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THE IMPACT OF FASTSHIP AND HIGH SPEED SEALIFT ON STRATEGIC SEALIFT

by

Shawn M. Callahan, LCDR, USN

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Advisor: CDR Robert Threlkeld

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Preface

The issue of military high speed sealift has gathered momentum over the course of the last few years. I first became aware of the interest while serving on the OPNAV staff as a mission analyst. Interest grew when a paper was presented at the 1998 Military Operations Research Symposium in Monterey, CA. The idea of modeling the impact of FASTSHIP grew out of a spreadsheet-based decision analysis course of instruction. While this paper does not attempt to offer a rigorously complete, final solution, it is hoped that it will serve as the foundation for future efforts in this direction and can be used a quick reference for future decisions.

I would like to acknowledge the much appreciated guidance and assistance provided by CDR Robert Threlkeld during the course of the paper. Palisade Corporation also deserves a note of thanks for making available a free trial version of their EVOLVER Genetic Algorithm without which, fractional ships would still rule.

Abstract

The commercial sealift industry is breaking free of the constraints of traditional hull designs that characterize present vessels. Several alternative designs are being developed to fulfill the need for high speed, heavy payload capable, long distance transportation. One such design, FASTSHIP is thought to be capable of speeds of 45 knots, carrying 8000 long tons, over 5000 nautical miles. This paper uses a combination of spreadsheet based linear programming (LP) and genetic algorithms (GA) to find the best mix of a military application of FASTSHIP's capabilities in strategic sealift. Using data and requirements from past Mobility Requirements Studies (MRS), the Excel based Sealift Optimization Model finds a minimum Net Present Value (NPV) cost mix of sealift ships needed to meet given requirements of cargo and containers within a specified time period subject to several constraints. Various acquisition methods are explored in the determination of cost to include buy, lease, and joint commercial use. Analysis of the model output validates that the current sealift mix is sufficient, however FASTSHIP may provide added capability to meet increased requirements at a cost with a commercial joint venture offering the least cost solution, especially if the Ready Reserve Force (RRF) is allowed to decrease.

Chapter 1

Introduction

As we have always done, we keep the vital seaborne logistics pipeline flowing…

—Admiral Jay Johnson, CNO

Problem Statement

Operation Desert Storm highlighted the importance of and problems associated with moving material, equipment, and personnel across vast distances in support of national and international objectives. While figures vary somewhat, it is generally accepted that strategic sealift assets delivered about 95% of the equipment and supplies required by American war plans. While steps have been taken to improve lift capabilities and performance since Desert Storm, no significant technological leap has aided this ongoing effort. While additional sealift ships have been procured and improvements have been made to existing ships, the capabilities of these ships has remained roughly constant in terms of cargo handling, capacity, and speed. A combination of various external limitations have kept a tight reign on some aspects of improvements such as port depths and canal size restrictions, however speed has increasingly been a target for improvement. Several research and development efforts have produced tangible advances in the area of high-speed transport. Surface effect ships, hydrofoils, planing hulls and wingships all have shown some degree of promise in solving this dilemma. However the commercial viability of such generally small displacement projects have been extremely limited, thus production costs have been prohibitive. The market for overseas medium cost/medium speed (compared to high cost/high speed air delivery and low speed/low cost traditional seaborne delivery) cargo delivery has not materialized just yet. Proposals to meet this demand have been offered by commercial enterprises such as FASTSHIP Atlantic. The FASTSHIP design incorporates a semi-planing monohull that hopes to maintain relatively high gross tonnage capacity while delivering significantly higher transit speeds. The military value of such a craft is its ability to quickly deploy and support forces abroad, thus multiplying the deterrent effect of U.S. based assets.

Purpose

The rational behind investigating the continuing development of high-speed sea based transportation options are twofold. First, as the military continues to evolve, attempting to discover the next revolution in military affairs (RMA) remains a priority. The Army in particular is very interested in trimming itself down to better react to the post Cold-War strategic environment. This means lighter forces with quicker deployment times. A leap in deployment reaction time possible through high-speed sealift ships greatly increases both actual effectiveness and the deterrent effect. Secondly, the military would be remiss if it failed to capitalize and leverage the research and development associated with commercial industry improvements in this somewhat neglected area of warfare. Through measuring the benefits and costs of this technology and reviewing a variety of options associated with high speed sea-based transportation, the military may be able to realize a significant improvement in strategic lift. The ultimate goal is to provide senior level decision-makers a quick and straightforward means to evaluate and prioritize future sealift recapitalization alternatives.

High Speed Sealift Background

Various ship designs have been built over the past decades that reduce hull displacement, coupled in some cases with new forms of motive force; these vessels have attained speeds in excess of sixty knots. A quick summary of several new and not so new technologies follows:

Hydrofoils. Ships of this type achieve greater speeds by riding on a pair of winglike extensions. New designs of this type employ front and rear extensions to create greater lift. Speeds of seventy knots may be attained with current technology.[1]

Surface Effect Ships (SES). Vessels of this type employ a cushion of air beneath the craft to essentially float over the water. While this is not quite a flying boat, these craft do have shallow drafts and can attain speeds of fifty knots.

Wingships. Watercraft of this type take the concept of SES to the next step, they are in effect small flying ships that fly just above the water surface. Tested by the Russians in the 1970's, these hybrid air/sea craft were capable of speeds of nearly three hundred knots.[2]

Small Waterplane Area Twin Hull (SWATH). Ships of this type employ multiple hulls and with a series of connecting above the waterline interior spaces to significantly reduce drag while providing superior stability. While not as shallow drafted as SES, SWATH hulls have attained speeds of over fifty knots.[3]

Semi-Planing Monohulls. Ships of this type exploit their unique deep, V-shaped bow hull design to create lift at the stern. Coupled with water jet propulsion this ship can carry heavy loads, with great stability at speeds up to 45 knots.[4] Due to its greater capacity, seakeeping ability, and speed, this design offered by FASTSHIP Atlantic may hold the greatest current near-term potential for military sealift applications. Due to these advantages FASTSHIP was chosen to be the model for future high speed sealift capabilities throughout the rest of this paper.

Methodology

While a significant body of work has examined the question of a proper mix of strategic lift forces, much of this effort has focused on present capabilities. Attempts to arrive at high-speed sealift solutions have been ongoing, however the majority of this effort has not progressed beyond the research and development stage. Current technology appears ready to make the breakthrough to a reasonably priced, significantly faster alternative. The goal of this body of work is to merge a FASTSHIP type craft into the current sealift mix in order to determine value versus projected costs. Logistics and lift data is extensive in the light of Desert Storm, several studies have attempted to answer the mix problem, perhaps most notable among these are the Mobility Requirements Studies and its Bottom-up-Review companion. Using the requirements set forth in these studies and U.S. Transportation Command planning estimates, this paper intends to compare and contrast a sealift force with high-speed capabilities to one without. Several ongoing analyses sponsored by OPNAV N-42 will be the basis for an aggregate spreadsheet based optimization of asset use to meet projected requirements. Alternate procurement approaches will be used as cost estimates using net present value calculations to determine a possible appropriate capital investment strategy. The end result of this analysis is to arrive at some conclusions regarding costs and benefits to aid in future recapitalization decisions.

The overwhelming majority of material is available from existing texts on strategic mobility, professional articles and research papers, and Department of Defense sponsored studies. The difficulty is to pair down the body of work available to support very specific questions regarding force structure and cost estimates. A second difficulty involves estimating the technical feasibility and commercial viability of these unproven ship designs. Design models and theoretical computations may be biased, depending on the source of the data. Manufacturers optimistic figures must be balanced against the pessimistic view of the American taxpayer. A number of assumptions must also be rationalized as this research progresses to keep the main focus intact while providing sufficient realism necessary to maintain relevance.

Notes

[1] Robert Toguchi and Joseph Gerard, "Strategic Maneuver in 2020" (paper presented at the Military Operations Research Society Symposium, Monterey, CA, 24 June 1998).

[2] Bradley Olds, "The Impact of Wingships on Strategic Lift" (master's thesis, Naval Postgraduate School, September 1993), 2.

[3] Toguchi and Gerard.

[4] David Giles, "Faster Ships for the Future," *Scientific American*, October 1997, n. p.; on-line, Internet, 18 September 1998, available from http://www.sciam.com/1097issue/1097Giles .html.

Chapter 2

Historical Overview

> *Victory is the beautiful, bright-colored flower. Transport is the stem without which it could never have blossomed.*
>
> —Winston Churchill

Strategic sealift is the responsibility of the Navy’s Military Sealift Command (MSC), working under the U.S. Transportation Command (TRANSCOM). The roots of sealift go back well beyond the creation of these recent command structures. Admiral Alfred Thayer Mahan described logistics as the “essential ingredients to a successful maritime strategy” advocating the forward basing of materials ashore.[1] World War II saw the high point of U.S. sealift capability as the country sustained combat forces around the world with a robust merchant marine fleet.[2] More recent history saw the buildup of the military during the 1980’s. As the military grew so did the strategic sealift force meeting a twofold dilemma. In order to support the culmination of Cold War force structure, providing reinforcements to Central Europe was central to a credible campaign. Secondly the acquisition of sealift forces provided a quick solution to the dwindling number of U.S. flagged merchant marine ships.[3] With a sizable strategic sealift force in being the stage was set for a harsh test of its ability to answer the call, Desert Shield and Desert Storm.

Desert Storm—Background and Lessons Learned

Saddam Hussien's invasion of Kuwait set in motion the largest military logistics operation since the end of the Vietnam War. While the problem certainly could have become more difficult given less time and increased opposition to sea-based lines of communication, the undertaking was no easy task.[4] Between August 1990 and March 1991, U.S. strategic lift resources transported over ten million tons of cargo nearly 8500 miles.[5] This total represented more than 95% of the cargo delivered to the theater which is generally in accordance with planning estimates.[6] While this is an impressive accomplishment it must be noted that this endeavor included a few failures. Of the eight Fast Sealift Ships (FSS) tasked to respond on C-day and C+1, one ship was one day late, another was three days late, while a third was in overhaul and responded nine days late. Enroute, one FSS suffered a series of boiler casualties and was diverted into Rota, Spain for repairs.[7] The first wave of the FSS averaged only 23 knots, well below their advertised maximum speed of 33 knots, thus adding five days to the transit.[8] Activation of the RRF began on C+3 with 17 ships being called despite their maintenance condition.[9] A total of 44 ships were activated through C+12. Their activation performance was below par with about 25% on time and about 50% over five days late. During the second phase of activation beyond C+119 an additional 26 ships were activated with even worse performance as only four were on time and over 50% over ten days late.[10] The majority of the problems associated with these delays were the poor condition of the propulsion plants, rusted machinery, and shortages in qualified crews to man the ships.[11] Due to the limitations of the RRF and the pressing timeline, chartered ships were hired from a variety of locations to include foreign flagged ships. In fact, the majority of charted ships were foreign flagged, as they were the most readily available and cost effective means of transportation.[12] Reasons for their use were clear; Roll-on/Roll-off ships (RO/ROs) were the preferred option and the RRF had only 17; the RRF was proving slow; qualified crews were difficult to obtain; and perhaps most important of all they were cheaper. The cost per day for a foreign flagged RO/RO was about $23,000 while an RRF RO/RO cost nearly twice that amount with an additional activation and deactivation price tag that was on the order of $2 million.[13] Clearly a shortfall existed in the readiness and availability of the U.S. sealift to meet the requirements of an operation the size of Desert Shield/Desert Storm. The following paragraphs will describe the sealift assets involved and take a look at the military's response to articulate the shortfalls in the war through a series of studies.

Strategic Sealift Assets

Existing sealift programs can be divided into two general categories: government controlled and U.S. flag commercial ships. Government controlled ships include both active ships controlled by the Military Sealift Command (MSC) and inactive ships maintained by the Maritime Administration (MARAD).

Maritime Prepositioning Ships (MPS). MPS consists of three squadrons of four to five ships that carry 30 days of supplies for a Marine expeditionary brigade (MEB). Manned and operated under charter to MSC, these ships are based overseas and are available to sail to a crisis on short notice.[14] MPS are planned to deliver initial heavy supplies arriving by C+14 thereby mitigating early risk.[15]

Afloat Prepositioning Ships (APS). APS are the MPS equivalent for the Army and Air Force; these 12 ships supply critical ordnance, supplies, and port operating equipment. Like MPS they are chartered by MPS, and planned as sustainment for early arriving forces.[16]

Fast Sealift Ships (FSS). These ships were purchased in 1983 and subsequently converted to RO/RO ships. Maintained by partial crews, they are planned to sail within four days of notice at speeds of up to 33 knots to provide surge mobilization of equipment and supplies for a heavy Army division.[17]

Ready Reserve Force (RRF). The RRF is a fleet of 91 military useful ships that includes 31 RO/RO ships, 29 breakbulk ships, and an assortment of other tankers, cranes, and heavy lift ships. In peacetime, these ships are maintained in a non-operational status under the control of MARAD with planned activation times varying from five to twenty days.[18]

Commercial Charter. In addition to the resources listed above, MSC can charter additional ships from the civilian fleet to meet shortfalls and respond to contingencies. The availability of these ships is hard to predict and the cost associated may be predicated on the losses the owner may incur from the lost opportunity cost associated with profitable commercial cargo. The search for potential solutions to this availability and cost problem has led to the creation of subsidy programs such as Voluntary Intermodal Sealift Agreement (VISA) and National Defense Features (NDF) which pay for priority service similar to the Civil Reserve Air Fleet (CRAF) program.

Mobility Requirements Studies

Due in part to the problems encountered during Desert Shield/Desert Storm the Department of Defense was tasked to generate a mobility strategy to account for future requirements. The resulting Mobility Requirements Study (MRS) determined that future plans must include the capability to deploy to meet two objectives. An early risk period was defined as approximately two weeks and a late risk period was defined as lasting up to eight weeks.[19] Each of these periods had defined forces that required lift, thereby generating a specified capacity to be delivered by a combination of air and sealift assets. Based on these planning figures the DOD concluded that strategic lift capability needed to be increased. Specific recommendations for the sealift portion included:

- The lease of two additional container ships.
- The acquisition of 20 large, medium-speed roll-on/roll-off ships (LMSRs) with nine used as prepositioning ships.
- The prepositioning of two million square feet of Army equipment on the nine LMSRs, with the remaining eleven LMSRs to be placed in a. reduced operating status (ROS) to provide three million square feet of surge capability.
- The expansion of the RRF to 142 ships with increased readiness.[20]

Critique and refinement of U.S. deployment capabilities continued beyond the MRS. Changes to MRS recommendations based on new assumptions were the subject of testimony before the House of Representatives Committee on Armed Services in the following years.[21] A follow on MRS was completed three years later as part of the Bottom-up Review (BUR). This update known as the MRS BURU reaffirmed and validated the previous study's acquisition recommendations, but put more emphasis on prepositioning assets. Modifications are shown below:

- Shift one LMSR or two RRF RO/ROs from surge to prepositioning role.
- Reduce the RRF dry cargo ships from 104 to 65.
- Established a requirement for ten million square feet of surge sealift by 2001.[22]

The integrated sealift plan recommended by the MRS BURU remains the cornerstone of sealift planning today. The following section details the changes that have been made to date to comply with the guidelines set down from these studies.

Recent Changes and Enhancements

In accordance with the recommendations from the MRS BURU, MSC operates a force of 54 ships that include 31 prepositioning ships, six dry cargo ships, seven tankers, eight FSS, and two hospital ships. MSC also updated the Readiness Operating Status (ROS) system to make it more responsive, conducting availability tests to measure "true" readiness.[23] The construction and conversion of LMSRs continues with three LMSR new construction contracts awarded and five conversions being completed to expand prepositioning capability to allow for the return of seven RO/RO to the surge fleet. One shortfall is in the area of RO/RO ships in the RRF. Only 31 of 36 ships are projected by the year 2001. A number of strategies are being examined to resolve this discrepancy to include NDF and VISA contracts as well as modifications to existing RO/RO ships.[24]

Summary

The military was not fully prepared to meet the logistics sealift challenge posed by a full mobilization during the Gulf War. Military planners learned the lessons of Desert Shield/Desert Storm and have identified the required forces that need lift during a contingency; thereby setting planning factors for the acquisition community to size the sealift force. The two Mobility Requirement Studies made concrete recommendations that have been reinforced by the Chairman of the Joint Chiefs of Staff (CJCS) as requirements to be met by service acquisition plans. While not quite there yet, the military has made great strides to ensure sufficient sealift will be available to meet the next such occasion. The advent of the next MRS may well change the requirements that define sealift requirements. Future lighter forces may require less equipment and new crises may require faster timetables of response. The next section takes a look at new concepts of ship design that may change our present sealift calculus.

Notes

[1] Philip A. Crowl, “Alfred Thayer Mahan: The Naval Historian,” in *Makers of Modern Strategy from Machiavelli to the Nuclear Age,* ed. Peter Paret. (Princeton: Princeton University Press, 1986), 460.

[2] Pamela J. Whiting, “Sealift in the 21st Century: An Examination of Affordability Versus Military Risk of Two Sealift Options” (master’s thesis, Naval Postgraduate School, June 1994), 7.

[3] Barbara J. Scheidt, “A Force Structure Analysis of Strategic Sealift: How Much is Enough?” (master’s thesis, U.S. Army Command and General Staff College, 1994), 62.

[4] David Kassing, “Strategic Mobility in the Post-Cold War Era,” in *New Challenges for Defense Planning,* ed. Paul K. Davis, (Santa Monica, CA: RAND, 1994), 672.

[5] Basil B. Bates, “U.S. Strategic Sealift Capability in 1994: Is it Ready For the Threat?” (unpublished research paper, Naval War College, February 1994), 6.

[6] Jon Kaskin, “Future of Strategic Sealift,” brief, Air University, Maxwell AFB,AL, 7 August 1998.

[7] Center for Naval Analyses, *Sealift in Operation Desert Shield/Desert Storm: 7 August 1990 to 17 February 1991*, Research Memorandum 91-109 by Ronald F. Rost, John F. Adams, and John J. Nelson, (Alexandria, VA: CNA, May 1991), 28.

[8] Scheidt, 68.

[9] Douglas Menarchik, *Powerlift – Getting to Desert Storm.* (Wesport, CT: Praeger Publishers, 1993), 103.

[10] Center for Naval Analysis, 29.

[11] Scheidt, 69.

[12] Ibid., 30.

[13] Ibid., 31.

[14] Whiting, 10.

[15] Kaskin.

[16] Whiting, 11.

[17] Scheidt, 24.

[18] Center for Naval Analysis, 11

[19] U.S. Joint Chiefs of Staff**,** *Mobility Requirements Study (MRS), Vol. 1(U)* (Washington, DC: January 1992), ES-3.

[20] Ibid., ES-5.

[21] Norman Rabkin, Testimony before Subcommittee on Readiness, Committee on Armed Services concerning *Strategic Mobility: Serious Problems Remain in U.S. Deployment Capabilities* (Washington, DC: U.S. General Accounting Office, April 1994).

[22] Kaskin.

[23] Gust W. Pagonis, “Optimizing Strategic Sealift” (master’s thesis. Naval Postgraduate School, September 1995), 11.

[24] Kaskin.

Chapter 3

New Concepts in Commercial Transportation

As international trade continues to blossom, the demand for a means to transport large amounts of cargo at a moderate price continues to grow. Currently the two most popular methods of commercial cargo transportation are via air or sea. The obvious advantage of air transportation is its speed. However, this luxury comes at a price, approximately 10 times the cost of conventional seaborne delivery.[1] Sea based transportation on the other hand is notably slower, on the order of 1/30th the speed of modern transportation aircraft. The gap that has yet to be filled in this profit driven area is that of moderately priced and moderately fast modes of cargo transportation. Modern naval architects have been and continue to look for ways to provide just this capability. Recent small-scale successes have been encouraging but their application has been limited to special cases. A brief description of the problems that must be overcome is discussed in the following section.

Past Limitations

The history of transporting people and various cargoes via ships goes back many centuries. From oars to the days of sail, from the giant coal driven engines to modern day gas turbines, ship propulsion has come a long way. However, certain natural principles have held designers and architects at bay. The nature of the problem involves the interaction of the ship and its liquid medium. As a ship passes through the sea it displaces the water around it creating disturbances.

As speed increases these disturbances combine to form destructive interference of a sort causing the stern to “sink” in relation to the rest of the ship thereby increasing drag. William Frounde formally expressed this phenomenon first in the 1800s, he noted that the maximum speed of a ship varies with its displacement and length.[2] The problem then has become one of attempting to bypass this naturally occurring limitation technically known as a captive wave.

New Technology in Design

Obvious solutions to overcoming or lessening the effects of captive waves included increasing the length of the ship, decreasing volume or displacement, and increasing engine power. Each solution has its inherent drawbacks, long, slender ship’s seakeeping ability suffers in anything but relatively calm seas, lesser displacement ships cannot carry a significant amount of cargo, and the cost of dramatically improved engine performance is prohibitive. Nevertheless, ship designers continue to challenge this barrier in much the same way aircraft designers tackled the leap to supersonic air travel[3]. As discussed in the introduction, there are several noteworthy designs that have useful applications. Hydrofoils and SES craft have been used as ferries in the commercial world as well as military applications as fast patrol craft (The U.S. Navy’s Pegasus class) and amphibious ship-to-shore transport (LCAC – Landing craft, air cushioned). While these vessels are useful in their own right, they are not suited to a cost effective means to transport large amounts of cargo. Two recent technical breakthroughs in the area of propulsion and hull design offer hope in the quest to “break the sound barrier.” Water jets use spinning turbine blades to produce high-pressure water streams that propel the ship. Unlike propellers, water jet performance does not decrease with speed as cavitation or the formation of destructive air bubbles does not occur due to increased pressure beneath the hull.[4] The second breakthrough is coupled to the first. New hull designs were required to take advantage of the unique properties of water jet propulsion. Multihulls and semi-planing monohulls were the products of this effort. Multihull craft show some promise, but their smaller hulls and spanned decks may not have the strength to handle heavy cargo loads. FASTSHIP uses the semi-planing monohull concept combined with water jet propulsion as described in the following paragraph.

FASTSHIP

FASTSHIP has a deep V-shaped bow combined with a shallow, concave shaped underwater stern. The planing action occurs as the ship gains speed, causing the waveform to dynamically lift the stern, thereby decreasing drag and increasing stability.[5]

Capabilities

Preliminary designs of FastShip Atlantic, the licensed patent holder, have the following characteristics:

• Speed	45 knots
• Length	774 feet
• Payload	8070 long tons or 1360 twenty-foot equivalent containers (TEU)
• Propulsion	Eight GE LM6000 gas turbine engines with five water jet propulsors[6]

Costs and Net Present Value

Cost estimates for a ship of this variety vary greatly. An analogy offered by the one of the designers, David Giles of the firm Thornycroft, Giles & Company, likens FASTSHIP to the early days of commercial air transportation. He notes that it will be expensive at first, but just as customers flocked to the early jet aircraft because of their speed, capacity, and reliability, so will they to FASTSHIP.[7] As customers demand more, economies of scale will help drive down costs in both construction and fares.

For the purposes of this paper three options will be explored as means to access the capabilities of FASTSHIP. The first option is a straightforward idea of purchasing the ship through new construction. The second and third alternatives are creative options that hope to retain the ship at a lesser price, or spread the cost over many years. All alternatives will be evaluated using the financial concept of net present value (NPV). NPV takes into account the time value of money, thereby discounting future expenditures by a predetermined discount rate. In this case NPV compares total negative cash flows at an inflation adjusted constant rate of 2.5% annually.

Buy. As stated earlier cost estimates for FASTSHIP vary widely. The low end of the spectrum represented by steady state production under high demand may be as low as $200 million apiece.[8] Examining recently completed sealift ships and current projections for new construction projects may make more likely estimates. The large, medium-speed roll-on/roll-off ships (LMSRs) recently acquired were priced at $309 million apiece in 1995.[9] Cost estimates for the Auxiliary Dry Cargo Carrier (ADC(X)) were in the vicinity of $496 million in 1996.[10] Since both of these projects were conventional hull designs with conventional propulsion their expected cost would be substantially less than a new design with more power. An additional data point from a companion SES design of smaller dimensions estimated an average cost of $457 million in 1988.[11] Adjusted to year 2000 dollars, a steady state estimate of $600 million per FASTSHIP appears reasonable and will be used as a planning figure. Follow on expenses to operate and maintain the ship would be expected to be on the order of other similar RRF sealift ships. Again using the LMSR as a benchmark, the estimated 1995 cost of $7.3 million for surge ships is adjusted to $8.25 million in 2000.[12] Creating an average cost per year involves discounting the initial cost of procurement and operating and maintenance costs over the nominal 30-year life of the ship to year 2000 levels. Performing this calculation yields an average yearly cost of $22.9 million.

Charter and Build. The conceptual framework behind Charter and Build is to have a commercial shipbuilding firm risk it's capital in the actual construction of the ship (build) with an understanding that the government will enter into a long-term lease upon completion (charter). The net effect of this type of agreement is to spread the cost out over many years rather than paying a lump sum in the first year. While at face value this would appear to cost much more over the life of the ship, in fact rigorous analysis using NPV as a benchmark shows that the costs are roughly equal at today's interest rates available through the Federal Financing Bank. As a quick example a ship costing $600 million today would generate 50 semi-annual lease payments of approximately $23.5 million. Using the formula shown below the value of the payments with interest set to 5.5% equates to just over $601 million.

$$NPV = PMT \sum_{t=1}^{50} \frac{1}{(1+i)^t}$$

In this scenario then, the average yearly cost over the life of the ship is essentially equal to that of the buy option discussed above. The added benefit of this procurement option is the spreading out of payments, thereby perhaps making it easier to fund. A significant drawback to this concept though is the Office of Management and Budget (OMB) and Congressional opposition to entering into long-term (over five year) leases. Current OMB guidelines prohibit this type of financing, however the Navy is seeking relief from this ruling in the acquisition of the T-ADC(X).

National Defense Features (NDF) Program. The National Defense Features (NDF) concept involves the use of civilian shipping in the event of a military contingency. The Navy would pay to have military features built into the ship during initial construction and conduct periodic maintenance and upgrades to these same features. In exchange for this payment the operators of the ship would be required to make the ship immediately available when needed.[13]

A few examples of these features include deck strengthening, additional electrical power generation capability to run additional gear such as add-on cranes, and convertible container holds.[14] Congressional restrictions apply in this case as well. Part of the logic behind this initiative is to maintain U.S. shipping and the U.S. shipbuilding industry therefore, while the ships would be privately owned, the crews would be U.S. merchant seamen and the ships must be built in U.S. shipyards.[15] While similar to the Civil Reserve Air Fleet (CRAF) program which pays for and recalls aircraft in much the same manner, NDF activation would primarily support the follow on surge requirement to include sustainment. The cost for such a program is difficult to estimate. Envisioned as an incentive to traditional shipping and shipbuilding, NDF has a historical database to rely on to price this market. A vessel such as FASTSHIP has many unknowns in the cost of construction and subsequent demand for its services. In this case it would be analogous to putting the Concorde in the CRAF program, a high demand commodity that would cost a premium in lost revenues to the owner when recalled. Since no estimates are available to model the costs, a common sense approach was used to produce a baseline. Military features were estimated at ten percent of the total cost and maintenance fees were set equal to the cost of a typical Ready Reserve Force (RRF) ship at an inflation-adjusted figure of $2.8 million per year.[16]

Potential Military Applications

The future direction the military as put forth in the 1997 National Military Strategy includes the ideas of joint technical superiority, dominant maneuver, and focused logistics.[17] The ability to get there fast is an inherent aspect of this future vision where all military forces arrive in such a manner as to mass their effects and overwhelm any potential adversary. The U.S. Army is exploring the concept of high speed transport to provide increased power projection in the

"Army after next." Although no formal requirement exists to date for this capability, a workshop was held in October 1997 to investigate the potential application of high speed transport.[18] Future applications of this technology and capability may well change the way the U.S. thinks about transportation and may force us to reevaluate our sealift needs.

Notes

[1] David Giles, "Faster Ships for the Future," *Scientific American,* October 1997, n. p.; on-line, Internet, 18 September 1998, available from http://www.sciam.com/1097issue/1097Giles .html.

[2] Ibid.

[3] Ibid.

[4] Ibid.

[5] Ibid.

[6] Robert Toguchi and Joseph Gerard, "Strategic Maneuver in 2020" (paper presented at the Military Operations Research Society Symposium, Monterey, CA, 24 June 1998).

[7] Giles.

[8] Toguchi and Gerard.

[9] U.S. Joint Chiefs of Staff, *Mobility Requirements Study, Bottom-up Review Update (MRS BURU) (U)* (Washington, DC, March 1995), V-3.

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[11] Myron Hura and Richard Robinson, *Fast Sealift and Maritime Prepositioning Options for Improving Sealift Capabilities*, (RAND, Santa Monica, CA, 1991), p. 33.

[12] U.S. Joint Chiefs of Staff, V-3.

[13] Jon Kaskin, "Future of Strategic Sealift," brief, Air University, Maxwell AFB,AL, 7 August 1998.

[14] Ibid.

[15] Ibid.

[16] Peter C. Laches, "An Analysis of the Mobility Requirements Study and the Future of Strategic Sealift" (master's thesis, Naval Postgraduate School, March 1993), 30.

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[18] Kaskin.

Chapter 4

Model Description

In order to measure the effect of FASTSHIP on strategic sealift a simplified spreadsheet model was developed in order to gain perspective into the scope of the problem and some of the associated variables. Excel was chosen due to its wide base of availability and common user understanding. While a more detailed model could have been developed in programming languages or in specific linear programming packages, a desire for wider audience appeal favored ease of use.

Microsoft Excel Solver

Microsoft Excel Solver is a powerful computational instrument located in Excel’s tools menu. Solver provides users a relatively straightforward manner in which to solve linear programming problems. Using a derivative of the simplex method developed by George Dantzig, Solver uses a branch and bound method to sift through possible solutions for an answer that optimizes the given objective function.[1] Solver requires the user to define three parameters; a target cell to optimize, a cell or cells to manipulate that represent the answer, and a list of constraints or bounds that the objective function must satisfy. Once these parameters are set Solver attempts to satisfy all constraints and maximize or minimize the desired cell through manipulation of the free variables or answer cells. Although the answer provided is a single point solution multiple solutions may exist, alternatively no feasible solution may exist particularly when attempting to obtain integer solutions.[2] Other models exist that solve a variety of problems, using different algorithms. In the case of non-integer solutions another model is used as backup as described in the next section

Genetic Algorithms

Genetic Algorithms (GA) use a completely different process to search for solutions than Solver. Based on the study of nature, genetic algorithms use a series of mutations from a parent solution to search the answer space. Generally slower than true linear programs, GA can provide answers where Solver cannot especially in complex models were local minimums exist which may not constitute a global minimum. While GA searches a wider array of solutions there is no guarantee that the answer is “the” optimal solution, instead it refines a series of “near-optimal” answers within the given parameters. While this explanation is not meant to be exhaustive it is sufficient for the purposes of a modeler. For those interested, a detailed overview of GA is contained in Appendix B. Palisade Corporation’s Evolver is one commercially available GA program that acts as a plug-in to Microsoft Excel. Since the operation of this program is similar in design and runs in an existing Excel spreadsheet it was chosen as an integer solution checker for this optimization problem.

Data Sources

The data gathered as input to the model was derived from many sources, areas of conflicting information were resolved by reference within the Mobility Requirements Study (MRS) and its Bottom-up Review Update (BURU). Whenever possible, factual data was used to provide realism and relevance, however, in order to remain at unclassified level, generic data was used in some cases. A summary of data used in the model and its source is provided in Table 1 below:

Table 1. Data Assumptions and Sources

Data item	Rational and Source(s)
Representative Port Capacities	Higher capacity preferred if possible, based on MRS BURU data[3]
Representative Load Times	Average by ship[4]
Cargo Requirements and Delivery Times	Based on Army and Marine Corps unit requirements[5,6]
Existing Ship Data	Averages of ship types[7,8]
Ship Cost Data	As described in Chapter 3
FASTSHIP Data	Current design[9,10]
Conversion Data (TEU to Stons to Sqft)	Rough estimates from previous studies[11,12]
Port Drafts and Distances, Refueling time penalty, Ship Life, Future Inflation	Author's estimates based on accumulated observation

Assumptions

A number of assumptions were made in the modeling processes. Many of these were made for ease of modeling purposes, or because the author felt that the added complexity did not warrant the impact that they would have in significantly affecting the output. A summary of those judged as non-critical follows:

- Ship data assigned weighted average across platforms (i.e. FSS and LMSR speeds and capacity).
- MPS/APS delivery equipment on time but not available for further tasking.
- Ships life estimates are accurate.
- Inflation remains at a constant at low rate.
- No other additional sealift assets are acquired from present levels.
- Crews remain available to man ships.
- Military Unit equipment requirements remain unchanged
- No attrition of sealift ships

Assumptions that may have significant impact but were not modeled:

- U.S. ports are able to handle cargo loading without added delay.
- The cost of RRF activation and fuel use would not impact answer due to similarity of costs for all ships.
- FASTSHIP cost, speed, and capacity estimates are accurate and that a commercial market exists for ship thereby making NDF a viable option.
- FSS/LMSR/RRF meet activation times.

- Destination port arrivals are distributed evenly over available time to enable maximization of daily capacity.
- Ship cargo capacity is not reconfigurable between containers and square feet: what you have is what you get.

Sealift Optimization Model Processes

As shown in Appendix A, the Sealift Optimization Model developed appears simple at first glance. Assumptions and given data is highlighted in blue while data cells outlined in red are the solution set.

The first step in the process is to define first time one-way times associated with each ship and each port, this is done in two cases, to account for a ship that is assigned to meet the short timeline or the extended time line. This relationship is represented by the equation:

$$Traveltime = \frac{Range}{Speed * 24} + Loadtime_{US} + Loadtime_{OCONUS} + Activationtime + (Fueltime)$$

A statement is embedded to check to see if the ship can reach the port, if it cannot then a penalty refueling takes place thus adding to the time of arrival. A similar process is performed for subsequent roundtrips, without the addition of activation times. The next step checks ship drafts against port depths to ensure the completion of the trip is possible, then computes the (whole number only) number of trips possible by one ship using the following equation:

$$Trips = Int\left(\frac{Time - Timefirsttrip}{TimeRoundtrip}\right)$$

This result is then multiplied by Solver or Evolver's derived optimal number of ships assigned and cargo deliveries are calculated converting TEU to square feet. Solver and Evolver solutions must provide solutions that meet the constraints for number of ships available cargo delivered to theater and maximum cargo capacity of the ports of debarkation.

The GA parameters used throughout the analysis:

Mutation Rate	0.1
Population	50
Crossover	0.6
Stopping Control	time = 15 minutes

Notes

[1] Wayne L. Winston and S. Christian Albright, *Practical Management Science* (Duxbury Press, 1997), 26.

[2] Ibid., 214.

[3] U.S. Joint Chiefs of Staff, *Mobility Requirements Study, Bottom-up Review Update (MRS BURU) (U)* (Washington, DC, March 1995), C-31-32.

[4] Kris Winter, "Evaluating the Trade-offs Inherent in Strategic Sealift" (master's thesis. Naval Postgraduate School, 1993), 13.

[5] U.S. Joint Chiefs of Staff, IV B-4.

[6] Jon Kaskin, "Future of Strategic Sealift," brief, Air University, Maxwell AFB,AL, 7 August 1998.

[7] U.S. Joint Chiefs of Staff, C-28.

[8] Kaskin.

[9] Robert Toguchi and Joseph Gerard, "Strategic Maneuver in 2020" (paper presented at the Military Operations Research Society Symposium, Monterey, CA, 24 June 1998).

[10] Kaskin.

[11] Center for Naval Analyses, *Sealift in Operation Desert Shield/Desert Storm: 7 August 1990 to 17 February 1991*, Research Memorandum 91-109 by Ronald F. Rost, John F. Adams, and John J. Nelson, (Alexandria, VA: CNA, May 1991), A-1.

[12] U.S. Joint Chiefs of Staff, F-6.

Chapter 5

Analysis and Findings

Introduction

The general methodology used to conduct the analysis was to establish a baseline and vary parameters within the baseline first singularly and later in combination to measure the effect. This marginal approach attempted to gain insight into the various effects of certain scenarios on the model; also serving to validate the model through the observation of logically expected behaviors. As mentioned previously Solver, although set up to solve integer problems, usually could not determine whole ship solutions in the problem as set up (possibly due to the author's limited linear programming skills). Nevertheless, Solver proved a valuable tool, as a starting point in providing a starting point for Evolver, thereby dramatically cutting down problem run times.

Model Outputs and Sensitivity Analysis

Results of the various model runs were in the format shown in Appendix A. Solver and Evolver determined a given number of ships (less than or equal to the size of the fleet specified by the user) that minimized total cost. The output then can be read as the number of ships of each type and the total cost.

Since total cost is a function of the number of ships determined by the model only the figure is somewhat misleading. Stated differently, the model only “pays” for the ships that it uses in the particular scenario it solves for. This means that ships not used incur no costs. Clearly this is not appropriate in all cases, but if the worst case scenario does not require all ships then the U.S. is paying a premium for excess capacity. The model then identifies a minimum fleet size for the given parameters, it is up to higher level decision makers to determine a “worst case” scenario that would be maintained to handle all contingencies. Assuming that the current MRS force is the minimum for now, the model’s baseline number of 19 FSS and LMSR, and 31 RRF surge ships (assigned readiness times less than five days) would generate an annual cost of $472.7 million. Table 2 is a summary of model runs with varying parameters with the added column incorporating the idea of paying for surge sealift excess capacity.

Table 2. Model Run Results

Parameter changed	Solver ships	Solver cost	Evolver ships	Evolver cost	Adjusted cost
Baseline	4.85 19 6.7	$442.2M	5 17 15	$463.0	$587.1M
No FASTSHIP	0 19 27.2	$450.5M	0 19 30	$466.9M	$472.7M
NDF FASTSHIP	10 15.9 0	$293.4M	10 15 5	$308.4M	$701.5M
First Response 18 days	5.3 12.2 31	$491.6M	6 12 31	$502.5M	$610.0M
First Response 36 days	0 7.3 31	$293.1M	0 8 30	$297.9M	$472.7M
More Equipment +1000 sqft	6 19 22.41	$559.6M	6 19 27	$586.7M	$610.0M

Less Equipment -1000 sqft	0 14 0	$215.0M	Same	Same	$472.7M
Less Equip, TUE and time=15	10 10.4 31	$568.9M	10 12 31	$594.0	$701.5M
NDF and more Equipment	10 19 5.6	$373.0M	10 19 9	$393.2M	$701.5M
Distances +1000NM	4.85 13.45 31	$498.5	7 13 30	$534.9M	$632.9M
Distances -2000NM	0 12 14	$266.0M	Same	Same	$472.7M

Interpretation of Results

Solutions for time showed that FASTSHIP could not deliver sufficient cargo to meet the baseline unless additional ships were added or cargo requirements were lowered even though it arrived three to four days faster that other assets. For example, lowering early arriving requirements for cargo by 1000 square feet and TEU by 100 could meet time requirements of 15 days. Due to the nature of the step function however solutions can quickly become infeasible even if only small changes occur. Sensitivity analysis therefore, is of extreme importance since minor changes in some parameters yield major differences in the results. Table 2 shows a summary of the effects of changing various parameters. General trends show that as requirements increase, FASTSHIP uses increases and costs tend to increase proportionately. Also of note, the existing surge fleet could fulfill the requirements of the baseline case by themselves, indicating that FASTSHIP may only be an asset in certain cases. The use of an NDF version of FASTSHIP clearly cuts down costs, even added requirements prove not to be problematic as can be seen in the case where NDF FASTSHIP is available to help deliver an additional 1000 square feet of cargo. Analysis of this case shows heavy reliance on FASTSHIP and FSS/LMSR making a case for possible partial replacement of RRF assets.

Measures of Effectiveness (MOEs)

MOEs were rather straightforward since the model attempted to minimize cost. While this may not be the best way to make force structure decisions, in times of increasing fiscal awareness, it must be addressed. Measuring value added or military benefit can be harder to define. Using response time as a metric, FASTSHIP provides a clear advantage over traditional ships albeit at a cost premium. While the optimization model was not designed to solve to optimize a solution for minimum time, adjusting the minimum time parameter incrementally lower will eventually lead to a condition of infeasiblity, where it is not possible to deliver the required cargo in the time allotted. This phenomenon is actually quite easy to discover by inspection since as required first response time (sum of voyage time, load time, and activation time) falls below the first trip time it is not possible to deliver any cargo in time. This infeasibility condition may also be the result of the limit of ships available (i.e. not enough lift capacity available).

Cost-Benefit Tradeoffs

The question to be answered then Is the cost of FASTSHIP worth the expense? The analysis described above indicates that the answer depends on the assumptions that we are willing to make. If future requirements demand faster response times for surge sealift, then FASTSHIP provides a valuable tool. In all scenarios current sealift ships could deliver the required cargo if given enough time. In most cases the most economical solution did not use all assets implying excess capacity. This seems counterintuitive at first but makes better sense when you consider the costs and activation times involved in calling a ship out of the RRF. A mathematical approach was attempted to define some parameter to measure the incremental effect of tightening or loosening the time constraint thus obtaining a marginal cost. In practice though while the model responds predictably over large changes in required delivery times, over small increments there may be no difference, this reaction is most likely the result of the discontinuous nature of the cost step function.

Chapter 6

Summary

Conclusions

The analysis conducted in Chapter 5 shows that FASTSHIP could be a valuable asset in certain cases. However, since current assets meet known requirements, the addition of FASTSHIP trades added cost for an increased reaction time that may not be necessary. MPS and APS assets are planned to deliver the bulk of early arriving unit equipment therefore FASTSHIP becomes somewhat of a redundant capability. This is not to imply that FASTSHIP has no future in the strategic sealift mix. The next MRS is ongoing, responding to the changing strategic environment. The results of this MRS may change requirements as the military redefines its needs and directly related lift requirements. Lighter, mobile forces relying on speed and mobility may not require as much heavy lift, cutting down this figure directly affects the number of ships required to provide the lift. New initiatives such as NDF appear to represent a win-win situation, costing less than buying or leasing and still maintaining good response times while bolstering a sagging a U.S. shipbuilding industry. While not explicitly addressed in this paper, the continuing migration of high capacity sealift assets to the MPS and APS prepositioning roles has already eased much of the stress on surge assets. Continuing this trend may be of merit. Other recent analysis suggests that the U.S. should maintain access to commercial transportation assets.[1] The addition of faster ships is not the only revolution ongoing in the transportation realm. New methods of speeding loading and unloading times and intermodal transportation can reduce reaction times significantly by themselves, combined with high speed sealift, response is further optimized.[2]

Recommendations

The revolution offered through the innovation of new forms of high-speed seaborne commercial transportation should continued to be explored. Military application of commercial designs is not a far stretch in the world of cargo transportation. To cut down costs, the military must leverage Commercial Off-The-Shelf (COTS) assets and technology as they are developed. While the construction of FASTSHIP may still be a long-term project that may not be realized in its current configuration, it does offer hope for the future. The next MRS may not consider platforms such as FASTSHIP (since it is not projected to exist). However, follow-on studies should take into account such capabilities. As TRANSCOM and MSC look to recapitalize sealift and shape force structure serious consideration should be given to the inclusion of high speed sealift as it becomes readily available. From the analysis conducted in this paper, FASTSHIP can play a role in sealift particularly if NDF is available and RRF ships can be replaced. Too much uncertainty surrounds the issue at this juncture however to make any definitive programming decisions. Using some of the more robust models detailed in the next section, this sealift optimization should be performed in the future to aid decision-makers in making the best use of available assets.

Areas for Further Study

A complete decision making aid would involve many more variables and constraints on the resulting system. A rigorously accurate model would need to account for each level of unit equipment broken down by weight and square feet, embarkation port detailed data, possible debarkation port detailed data, and individual ship capacities with possible configurations and combinations of container space and square feet. This injection of realism would be better served using a time phased approach, breaking the movement of platforms between various ports into discrete periods of time in order to better track the movement of cargo, noting chokepoints and backlogs in the system. Actual TPFDD data could be used as a planning input to measure possible real "world" impacts of high speed sealift. Another area that may be of value is the choice of what to evaluate. While cost is certainly of concern, it is not the only driving factor in the sealift equation. As noted previously, the analysis conducted during the course of this research looked into time factors as a MOE. However, the value of increased response is difficult to measure. A possible solution to this problem involves defining a cost function that rewards earlier response and penalizes late arrival. Throughout this research single point estimates (in many cases aggregated) were used as representative data. While this approach works well in some cases (cargo), in others a distribution may better describe the parameter (i.e. port loading times, activation time, etc.) and Monte-Carlo simulation would provide a more robust modeling technique.

Notes

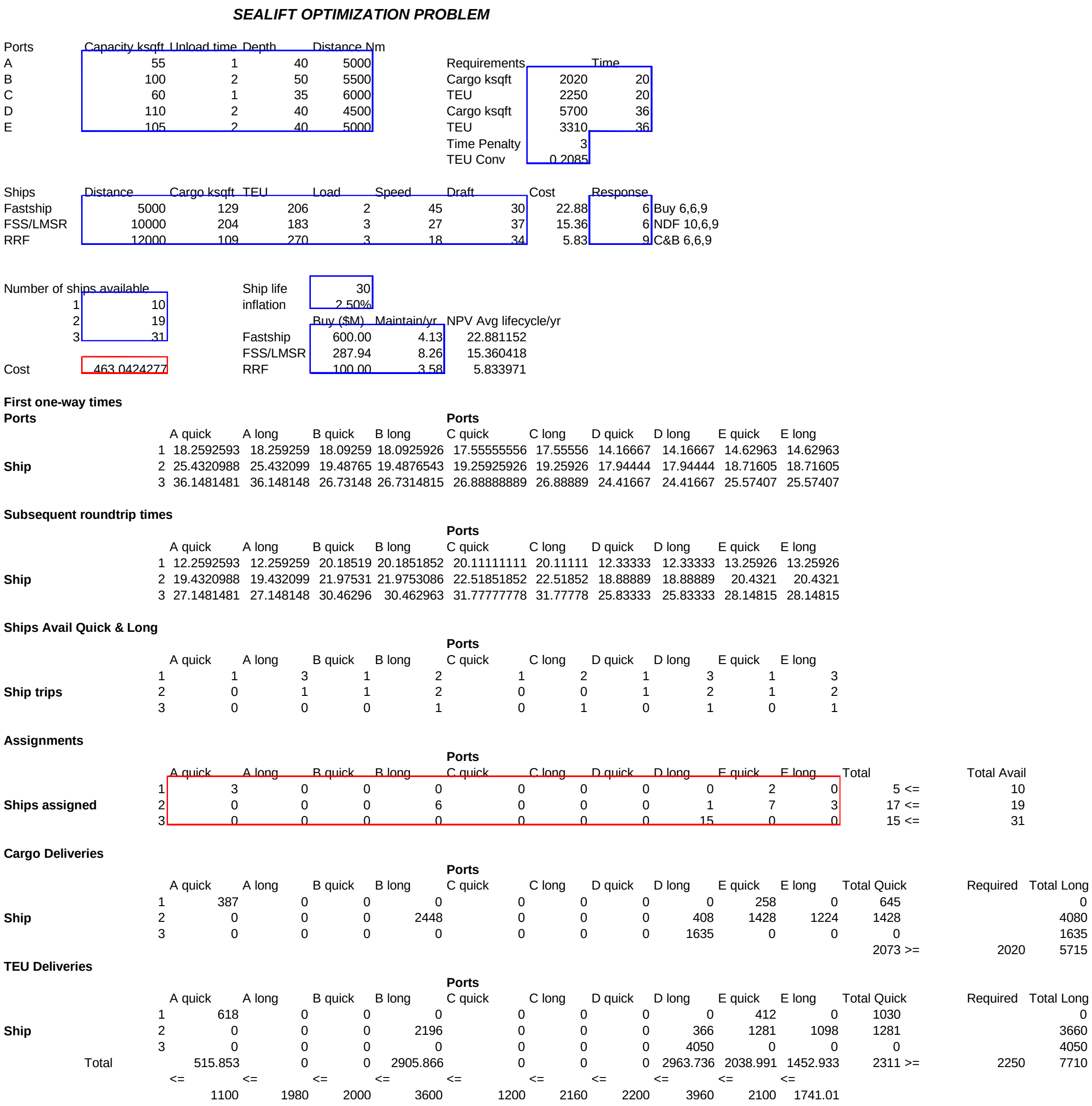
[1] David Kassing, "Strategic Mobility in the Post-Cold War Era," in *New Challenges for Defense Planning,* ed. Paul K. Davis, (Santa Monica, CA: RAND, 1994), 685.

[2] David Giles, "Faster Ships for the Future," *Scientific American,* October 1997, n. p.; on-line, Internet, 18 September 1998, available from http://www.sciam.com/1097issue/1097Giles.html.

Appendix A

Sample Model Output

This section is provided to illustrate the setup of the model and show results for one specific run. Shown in Figure 1 is the baseline solution using Evolver to provide an integer solution.



SEALIFT OPTIMIZATION PROBLEM

Ports	Capacity ksqft	Unload time	Depth	Distance Nm
A	55	1	40	5000
B	100	2	50	5500
C	60	1	35	6000
D	110	2	40	4500
E	105	2	40	5000

Requirements		Time
Cargo ksqft	2020	20
TEU	2250	20
Cargo ksqft	5700	36
TEU	3310	36
Time Penalty	3	
TEU Conv	0.2085	

Ships	Distance	Cargo ksqft	TEU	Load	Speed	Draft	Cost	Response	
Fastship	5000	129	206	2	45	30	22.88	6	Buy 6,6,9
FSS/LMSR	10000	204	183	3	27	37	15.36	6	NDF 10,6,9
RRF	12000	109	270	3	18	34	5.83	9	C&B 6,6,9

Number of ships available	
1	10
2	19
3	31

Cost 463.0424277

Ship life 30
inflation 2.50%

	Buy ($M)	Maintain/yr	NPV Avg lifecycle/yr
Fastship	600.00	4.13	22.881152
FSS/LMSR	287.94	8.26	15.360418
RRF	100.00	3.58	5.833971

First one-way times

Ports						**Ports**					
		A quick	A long	B quick	B long	C quick	C long	D quick	D long	E quick	E long
	1	18.2592593	18.259259	18.09259	18.0925926	17.55555556	17.55556	14.16667	14.16667	14.62963	14.62963
Ship	2	25.4320988	25.432099	19.48765	19.4876543	19.25925926	19.25926	17.94444	17.94444	18.71605	18.71605
	3	36.1481481	36.148148	26.73148	26.7314815	26.88888889	26.88889	24.41667	24.41667	25.57407	25.57407

Subsequent roundtrip times

						Ports					
		A quick	A long	B quick	B long	C quick	C long	D quick	D long	E quick	E long
	1	12.2592593	12.259259	20.18519	20.1851852	20.11111111	20.11111	12.33333	12.33333	13.25926	13.25926
Ship	2	19.4320988	19.432099	21.97531	21.9753086	22.51851852	22.51852	18.88889	18.88889	20.4321	20.4321
	3	27.1481481	27.148148	30.46296	30.462963	31.77777778	31.77778	25.83333	25.83333	28.14815	28.14815

Ships Avail Quick & Long

						Ports					
		A quick	A long	B quick	B long	C quick	C long	D quick	D long	E quick	E long
	1	1	3	1	2	1	2	1	3	1	3
Ship trips	2	0	1	1	2	0	0	1	2	1	2
	3	0	0	0	1	0	1	0	1	0	1

Assignments

						Ports							
		A quick	A long	B quick	B long	C quick	C long	D quick	D long	E quick	E long	Total	Total Avail
	1	3	0	0	0	0	0	0	0	2	0	5 <=	10
Ships assigned	2	0	0	0	6	0	0	0	1	7	3	17 <=	19
	3	0	0	0	0	0	0	0	15	0	0	15 <=	31

Cargo Deliveries

						Ports								
		A quick	A long	B quick	B long	C quick	C long	D quick	D long	E quick	E long	Total Quick	Required	Total Long
	1	387	0	0	0	0	0	0	0	258	0	645		0
Ship	2	0	0	0	2448	0	0	0	408	1428	1224	1428		4080
	3	0	0	0	0	0	0	0	1635	0	0	0		1635
												2073 >=	2020	5715

TEU Deliveries

						Ports								
		A quick	A long	B quick	B long	C quick	C long	D quick	D long	E quick	E long	Total Quick	Required	Total Long
	1	618	0	0	0	0	0	0	0	412	0	1030		0
Ship	2	0	0	0	2196	0	0	0	366	1281	1098	1281		3660
	3	0	0	0	0	0	0	0	4050	0	0	0		4050
Total		515.853	0	0	2905.866	0	0	0	2963.736	2038.991	1452.933	2311 >=	2250	7710
		<=	<=	<=	<=	<=	<=	<=	<=	<=	<=			
		1100	1980	2000	3600	1200	2160	2200	3960	2100	1741.01			

Figure 1. Sealift Optimization Model baseline using Evolver

Appendix B

Detailed Overview of Genetic Algorithms

Genetic Algorithms (GAs) are a general, domain-independent search and optimization algorithm developed in the 1970's. Many terms and concepts in GA research are borrowed from natural events and processes, essentially natural evolution and genetics. The original focus of the research was to use the principle of evolution (essentially the Darwinist principle of "survival of the fittest") to simulate the adaptive nature of natural processes for artificial systems.

GAs do not deal with a data contained in a problem (or its possible solutions) directly; GAs use a representation of these data. This representation is mostly an encoding of the original numerical (decimal) values into a binary string of '0' and '1'. In theory the encoding can be done over any form of finite alphabet, but the binary representation is the most efficient as it is the most basic form of representation.

All data within a domain specific object, represented through numerical values, are translated into their binary representation, which is then expressed as a string and concated into one single binary string that represents the entire domain object. The GA engine internally keeps track of which variable is represented by which section of the string, but the learning process deals with the entire string. By using a problem representation (rather than dealing with data directly) the Genetic Algorithm achieves already a high level of domain independence, which also allows integrating very different types of data or possible solutions into one, single learning process.

The GA engine always deals with an array of solutions that compete against each other during the evolution in direction of the optimum solution. In evolutionary theory this concept is called “survival of the fittest.” In order for the GA process to evaluate each possible solution there must be a measurement on how successful each solution is, consequently called the “fitness value.” The fitness value is a very import reference value for the GA engine. It is used to sort the array of solutions, compare, and select individual solutions for further evaluation. Within the basic GA architecture, the fitness function is the only domain-specific function that has to be implemented by the application. The Genetic Algorithm always deals with optimizing an array of possible solutions, ideally simultaneously (in a multi-threaded or distributed parallel process). Such an array of objects is a called a population, with each object within that population called an individual. Upon creating the GA, this array of individuals is initialized randomly by randomly assigning ‘0’ and ‘1’ values to each byte in the binary string that is used to represent the problem domain. Using that random assignment lets the GA process start with an unbiased knowledge of the possible solution space. After a population of solution is completely evaluated, the GA engine selects individuals from the population to create a new population set. Each selection from the previous population involves selecting a pair of two individuals, which are combined to create two new individuals for the new population set. This combination of individuals resembles the genetic process performed by all natural individuals using sexual reproduction.

The most important method of combining two individuals involves a genetic operator called “Crossover.” The data contained in each individual are represented as a binary string. Because these individuals are combined to create two new individuals (“off-spring”), the original individuals are often called “parents” and the off-spring “children.”

For Example:

Selected Parent String A: 0010101010000101010100101010101

Selected Parent String B: 0011100100010100101010101010000

The GA engine applies a random generator to cut the strings at any position (the crossover point) and exchanges the substrings between these two individuals: Assume, the random generator returns random value 8.

Parent String A: 00101010—10000101010100101010101

Parent String B: 00101001—00010100101010101010000

(Crossover point put randomly at byte position 8)

Now performing the string-crossover to create two children (off-spring):

Child 1: 00101010—00010100101010101010000

Child 2: 00101001—10000101010100101010101

After the cross over is performed, these two new off-spring are then added to the new population set:

The improvement of the average fitness of a population is achieved through the selection of individuals as parents from the completed population. When the GA engine selects parent individuals, byte strings exhibiting higher fitness values are made more likely to be selected as parents. Because of this “mating” process and the creation of off-spring, each population set is referred to as one “generation.” Allowing the GA process to evaluate a sufficiently large number of “generations” is a very important part of the GA based learning process. The selection process is random, but, through various techniques, biased towards higher-fitness individuals.

The mating (crossover) process simulates the process of how chromosomes are combined in a sexual re-production process. The assumption is that among the variables represented in the binary string, some variables are more relevant to the fitness of the individual than others. Some variables within that string might even contribute to lowering fitness. If the crossover process selects two sub-strings for combination that contain variables contributing to increased fitness, the resulting child string will have a much higher fitness than each of the parent individuals.

There is, of course, no guarantee that the crossover process results in a higher fitness off-spring. This is why the main aspect of the GA structure is the diversity of the population. The target is not to test and improve one single solution, but to create an array of solutions and evolve the entire population. It is very likely that even after a large number of generations, some individuals within that population will exhibit low fitness values. The structure of the GA process requires definition of a number of parameters, which can effect the efficiency of the search process in several ways. The population size, i.e. the number of individuals forming a population, must be sufficiently large to create sufficient diversity covering the possible solution space. There are no absolutely optimal values. Clearly, a more complex problem domain requires a larger population size due to the larger possible combination of variables. Another user-defined criterion is the point at which the optimization process terminates. For most real-world applications, the target value is not known. If an estimate exists, then the terminating fitness value for the learning process can be defined relative to this estimate.

The performance of the GA process is very much dependent on the problem domain and largely on the complexity of the possible solution. A more complex, larger potential solution space requires a higher population diversity, i.e. a higher population size, and a higher number of generations to evolve a sufficiently fit population. The absolute number of individuals evaluated is not necessarily a relevant criterion for success of the learning process. It is often observed that in the short run, that is, for a small number of generations, the GA process produces similar, if not inferior, results compared to a random search. Other parameters, such as crossover probability, mutation rate, selection and cross-over mechanism seem to effect the GA process less significantly, when evaluated over a larger number of generations. This can however only be evaluated for specific problem domains. [1]

Notes

[1] Rabatin Investment Technology. "Introduction to Genetic Algorithms." n.d, n.p.; on-line, Internet, 12 September 1998, available from http://www.rabatin.com/ga_intro.html.

Glossary

APS	Afloat Prepositioning Ships
CJCS	Chairman, Joint Chiefs of Staff
CRAF	Civil Reserve Air Fleet
DOD	Department of Defense
FSS	Fast Sealift Ship
GA	Genetic Algorithm
LCAC	Landing Craft, Air Cushioned
LMSR	Large, Medium-speed Roll-on/Roll-off
LP	Linear Program or Programming
MARAD	Maritime Administration
MEB	Marine Expeditionary Brigade
MOE	Measure of Effectiveness
MPS	Maritime Prepositioning Ship
MRS BURU	Mobility Requirements Study Bottom-up Review Update
MSC	Military Sealift Command
NDF	National Defense Features
NPV	Net Present Value
RMA	Revolution in Military Affairs
RRF	Ready Reserve Force
RO/RO	Roll-on/Roll-off
SES	Surface Effect Ship
SWATH	Small Waterplane Area Twin Hull
TRANSOM	U.S. Transportation Command
TEU	Twenty-foot Equivalent Unit

C-Day. The day of the commencement of the contingency.
C+(Number of Days). The number of days after C-day.

High speed sealift. Fulfilling the requirements of strategic sealift as defined previously, using ships that are capable of higher speed. While not a universally accepted figure, generally defined as sustained transit speeds in excess of forty knots.

Ready Reserve Force (RRF). A contingency sealift fleet of ships owned by the U.S. kept in a state of readiness that allows them to be called up in case of emergency. The readiness of the ship is defined by the number of days that it is supposed to be able to sail, usually five, ten or twenty days.

Strategic sealift. The transportation of surge unit equipment, sustaining ammunition, petroleum, and supplies as well as the ships and systems used to accomplish the inter-theater shipment of military cargo ashore.[1]

Notes

[1] Jon Kaskin, "Future of Strategic Sealift," brief, Air University, Maxwell AFB,AL, 7 August 1998.

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