demonstrated that the FBCS model can be valuable in supporting other types of decision problems. In particular, it allows for route selection decisions to be made with more complete information about costs. Hathorn introduced an optimization model for route selection which determines how to provide a given amount of supply to a specified location at minimum (fully-burdened) cost. Constraints may be added to the optimization model based on the current environment; for example, there may be scenarios in which certain arcs in the network are unavailable.

As an example, Hathorn analyzed a supply route from San Diego to the Spratly Islands. An illustration of this supply route is shown in Figure 3, reproduced from Hathorn (2013). Depending on threat level and convoy composition, the total cost per short ton of supply delivered to the destination ranges from $1,638.70 to $3,144.47. When developing planning scenarios to support decision-making, it is important to consider the possibility of both high-threat and low-threat environments, as the associated fully-burdened costs of supply can be extremely different.

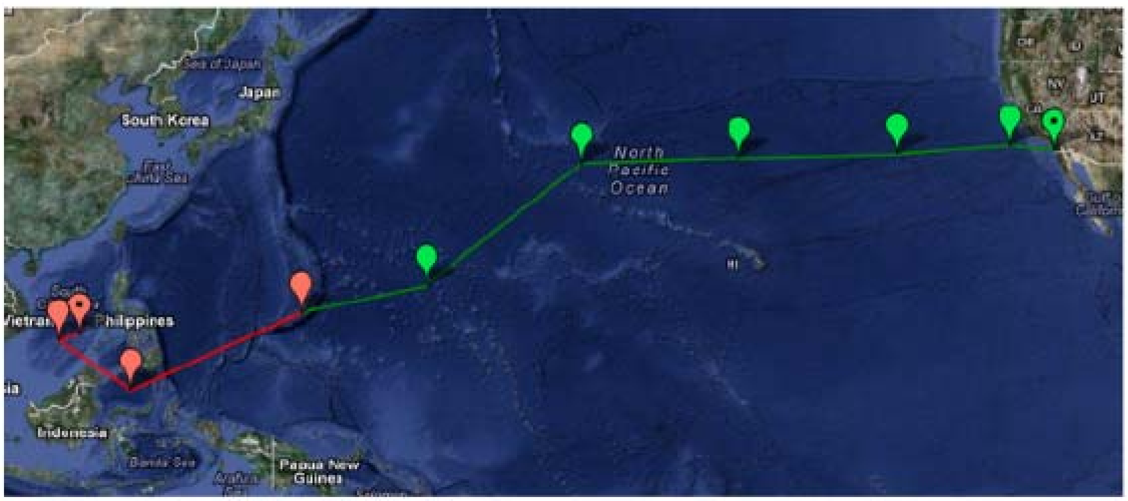

Figure 3. A Possible Supply Route From San Diego to the Spratly Islands
(reproduced from Hathorn, 2013)

Hathorn's work highlights the importance of considering ammunition requirements of the logistics network in a high-threat environment. Consumption of ammunition during force-protection may be considered a requirement—rather than a choice—driven by the threat and thus might reasonably be modeled using planning factors. However, there could be a very wide range of assumptions about the appropriate ammunition consumption rate (parameter r_i^c for *c* = ammunition). In addition, ammunition requires specialized transportation assets, and different kinds of ammunition have very different requirements (cruise missiles vs. anti-submarine torpedoes). Modeling their demand by the warfighter and logistics ammunition requirements in planning scenarios during acquisition is an important but challenging problem.

References

Dubbs, S. R. (2011). *Estimating the fully burdened cost of fuel using an input–output mode: A micro-level analysis* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA.

Hathorn, B. (2013). *Resource burden of logistics to Navy ships under threat scenarios* (Unpublished master's thesis). Naval Postgraduate School, Monterey, CA.

Leontief, W. (1970). Environmental repercussions and economic structure—Input–output approach. *Review of Economics and Statistics, 52*(3), 262–271.

Leontief, W. (1986). *Input–output economics* (2nd ed.). New York, NY: Oxford University Press.

Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (OUSD[AT&L]). (2008). *Report of the Defense Science Board Task Force on DoD Energy Strategy: More fight–Less fuel.* Retrieved from http://www.acq.osd.mil/dsb/reports/ADA477619.pdf

Regnier, E., & Simon, J. (2013). *Self-sustaining multi-commodity supply chains* (Working paper).

Regnier, E., Simon, J., & Nussbaum, D. (2012). *Estimating logistics burdens in support of acquisition decisions* (NPS-AM-12-C9P24R01-091). Retrieved from Naval Postgraduate School, Acquisition Research Program website: http://www.acquisitionresearch.net/files/FY2012/NPS-AM-12-C9P24R01-091.pdf

Regnier, E., Simon, J., Nussbaum, D., & Whitney, L. K. (2013). *The fuel multiplier in multi-stage supply chains*. Under review.

ACQUISITION RESEARCH PROGRAM
GRADUATE SCHOOL OF BUSINESS & PUBLIC POLICY
NAVAL POSTGRADUATE SCHOOL
555 DYER ROAD, INGERSOLL HALL
MONTEREY, CA 93943

www.acquisitionresearch.net