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THESIS

EVALUATING THE TRADE-OFFS INHERENT IN STRATEGIC SEALIFT

by

Kris Winter

June, 1993

Thesis Co-Advisor:	Dan C. Boger
Thesis Co-Adivsor:	David G. Brown

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Evaluating the Trade-offs Inherent in Strategic Sealift

by

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Submitted in partial fulfillment
of the requirements for the degree of

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ABSTRACT

This thesis examines some of the trade-offs to be considered when assigning sealift to a deployment. How sealift costs are defined, calculated and assigned is discussed. The trade-offs between different voyage characteristics, vessel types, and vessel mixes are compared using time and money as the standard measures. Recommendations for further use of trade-off analyses are also presented.

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I. INTRODUCTION

A. BACKGROUND

Strategic sealift is a primary mission area of the U.S. Navy, and is a major factor in the response and mobilization capability of the Nation's Armed Forces. Sealift can account for 90-95% of cargo movement during a major operation. Because of the importance of sealift and the magnitude of the associated costs, it is important to understand the trade-offs among different sealift alternatives. These trade-offs can be measured in time and money.

Numerous types of vessels are used in a deployment. They include government owned and operated vessels, and commercial vessels. The type of vessel used can depend upon scenario characteristics, legislative restrictions, or a combination of both.

In the commercial arena, vessel selection is made after as many of the trade-offs as possible have been considered. A trade-off could be increased speed versus increased fuel consumption and the related lower total per diem charges. In the Department of Defense (DOD) realm, the trade-offs to be considered include those from the commercial arena in addition to some which are unique to DOD.

The present, fiscally constrained environment under which DOD operates demands that commanders carefully allocate their resources. Resources include not only dollars but assets such as ships. Therefore an understanding of the trade-offs to be considered in vessel assignment is important. This will help ensure optimal use of available resources.

This understanding of trade-offs will aid a commander in determining what type of vessel should be assigned to a cargo and may influence the choice of a load port. Because each cargo is assigned a priority by the supported Commander in Chief (CINC) it is important that vessels are assigned in a manner that matches the CINC's priorities and that this assignment is within the limits of the law and available assets. In other words, a high priority cargo should be moved in a shorter time than a low priority cargo. Money should be allocated in a manner which allows this to happen.

B. PROBLEM STATEMENT

This thesis will attempt to answer several questions about some of the trade-offs to be considered when employing sealift during a deployment. These include:

1. How are sealift costs derived and assigned?
2. What are some of the trade-offs to be considered?
3. What impact do these trade-offs have on total cost of a deployment?
4. What impact do these trade-offs have on total deployment time?

C. RESEARCH METHODOLOGY

This thesis will examine some of the trade-off considerations when deploying units with sealift assets. Information on cost derivation and assignment and capabilities of vessel and port assets were acquired through interviews and readings of various Military and Government reports and publications. The Military Sealift Command (MSC) and Military Traffic Management Command (MTMC) were the main sources of information.

Wherever possible, actual cost data is employed to analyze the trade-offs. If this data was not available, cost estimates, based on government agencies' practices or experiences, and cost averages, based on statistical practices, are used.

Once cost and port capability data was obtained, a spreadsheet model is used to determine total costs and times for deployment for various options based on MTMC scenarios.

D. CONTENTS OF THE THESIS

The following chapter contains a historical overview of how sealift has been acquired and assigned. It also includes an overview of some of the trade-offs traditionally associated with sealift.

Chapter III describes the methodology used in assigning sealift costs.

Chapter IV discusses the findings of the quantitative analysis. An in-depth discussion of the trade-offs is also included.

Chapter V comprises the conclusions, recommendations for the use of trade-off analysis and for further study, and a final note.

II. SEALIFT ASSIGNMENT, ACQUISITION AND TRADE-OFFS

A. THE MILITARY SEALIFT COMMAND AND ITS STRATEGIC SEALIFT MISSION

The United States Transportation Command (TRANSCOM) provides global air, land and sea transportation to meet national security objectives. As one of TRANSCOM's components, the Military Sealift Command (MSC) has the primary mission of providing sealift for strategic mobility in support of national security objectives. This mission, known as strategic sealift, demands the capability to deploy and sustain military forces wherever and whenever needed, as rapidly and for as long as operational requirements dictate. Sealift requirements are met through use of government owned (or controlled) vessels, chartered commercial vessels, and other ships available through applicable laws, treaties and international agreements such as those provided through NATO and other nations.

B. SEALIFT ASSIGNMENT AND ACQUISITION

Under the best conditions, the deployment of forces during a crisis is the result of an extensive planning process during which the Time Phased Force and Deployment Data (TPFDD) file, "a computer-supported database portion of an operation plan that contains time-phased force data, non-unit-related cargo and personnel data, and movement data for the operations plan," is developed [Ref. 1: p. I-34]. Information includes prioritized arrival of units deployed to support the Operation Plan in Complete Format (OPLAN), routing of forces to be deployed, movement associated with deploying forces and estimates of transportation requirements [Ref. 1: p. I-34]. Under worse conditions, no TPFDD exists and planning is short-fused and ongoing as the deployment evolves. Such was the case during Desert Shield. Either way, assignment of vessels to move cargo is aided by computer simulation and restricted by asset availability.

The precedence in which vessels are used during a deployment or exercise is strictly regulated. The Federal Acquisition Regulation (FAR), Competition in Contracting Act (CICA) and numerous cargo preference acts restrict the sealift assignment process. The priority for assignment of vessels is as follows:

1. Maximum utilization of available U.S. flag commercial carriers.

2. Commercial vessels under charter to MSC which are part of the MSC force. The MSC Force is comprised of government-owned ships assigned to Commander Military Sealift Command (COMSC) and privately-owned ships under the control of COMSC at any given time.

3. Activation of Ready Reserve Force (RRF) vessels

4. Chartering of foreign flag vessels. [Ref. 2]

It must be noted however that exercise plans and TPFDD's frequently identify one specific type of vessel to carry a designated unit. This is frequently the case when FSS, RRF and MPF vessels are employed. During a large scale deployment of forces once a vessel has completed it's assigned mission it is put into the common user pool and assigned cargos as necessary and within the above priority guidelines.

Of course, availability of assets plays a major role in what type of ship cargo will be transported in. During Operation Desert Shield, vessels from the Maritime Preposition Force (MPF) and RRF, and U.S. and foreign chartered vessels were employed. A shortage of available U.S. flag vessels resulted in a number of foreign charters, especially roll-on, roll-off (RO/RO) vessels. Of the 206 ships MSC chartered between August 10, 1990 and January 18, 1991, 177 were foreign flag ships [Ref. 3: p. 2]. The RRF is the U.S. Government's main source of commercially designed, militarily suitable, general cargo ships capable of carrying military equipment. Defense exercises frequently include the activation of RRF vessels to either test the activation system or because the RRF is the only source of a specific type of vessel.

C. TRADE-OFFS

Webster defines trade-off as "the exchange of one thing in return for another, especially relinquishment of something desirable, as a benefit or advantage for one regarded as more desirable" [Ref. 4: p. 1224]. A trade-off is optimized when net improvements can no longer be obtained through such an exchange, and hence no other allocation can make better use of the available resources under consideration.

During sealift operations, a number of trade-offs can be considered. However, due to current legislation, some are not viable. A controversial trade-off not presently considered is the low cost of chartering foreign vessels compared to the cost of chartering U.S. flag vessels.

AFSC Pub 1 lists a number of limitations to be considered in strategic transportation decision making. This includes limitations of the support capabilities; limitations of the personnel processing, material handling and material storage; capabilities of theater transportation and required transport time. [Ref. 1: p. 6-60] Nowhere are fiscal limitations mentioned.

However, fiscal trade-offs for a deployment can be measured. For example the time and cost differences between deploying relatively slower, smaller breakbulk vessels and faster, larger RO/ROs or Fast Sealift Ships (FSS) can be assessed. The cost of increasing a vessel's speed and the associated increase in fuel consumption; the load/discharge rate of one type of vessels, say a RO/RO, instead of another, perhaps a breakbulk; and transit times of various vessels and their associated voyage costs can all be measured and compared.

1. THE TRADE-OFF BETWEEN VESSEL SPEED AND FUEL COST

Stopford discusses the fuel trade-off in his book *Maritime Economics* [Ref. 5: pp. 108-111] Both increased speed and reduced costs are desired. One can be had only at the expense of the other and hence the trade-off. The amount of fuel actually used by a vessel underway depends on its hull condition and the speed at which it is operated [Ref. 4: p. 110]. The fuel consumption of an FSS at different speeds is shown in Table 1. Fuel usage per nautical mile increases as speed increases, and nautical miles steamed per barrel decreases as speed increases.

TABLE 1. FSS HOURLY FUEL CONSUMPTION

Speed (Knots)	Barrels Per Hour of Fuel	Barrel Per Nautical Mile	Nautical Mile Per Barrel
20	42.00	2.10	.4762
21	55.00	2.62	.3818
22	67.75	3.08	.3247
23	73.58	3.20	.3126
24	81.13	3.38	.2958
25	90.00	3.60	.2778
26	99.58	3.83	.2611
27	114.75	4.25	.2353
28	131.58	4.70	.2128
29	141.25	4.87	.2053
30	153.58	5.12	.1953
31	164.92	5.32	.188

[Ref. 6].

Figure 1 graphically displays this trade-off, whereby fuel consumption increases as speed increases.

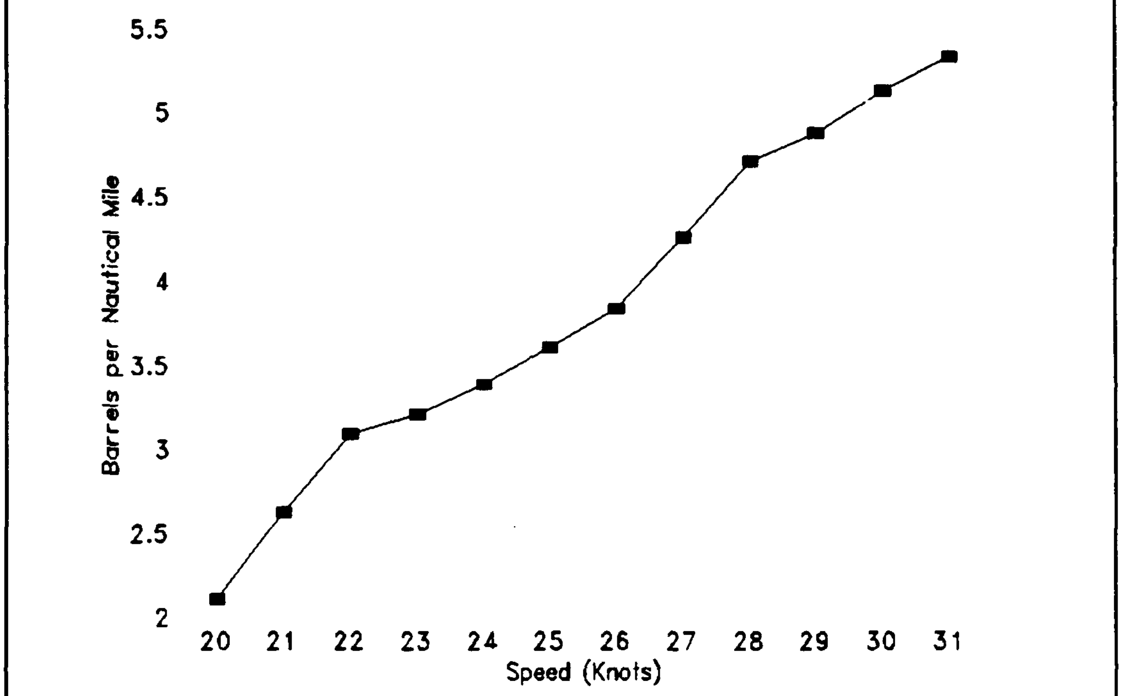

Figure 1. FSS Trade-off between Speed and Barrels Consumed Per Nautical Mile

2. PER DIEM AS AN ADDITIONAL TRADE-OFF FACTOR

Vessel voyage speed directly affects underway time and subsequently the number of days for which per diem is paid. For example if speed is reduced, fuel costs will decrease, but there will be an increase in the days required to complete the voyage and therefore an increase in voyage costs. The opposite occurs if speed is increased. Table 2 shows the transit time from Mobile, AL, to Ad Damman, Saudi Arabia, (9580 nautical miles) at various speeds. Assuming $20,000 as the per diem cost of an RRF vessel [Ref.7], voyage per diem costs were calculated by converting transit times from hours to days (rounding was done to the nearest day). As shown, per diem costs decrease as speed increases.

TABLE 2. TRANSIT TIME (HOURS) FROM MOBILE, ALABAMA TO AD DAMMAM, SAUDI ARABIA AND PER DIEM COST FOR DIFFERENT SPEEDS

Speed (Knots)	Transit Time	Per Diem Cost	Speed (Knots)	Transit Time	Per Diem Cost
14	685	$580,000	23	417	$340,000
15	639	$540,000	24	399	$340,000
16	599	$500,000	25	383	$320,000
17	564	$480,000	26	368	$320,000
18	532	$440,000	27	355	$300,000
19	504	$420,000	28	342	$280,000
20	479	$400,000	29	330	$280,000
21	456	$380,000	30	319	$260,000
22	436	$360,000	31	309	$260,000

Figure 2 graphically represents this data. As a vessel's speed increases it will spend less days at sea, and as a result the total cost for per diem will decrease.

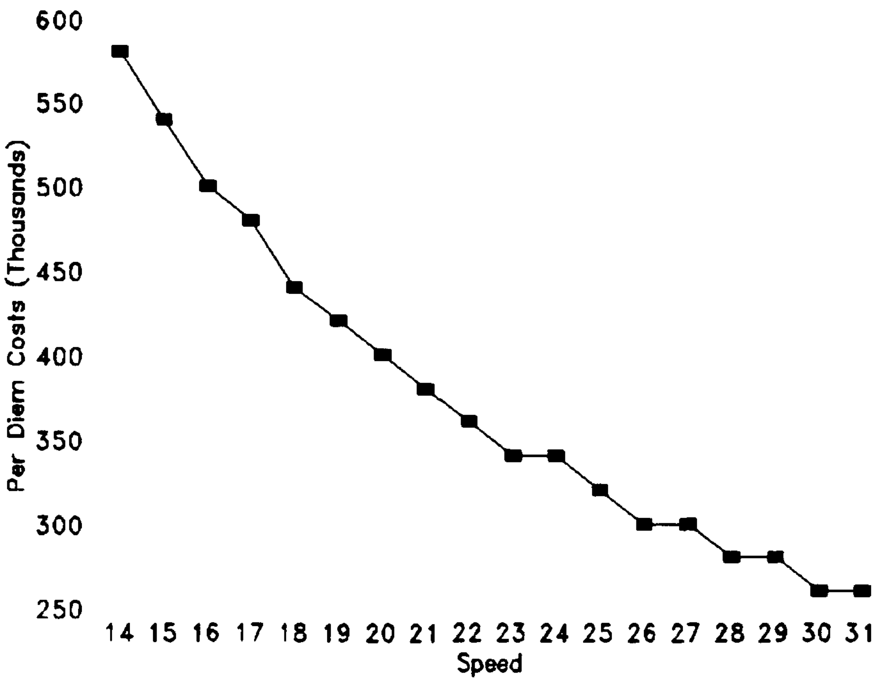

Figure 2. **Trade-off between Speed and Per Diem**

3. DISCHARGE RATES AND PORT AND COSTS

Load and discharge rates for a vessel are also important. Vessels with slower load and discharge rates can be more expensive due to additional days for which daily per diem and port charges are assessed. However, more modern ships with quicker material handling equipment may have higher per diem rates. Table 3 shows load and discharge rates (in 20 hour days) for various types of vessels [Ref. 8: p. 33 and Ref. 9]. Once again, total per diem charges are dependent upon the speed of discharge. Everything else remaining the same, vessels with slower material handling capabilities will incur higher total voyage costs.

TABLE 3. LOAD AND DISCHARGE TIME (20 HOUR DAYS)

Vessel Type	Load (Days)	Discharge (Days)
FSS	2	2
RRF RORO	1	1
RRF Breakbulk	4	4
Commercial RORO	1	1
Small Commercial Breakbulk	4	4

D. IMPORTANCE OF TRADE-OFFS

Consideration of trade-offs is essential to the efficient use of limited resources. As budgets get smaller and commanders become more responsible for the costs associated with their decisions, effectively identifying costs and potential savings is imperative. As unit commanders become more responsible for important fiscal decisions, they must be able to accurately measure and compare different alternatives.

When it comes to strategic sealift decisions, as many trade-offs as possible must be considered. Once potential trade-off factors are identified they must be analyzed together to optimize the trade-off between them. For example, the savings in per diem costs due to an increase in speed must be weighed against the increased cost in fuel. The amount of time each type of vessels spends in port for loading and discharging, i.e., voyage costs, must be compared to the different vessel types' operating costs.

When forces are deployed, reaching their destination as quickly as possible is the primary objective. Identifying and comparing the trade-offs between deployment time or speed and cost becomes important in allocating ships to different units or cargos.

With a finite supply of vessels available to support transportation needs, vessel allocation should be done in a manner which matches the supported Commander-in-Chief's (CINC) prioritization of cargo. A high priority unit or cargo should deploy on a faster ship, such as an FSS, while a low priority unit should be assigned a slower breakbulk or RORO. Of course, faster ships are more expensive.

Cost and time become uniform measures with which to compare the different trade-offs. Allocation of transportation funds should reflect a cargo's priority. A unit or cargo considered to be high priority by the supported CINC should have a larger transportation budget compared to the budget of a lower priority unit. More money means a faster deployment. Just as unit or cargo priority should determine the allocation of transportation funds, the amount of transportation funds available should drive transportation decisions and strategic sealift assignment.

III. METHODOLOGY

A. BACKGROUND

The Defense Planning Guidance (DPG), as reported in the *New York Times* [Ref. 10], lists seven conflicts that might draw United States forces into combat. One of these is an Iraqi invasion of Kuwait and Saudi Arabia. Based on the recent deployment of forces to the Persian Gulf in support of Operation Desert Shield, the trade-off studies presented later in Chapter IV analyze deployment cost for units moving from Oakland, CA; Mobile, AL; and Norfolk, VA, to Ad Dammam, Saudi Arabia, with vessels returning empty to their port of origin. The combination of vessels assigned to transport the units is based upon the *Military Traffic Management Command Deployment Planning Guide* [Ref. 11].

The trade-offs between the following vessels are compared: FSS, CAPE H class, RRF C3/C4 vessels, RRF C7 vessels, commercial small breakbulks (BB), and commercial ROROs.

Total cost and time required to complete the deployment are the measures used to quantify the trade-offs between the various deployment alternatives available to a unit.

Initially the scope of this thesis was to include an analysis of the trade-off between deployment time and speed.

The increased cost in fuel consumption was to be measured for various classes of ships over ranges of speed for each vessel class. Contact with various organizations, the Maritime Administration (MARAD), MSC, American President Lines and the Massachusetts Maritime Academy, revealed that this information is not available for RRF vessels or similar commercial vessels. This data was available only for the FSS. Another problem encountered was conflicting cost data. Specific problems in acquiring data will be discussed when the individual cost classifications are presented.

Cost data was acquired through numerous interviews and literature on the deployment of forces during Operation Desert Shield. Average figures were used and their derivation is explained later.

B. COST CLASSIFICATIONS

Cost classifications are broken into two main categories, per diem and voyage costs. The per diem costs are daily fixed costs. The principal components of these operating costs are:

$$PD = WB + L + S + RM + E$$

where: PD = per diem
WB = wages and benefits
L = Leasing cost for the vessel
S = stores and supplies
RM = contractor maintenance and repairs
E = miscellaneous operating expenses.

Table 4 shows the per diem costs by vessel type. The per diem cost figures received from MSC had some of the cost categories lumped together. This is the case with the FSS and chartered vessels for which some of this information is not required in the contracting process.

TABLE 4. PER DIEM COST BY VESSEL TYPE

Vessel Type	Per Diem Cost
FSS	\$24,835
RRF RORO	\$20,000
RRF Breakbulk	\$20,000
U.S. RORO	\$27,950
U.S. Breakbulk	\$11,800
Foreign RORO	\$22,700
Foreign Breakbulk	\$9,500

[Ref. 12]

The primary elements of voyage costs are:

$$VC = F + P + AD + B + C + MO$$

where: VC = voyage costs
F = fuel
P = port costs
AD = activation and deactivation costs
B = special charter bonus
C = Canal Transit Fees
MO = MSC Overhead

Voyage costs are determined by the vessel's voyage characteristics (other than voyage length as it impacts total per diem). Voyage characteristics include warranted speed, ship type and the port itself. Route, and load and discharge ports determine the amount of fuel consumed, the amount of time inport and whether canal tolls are paid. If applicable to the vessel type, these factors also determine the activation and deactivation costs or special charter bonus costs that are incurred. The amount charged as MSC overhead is also dependent upon the type of vessel and how long it is used.

1. Wages and Benefits

Crew costs encompass all direct and indirect charges incurred when crewing the vessel and can account for over half the operating costs. Wages, overtime, subsistence, social insurance, pensions and provisions are all included in this amount.

2. Lease

This figure applies only to chartered vessels. It is the rent for use of the vessel. This figure is included in the per diem rate charged by the ship owner.

3. Stores and Supplies

Stores and supplies include all consumable items such as spare parts and lubricating oil. For the FSS and charter vessels these costs are included in the contract price.

4. Repairs and Maintenance

This includes all costs associated with maintaining the vessel within contract standards. Routine and corrective maintenance are included. For the chartered vessels these costs are included in the contract price.

5. Miscellaneous Operating Expenses

Miscellaneous operating expenses includes such things as communications cost and crew travel. For the FSS this also includes the daily rental for their assigned layberths. This rent is paid even when the vessels are deployed.

6. Fuel

The determination of an average fuel consumption for each classification of vessels was dependent upon the amount of information available. For the FSS and CAPE H class vessels, consumption figures were the same for each vessel within the class. For the C3, C4 and C7 class vessels, a weighted average was determined using consumption rates for all vessels within the class. For the commercial vessels, a random sample for each class was selected and consumption rates available from MSC were averaged. Vessel speeds for the specific consumption rates were determined with a weighted average.

Vessel fuel consumption both underway, at warranted speed, and inport are presented in Table 5. Fuel types are 180 (Intermediate Fuel Oil 180 Centistrokes), 380 (Intermediate Fuel Oil 380 Centistrokes), DFM (Diesel Fuel Marine) and MDO (Marine Diesel Oil). For Suez Canal transits it is assumed that each vessel would take one day each way to travel the canal, and fuel consumption would equal one-half day inport and one-half day underway. For vessels transitting from Oakland it is assumed that vessels will stop for bunkers one time each way. Fuel consumption will be equivalent to one day inport and one day underway.

TABLE 5. AVERAGE FUEL CONSUMPTION (BARRELS) INPORT AND UNDERWAY AT WARRANTED SPEED (KNOTS)

Vessel Type	Warranted Speed	Fuel Type	Underway Consumption	Fuel Type	Inport Consumption
FSS	30	DFM	3,686	DFM	300
CAPE H	18	180	630	180	50
C7	20	380	1,225	380	90
C4	18	380	610	380	75
C3	18	380	418.3	380	65
U.S. Small BB	16.9	380	333	380	42.45
FRGN Small BB (a)	15.7	180	202	MDO	21
U.S. RORO	17.5	380	345	MDO	39.5
FRGN RORO (a)	16.9	180	267	MDO	22

[Ref. 13, 14 & 15]
Note: (a) FRGN denotes foreign chartered vessel.

Fuel costs account for a large portion of voyage costs. Cost per barrel for the four fuel types burned were calculated by averaging the market prices published in last issue of each month in 1992 in *Fairplay.* Fuel prices for ten ports along the routes to be traveled by the vessels were used. The FSS consume Diesel Fuel Marine (DFM) and the average cost for 1992 was provided by MSC [Ref. 16]. Cost per barrel for the four fuel types are in Table 6.

TABLE 6. AVERAGE PRICE PER BARREL PER FUEL TYPE DURING 1992

Abbreviated Name	Fuel Type	Cost Per Barrel
180	Intermediate Fuel Oil 180 Centistrokes	$14.33
380	Intermediate Fuel Oil 380 Centistrokes	$13.64
DFM	Diesel Fuel Marine	$26.46
MDO	Marine Diesel Oil	$15.00

[Ref. 16]

7. Port Costs

Average port costs for each type of vessel were provided by MSC. There are two figures for each vessel class. Charges for the first and last day are higher and include berthing charges (tugs, etc.) and hotel services. The cost for all other days is for hotel services only. Port costs are shown in Table 7.

TABLE 7. PORT COSTS BY VESSEL TYPE

Vessel Type	**First and Last Day**	**Remaining Days**
FSS	$7,300	$1,300
RRF RORO	$5,800	$1,100
RRF BB	$5,800	$1,300
Commercial RORO	$6,100	$1,100
Commercial BB	$5,500	$1,000

[Ref. 17]

8. Activation and Deactivation Costs

These costs apply only to the RRF vessels. Costs for activation and deactivation vary depending upon the source. Admiral Donovan of MSC testified activation costs were $1.4

million per ship [Ref. 18:p. 43] while Captain Lebeck of MARAD testified activation costs were $1.6 million per ship [Ref.18:p. 102]. An average of $1.5 million will be used. An MSC figure of $3.5 million for the deactivation will be used. Activation and deactivation for an exercise is paid for by the user. During Desert Shield the activation price was initially charged to the first user of the vessel and deactivation costs were to be charged to the last user of the vessel. Due to numerous cries of foul from the various services who desired the cost to be split among all users of the vessels, the Department of the Navy absorbed activation and deactivation costs. [Ref. 19]

For most of this analysis, the cost of activation and deactivation will be assigned per voyage. It is assumed that each vessel will return to its original load port. The user pays from portal to portal, or for the round-trip. For a 255.5 day period, approximately the time of the deployment for Desert Storm, the number of round-trip voyages per vessel type was determined. By dividing the $5 million by the number of round-trip voyages possible, the user's share of the activation and deactivation costs per voyage was determined. For example, a C3 breakbulk traveling between Mobile and Ad Dammam at 18 knots would make 4.3014 trips. The user would be charged $1,162,753 as his portion of the activation and deactivation fee.

9. Special Charter Bonus

This element is applicable to only the foreign flag vessels. There was no average bonus as the amount of the special charter bonus was driven by the cash position of the company. Many foreign operating companies did not have sufficient capital to cover start up costs for a vessel. A major portion of these start up costs were for recruitment and transportation of crew members. These foreign vessels were offered at a low per diem rate with the special charter bonus used to adjust the rate up to an amount close to the per diem rate of vessels offered at a higher per diem rate with no special charter bonus. [Ref. 20]

For this analysis an average special charter bonus for foreign vessels was determined and added to the voyage costs of each vessel. The average special charter bonus was calculated by totaling the bonuses paid during Desert Storm and dividing by the total number of foreign vessels contracted. The average bonus is $177,566. Like the activation and deactivation costs, the portion of the bonus charged to the user is dependent upon how many round trip voyages a vessel can make in the seven month period.

10. Canal Transit Costs

Vessels departing from and returning to Mobile and Norfolk will transit the Suez Canal. Each vessel is assumed to take one day to transit the Canal whether transitting north or south. Cost for canal transits are dependent upon tonnage. However, numerous surcharges are applied for such things as time of transit, if the vessel is listed in *Jane's Fighting Ships*, late transit fees, etc. While the base fees for the types of vessels considered in this thesis range between $29 and $60 thousand, the actual costs during Desert Storm were between $58 and $392 thousand. [Ref. 21] Due to the variation in fees, MSC established standard fees to be charged to the user based on seven vessel classifications. These are listed in Table 8.

TABLE 8. SUEZ CANAL TRANSIT COSTS

VESSEL TYPE	CANAL TRANSIT COST (LOADED)	CANAL TRANSIT COST (EMPTY)
FSS	$275,000	$225,000
RRF BB	$130,000	$95,000
RRF RO/RO	$140,000	$105,000
LARGE COMMERCIAL RO/RO	$120,000	$120,000
SMALL COMMERCIAL BB	$90,000	$90,000

[Ref. 22]

11. MSC overhead

MSC overhead is calculated as a percentage of the total cost of providing transportation to a unit. The total cost includes all operating and voyage costs. Therefore activation and deactivation fees, canal transits and special charter bonuses are included in the calculation. MSC, a Naval Industrial Fund (NIF) activity, uses this money to cover its operating expenses, including the cost of civilian labor. Percentages used in calculating overhead charges are in Table 9.

TABLE 9. OVERHEAD CHARGE (PERCENT) PER VESSEL TYPE

Vessel Type	Overhead Charge
FSS	2%
RRF	1%
Commercial	.5%

[Ref. 23]

C. PORT INFORMATION

Units will be deployed from three United States ports; Norfolk, VA, Mobile, AL, and Oakland, CA, to Ad Dammam, Saudi Arabia. These ports were chosen because units were actually deployed from them during Desert Shield. Based on discussions with Military Traffic Management Command (MTMC) personnel at each port, the number of vessels, per class, that can be loaded at one time are in Table 10. For example in Oakland four FSS, four CAPE H, six breakbulks, or five ROROs can be loaded at one time. Combinations of these vessels can also be done. For example, two CAPE H and two FSS can be loaded at the same time.

It is assumed that commercial operations will not be disrupted and that only piers presently available for military use will be utilized. Due to Ad Dammam's superior port capabilites it is assumed that the port will be able to match the loading times of the three U.S. ports [Ref. 24].

TABLE 10. NUMBER OF VESSEL THAT CAN BE LOADED AT ONE TIME PER PORT

Vessel Type	Norfolk, VA	Mobile, AL	Oakland, CA
FSS	2	2	4
CAPE H	2	2	4
Breakbulk	3	5	6
RORO	2	2	5

[Ref. 25, 26 and 27].

D. DEPLOYMENT OF UNITS

Using some of the vessel combinations in the Military Traffic Management Command Deployment Planning Guide, the total costs and number of days required to complete the deployment of an Armored Division and Light Infantry Division were calculated [Ref 11.:pp. C-15 & C-17]. These two units were chosen because of the large difference in their vessel requirements. The Armored Division's cargo capacity requirements are relatively large compared to those of the Light Infantry Division.

Vessel mixes, including C3 or C4 and U.S. owned or foreign owned (FRGN) were assigned as follows. The C3 and C4 mix is a ratio of the actual number of these type ships in the RRF in 1990. There were 30 C3 and 18 C4. Therefore when a deployment scenario calls for a specific number of C3/C4 breakbulks, 62.5 percent will be C3 and 37.5 percent will be C4. As for the U.S owned and foreign owned mix, use follows contracting regulations, and U.S. ships are given first priority in contracting. During Desert Shield, 12 U.S. owned small breakbulks were used. Therefore the first 12 breakbulks will be U.S. owned with the remainder being chartered from the foreign market. One large RORO, the MALLORY LYKES, was chartered from the U.S. market. The first RORO assigned will be U.S. with the remainder from the foreign market.

Some of the vessel options to meet the requirement for deploying an Armored Division are in Table 11. Options 1, 3 and 4 utilize maximum containerization while the other options use minimum containerization.

Some of the vessel options for the deployment of a Light Infantry division are in Table 12. Note that due to the relative small size of the cargo no foreign vessels are required. Maximum contanerization is used in options 3 and 4, while the remaining options use minimum containerization.

From the data presented in this chapter, the total costs and total deployment days for each of the units' deployment options are calculated and presented in Chapter IV.

TABLE 11. ARMORED DIVISION DEPLOYMENT VESSEL COMBINATION OPTIONS

Vessel Type	Option 1 (a)	Option 2	Option 3 (a)	Option 4 (a)	Option 5	Option 6
FSS	4.67	8				
CAPE H	3	1.93				
C3			18.51		23.68	
C4			11.1		14.2	
C7	2		2.1			
U.S. BB				12		12
U.S. RORO				1		
FRGN BB				17.61		25.88
FRGN RORO				1		

Note: (a) Maximum containerization is used.

TABLE 12. LIGHT INFANTRY DIVISION DEPLOYMENT VESSEL COMBINATION OPTIONS

Vessel Type	Option 1	Option 2	Option 3 (a)	Option 4 (a)	Option 5	Option 6
FSS	2.97					
CAPE H		2.67				
C3			4.08		7.65	
C4			1.97		3.69	
C7		.32	1			
U.S. BB				6.05		11.34
U.S. RORO				1		

Note: (a) Maximum containerization is used.

IV. DATA ANALYSIS

Chapter IV examines the trade-offs between speed, vessel types, voyage route and load ports. Cost and time are used to measure the trade-offs. As will be shown, many times one trade-off is offset by another. To best understand sealift costs, each of the cost classifications in Chapter III must be analyzed individually and then their impact on the total cost must be analyzed. Sealift choices must also be analyzed on the basis of total deployment time. From these trade-offs between costs and total deployment time, a decision can be made which will ensure more efficient use of DOD's limited resources.

A. TOTAL DEPLOYMENT COSTS AND DEPLOYMENT DAYS

From the data presented in Chapter III, the total costs and total deployment times per option were determined. Total costs are based on the cost incurred while inport loading and unloading, and on the round trip transit to and from Ad Dammam. Deployment times were calculated by summing the total days in port to load and discharge the vessel and the transit time one way to Ad Dammam. The return trip from Ad Dammam is not included in the total deployment time calculations.

For ships transiting from Oakland it is assumed that they will spend one day each way refueling at an enroute port.

Tables 13, 14 and 15 present the costs for the movement of an Armored Division from Oakland, Mobile and Norfolk respectively. The options used in these tables are the vessel mix alternatives presented in Table 11 of Chapter III. Figures 3, 4 and 5 graphically depict this data.

Tables 16, 17 and 18 provide the costs for the movement of a Light Infantry Division from Oakland, Mobile and Norfolk respectively. The options in these tables are the vessel mix alternatives presented in Table 12 of Chapter III. Figures 6, 7, and 8 graphically display this data.

TABLE 13. TOTAL COST AND DEPLOYMENT DAYS, PER OPTION, FOR THE DEPLOYMENT OF AN ARMORED DIVISION FROM OAKLAND

Option Number	Total Cost	Total Deployment Days
1	$27,019,244	36.71
2	$27,676,807	38.71
3	$89,927,218	68.71
4	$32,367,838	75.48
5	$107,475,842	82.21
6	$36,296,291	87.47

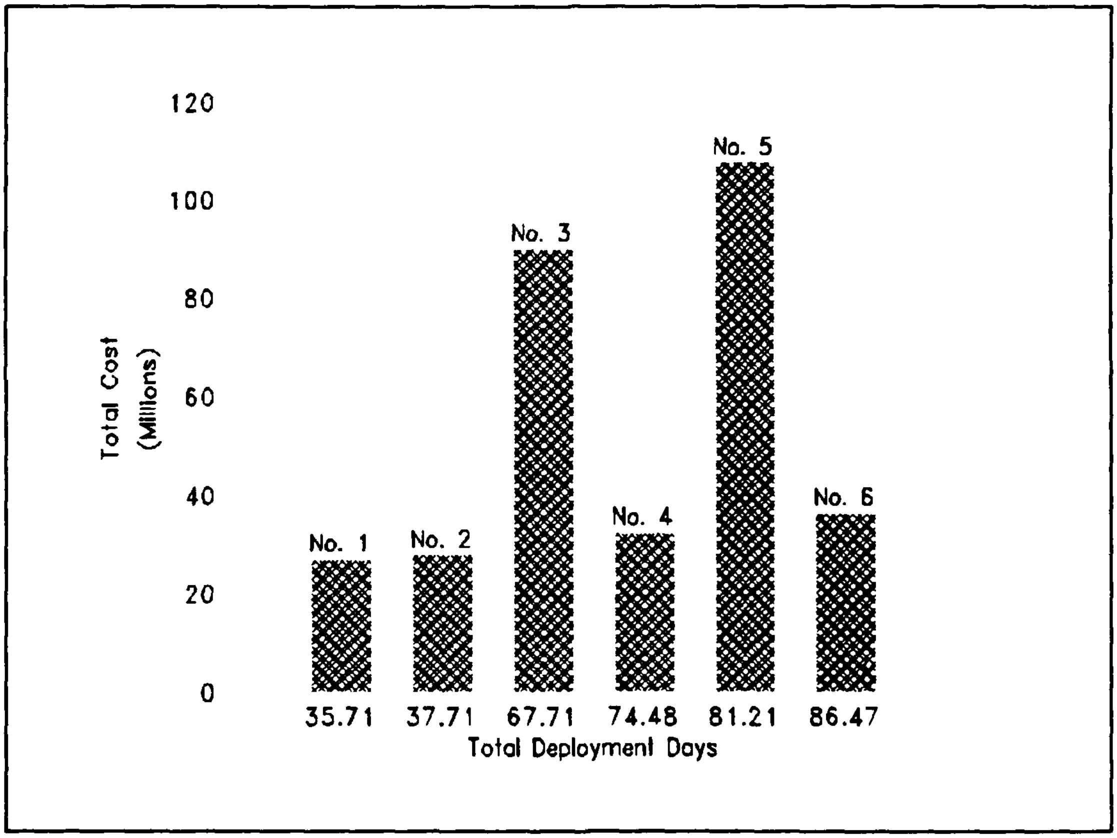

Figure 3. Total Cost and Deployment Days, Per Option, for the Deployment of an Armored Division From Oakland

TABLE 14. TOTAL COST AND DEPLOYMENT DAYS, PER OPTION, FOR THE DEPLOYMENT OF AN ARMORED DIVISION FROM MOBILE

Option Number	Total Cost	Total Deployment Days
1	$27,345,386	41.46
2	$28,864,092	43.18
3	$86,719,439	73.38
4	$34,348,720	78.42
5	$103,631,736	87.18
6	$38,865,189	90.42

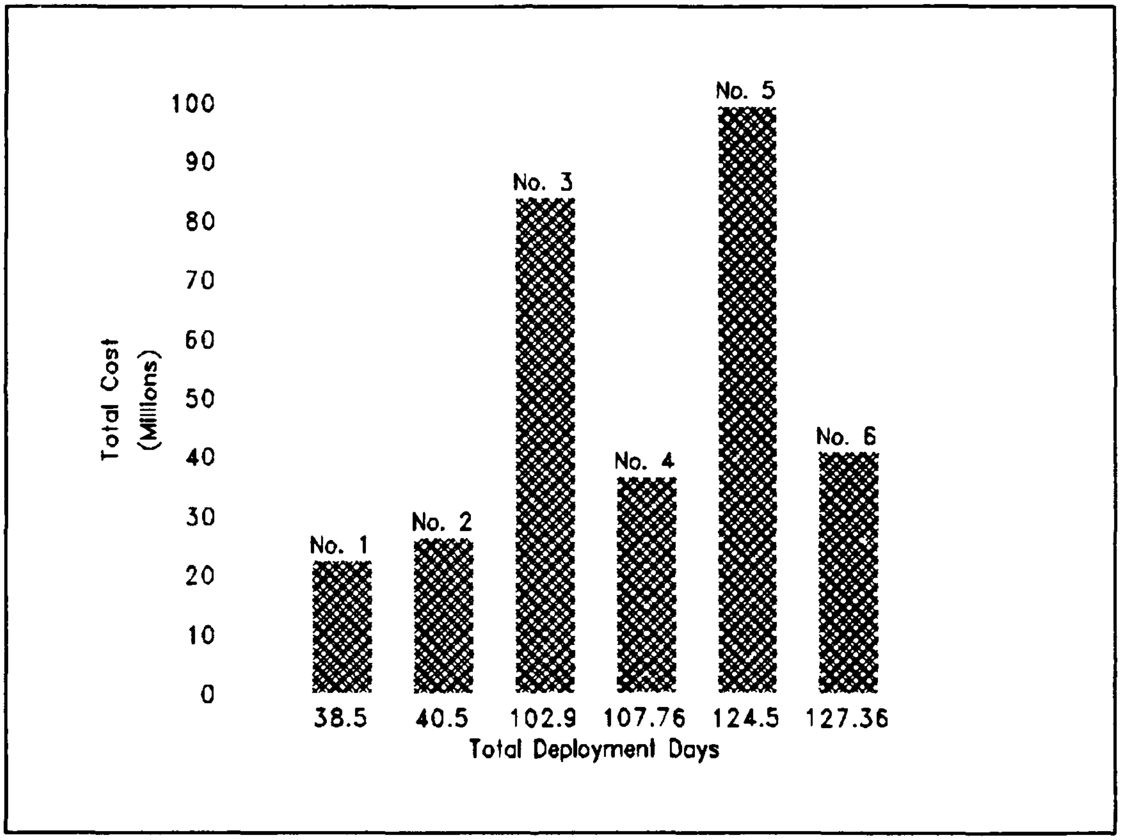

Figure 4. Total Cost and Deployment Days, Per Option, for the Deployment of an Armored Division From Mobile

TABLE 15. TOTAL COST AND DEPLOYMENT DAYS, PER OPTION, FOR THE DEPLOYMENT OF AN ARMORED DIVISION FROM NORFOLK

Option Number	Total Cost	Total Deployment Days
1	$24,713,769	38.5
2	$26,111,465	40.5
3	$78,943,812	102.9
4	$31,591,784	107.76
5	$94,429,878	124.5
6	$35,785,982	127.36

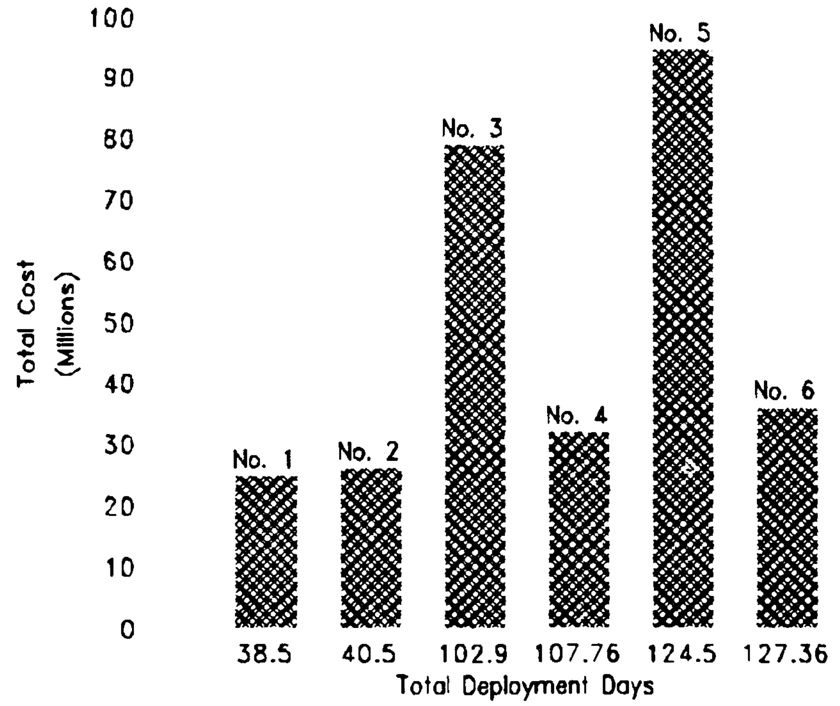

Figure 5. Total Cost and Deployment Days, Per Option, for the Deployment of an Armored Division from Norfolk

TABLE 16. TOTAL COST AND DEPLOYMENT DAYS, PER OPTION, FOR THE DEPLOYMENT OF A LIGHT INFANTRY DIVISION FROM OAKLAND

Option Number	Total Cost	Total Deployment Days
1	$8,275,053	20.43
2	$8,354,047	30.71
3	$19,940,825	36.91
4	$8,335,263	38.58
5	$32,096,303	42.71
6	$11,983,568	44.38

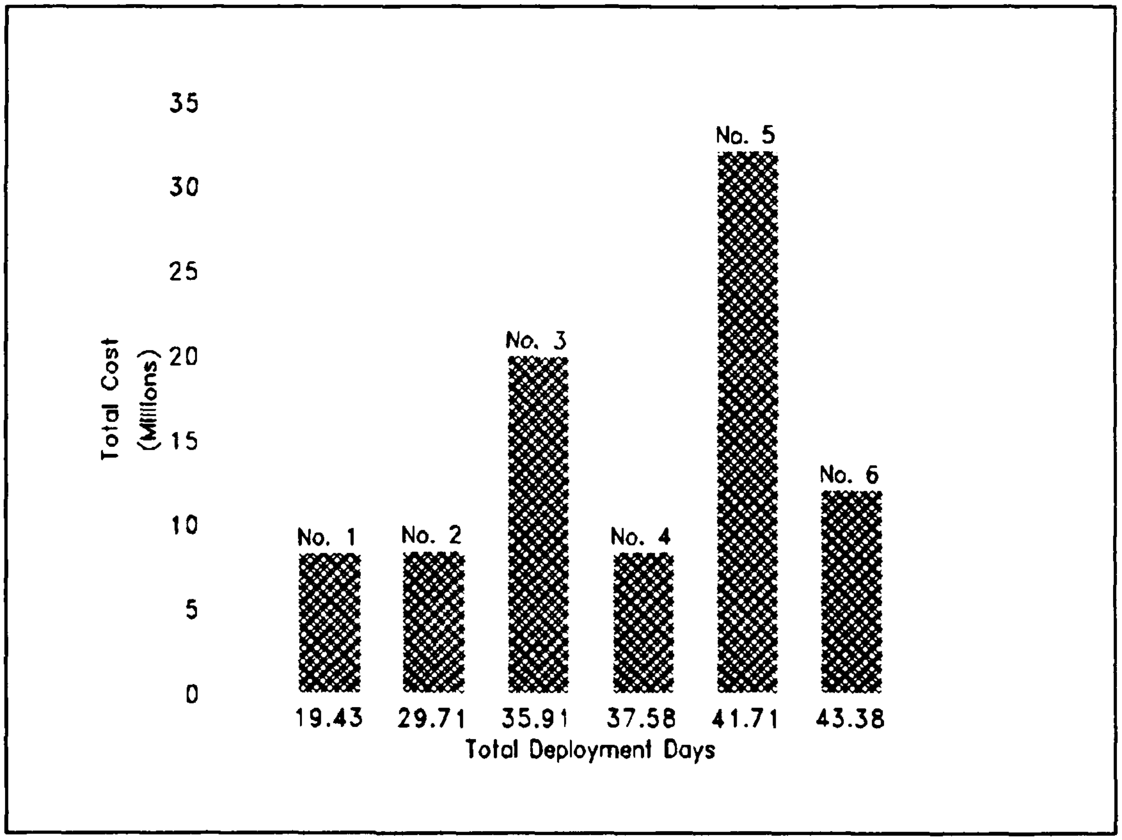

Figure 6. Total Cost and Deployment Days, Per Option, for the Deployment of a Light Infantry Division from Oakland

TABLE 17. TOTAL COST AND DEPLOYMENT DAYS, PER OPTION, FOR THE DEPLOYMENT OF A LIGHT INFANTRY DIVISION FROM MOBILE

Option Number	Total Cost	Total Deployment Days
1	$8,778,818	22.19
2	$8,088,417	29.86
3	$19,235,801	39.18
4	$8,658,132	40.62
5	$30,955,986	47.18
6	$12,569,619	48.62

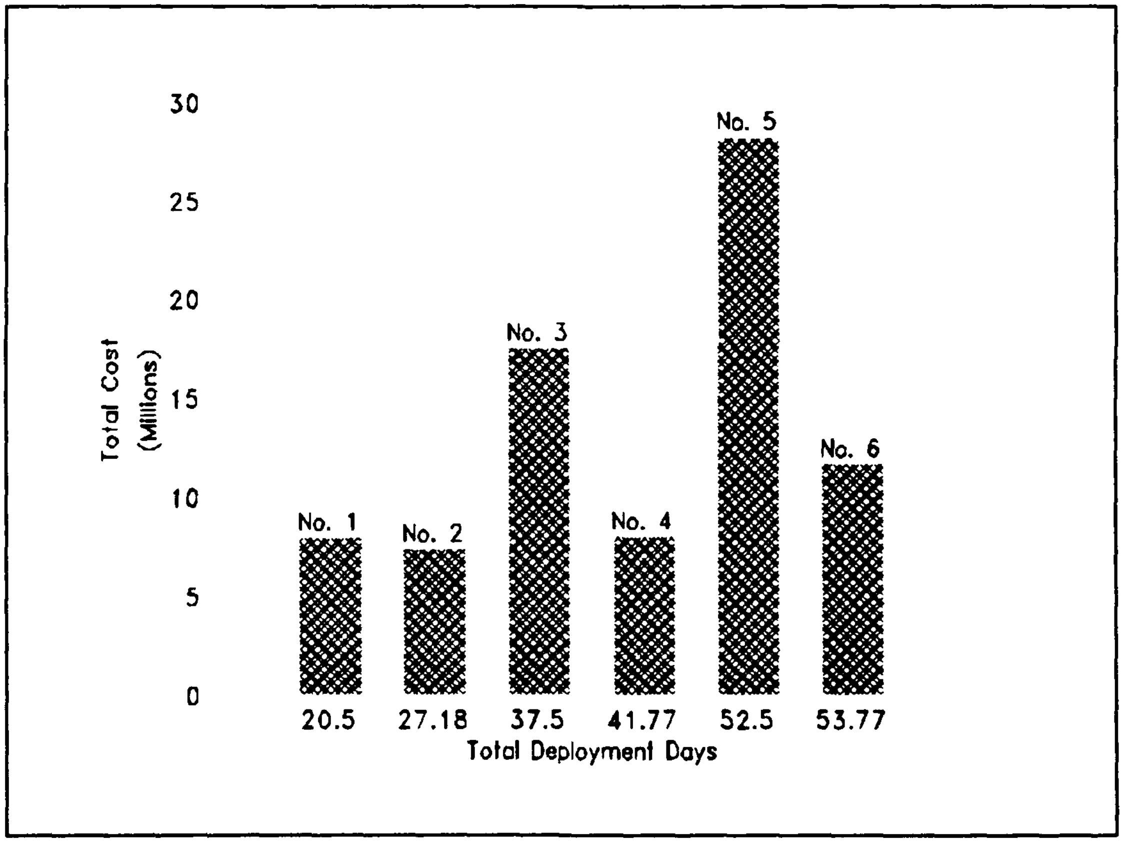

Figure 7. Total Cost and Deployment Days, Per Option, for the Deployment of a Light Infantry Division from Mobile

TABLE 18. TOTAL COST AND DEPLOYMENT DAYS, PER OPTION, FOR THE DEPLOYMENT OF A LIGHT INFANTRY DIVISION FROM NORFOLK

Option Number	Total Cost	Total Deployment Days
1	$7,940,031	20.5
2	$7,317,225	27.18
3	$17,492,849	37.5
4	$7,947,397	41.77
5	$28,209,186	52.5
6	$11,602,135	53.77

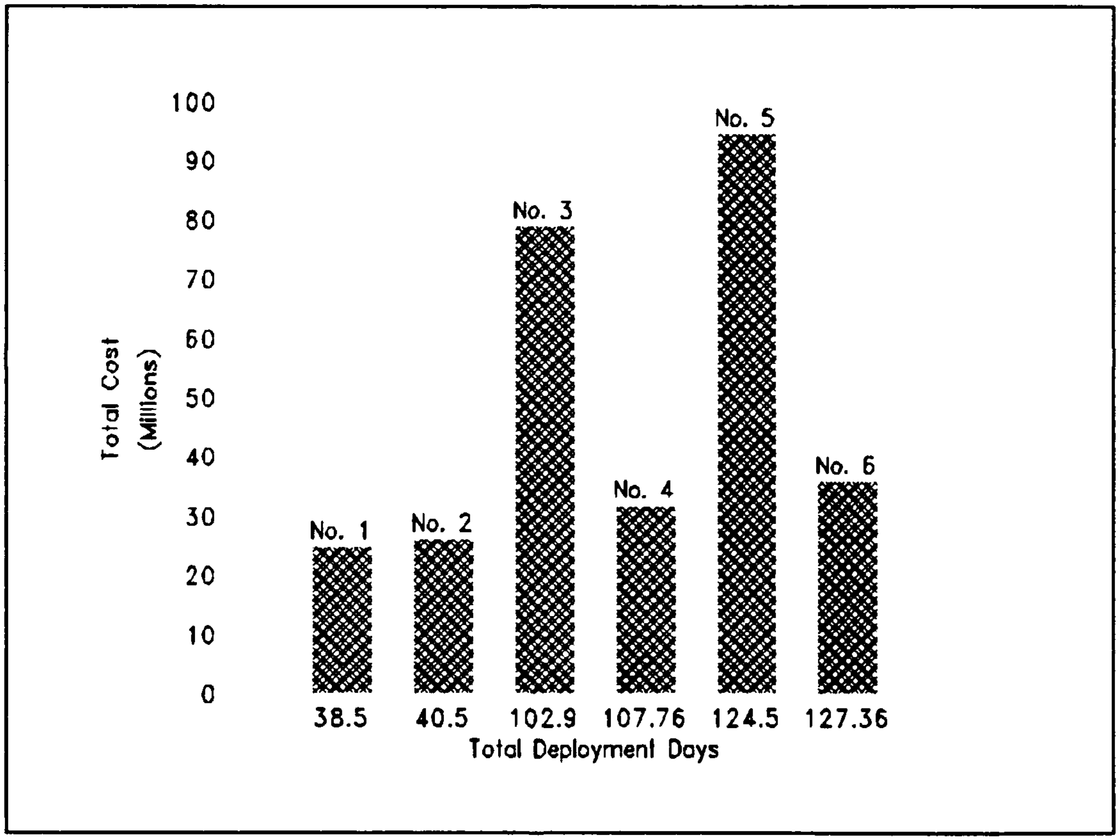

Figure 8. Total Cost and Deployment Days, Per Option, for the Deployment of a Light Infantry Division from Norfolk

B. ROROs COMPARED TO BREAKBULKS

Figures 3 through 8 show that ROROs (FSS, CAPE H class, C7 and commercial ROROs) are the least expensive means to move an armored division and light infantry division. For example in Figure 3, options 1 and 2 are the cheapest for moving an armored division; both these options, as discussed in Chapter III, use only ROROs. This, however, contradicts our intuition that the faster the deployment, the higher the costs. Table 19 lists the total cost (total operating cost plus total voyage cost) per vessel type from each port.

TABLE 19. TOTAL COST PER VESSEL TYPE

Vessel Type	Oakland	Mobile	Norfolk
FSS	$2,786,213	$2,953,831	$2,673,411
CAPE H	$2,791,245	$2,703,339	$2,447,760
C7	$2,816,947	$2,720,319	$2,442,830
U.S. RORO	$1,941,913	$1,952,118	$1,757,545
Foreign RORO	$1,675,934	$1700,436	$1,560,469
C3	$2,784,914	$2,690,435	$2,452,811
C4	$2,924,583	$2,811,425	$2,559,670
U.S. Breakbulk	$1,056,752	$1,108,432	$1,023,116
Foreign Breakbulk	$912,491	$987,790	$908,369

Although Table 19 shows the commercial breakbulks as the least expensive vessel per single voyage, from the options it is known that more breakbulks are required to deploy a unit due to their relatively small carrying capacity. To better understand the total cost figures in Table 19, they have been converted into cost per notional square foot. Table 20 lists the notional square foot (SQ FT) and cost per square foot per vessel type. Due to the variation in vessel cargo capacity this is a standard and more accurate means of comparing the costs among the vessel types.

Table 20 shows that, per square foot, the ROROs are less expensive than the breakbulks. This explains why the RORO options were the least expensive.

TABLE 20. VESSEL COST PER NOTIONAL SQUARE FOOT (SQ FT)

Vessel (Thousand SQ FT)	Oakland Cost per SQ FT	Mobile Cost per SQ FT	Norfolk Cost per SQ FT
FSS (150)	$18,575	$19,706	$17,823
CAPE H (139)	$20,081	$19,448	$17,610
C7 (115)	$24,495	$23,655	$21,242
U.S. RORO (115)	$16,886	$16,975	$15,283
Foreign RORO (115)	$14,573	$14,786	$13,569
C3 (48)	$69,623	$67,261	$61,320
C4 (40)	$60,928	$53,326	$58,571
U.S. Breakbulk (45)	$23,483	$24,632	$22,736
Foreign Breakbulk (45)	$20,278	$21,951	$20,186

[Ref. 28]

C. SPEED'S IMPACT ON PER DIEM AND FUEL COSTS

As discussed in Chapter II, speed impacts both per diem and fuel costs. The trade-offs between vessel speed and costs for the government owned and commercial ROROs are presented in Table 21. Table 21 shows the warranted speed, round trip transit time (days), total per diem and total fuel costs per voyage for each RORO.

TABLE 21. RORO TOTAL PER DIEM AND FUEL COSTS PER ROUND TRIP TRANSIT FROM OAKLAND AT WARRANTED SPEED

Vessel Type	Warranted Speed	Round Trip Transit Time (Days)	Total Per Diem Cost	Total Fuel Cost
FSS	30	36.85	$918,895	$1,783,486
C7	20	48.28	$1,000,000	$793,600
CAPE H	18	57.42	$1,140,000	$476,794
U.S. RORO	17.5	58.89	$1,649,050	$258,801
Foreign RORO	16.9	60.76	$1,384,700	$193,311

Table 21 shows that the FSS have the lowest total per diem cost. Although the daily per diem for the FSS is greater than the other government ROROs, this is offset by the shorter total voyage time due to the higher speed. This inverse relationship between total voyage time and total per diem costs is easily demonstrated with the government ROROs.

The per diem rate for both vessels is $20,000 per day. The C7 warranted speed is 20 knots and is charged for 48 days of per diem (user is not charged for less than a half day's use). The CAPE H has a warranted speed of 18 knots and requires 57 days to make the journey. As can be seen in Table 21, the C7, with the higher warranted speed and shorter voyage time, has a lower total per diem cost than the CAPE H.

Table 21 confirms our intuition about the trade-off between cost and speed. The total fuel costs for government vessels in Table 21 show that the faster the vessel the higher the fuel costs. The vessel costs which are dependent on speed, fuel and per diem costs, were summed and their totals are in Table 22. Table 22 shows that, for each government owned RORO, the sum of the speed dependent costs are higher for fast vessels and lower for the slower ones.

TABLE 22. TOTAL COST OF PER DIEM AND FUEL FOR THE ROROS

Vessel Type	Total Cost of Per Diem and Fuel
FSS	$2,702,081
C7	$1,793,600
CAPE H	$1,616,794
U.S. RORO	$1,907,871
Foreign RORO	$1,578,011

Although the same can be said of the commercial vessels, Table 21 shows that the U.S. RORO, while faster than a foreign RORO, has higher total per diem and total fuel costs. This can be explained by looking at the per diem rates, fuel consumption rates, and fuel prices presented in Chapter III. The U.S. RORO not only consumes more fuel than a foreign RORO, it also has a higher per diem rate. Additionally, even though the U.S. ship burns a cheaper fuel ($13.64 per barrel) than the foreign RORO ($14.33), this is offset by the greater amount of fuel the U.S. RORO consumes. Because of the complexity of the costly and expensive regulations under which

U.S. flag vessels operate, and the government-mandated priority system under which vessels are acquired (as discussed in Chapter II), this thesis will include little discussion of the trade-offs between employing U.S. or foreign owned vessels.

D. THE IMPACT OF SUEZ CANAL TRANSITS ON TOTAL VOYAGE COST

When comparing the total voyage costs for the FSS, U.S. RORO, foreign RORO, U.S. breakbulk, and foreign breakbulk in Table 19, the cost of a round trip from Oakland is at least slightly less than the cost of a round trip from Mobile for the same vessel. This is interesting because the voyage from Oakland is much longer, 22,012 nautical miles vice 19,160 nautical miles from Mobile. Because of vessel routing, the vessels deploying from Mobile and Norfolk must go through the Suez Canal and therefore incur one more cost than the same vessels deploying from Oakland.

Figure 9 compares the total costs of the six options when deploying an armored division from the three ports. Options 1, 2, 4 and 6, which rely on the use of the FSS and commercial vessels, show that it costs more to deploy the division from Mobile than Oakland.

Figure 10 compares the total costs of the six options when deploying a light infantry division from the three ports. Options 1, 4 and 6, which also employ the FSS and commercial vessels, are cheaper to deploy from Oakland than Mobile.

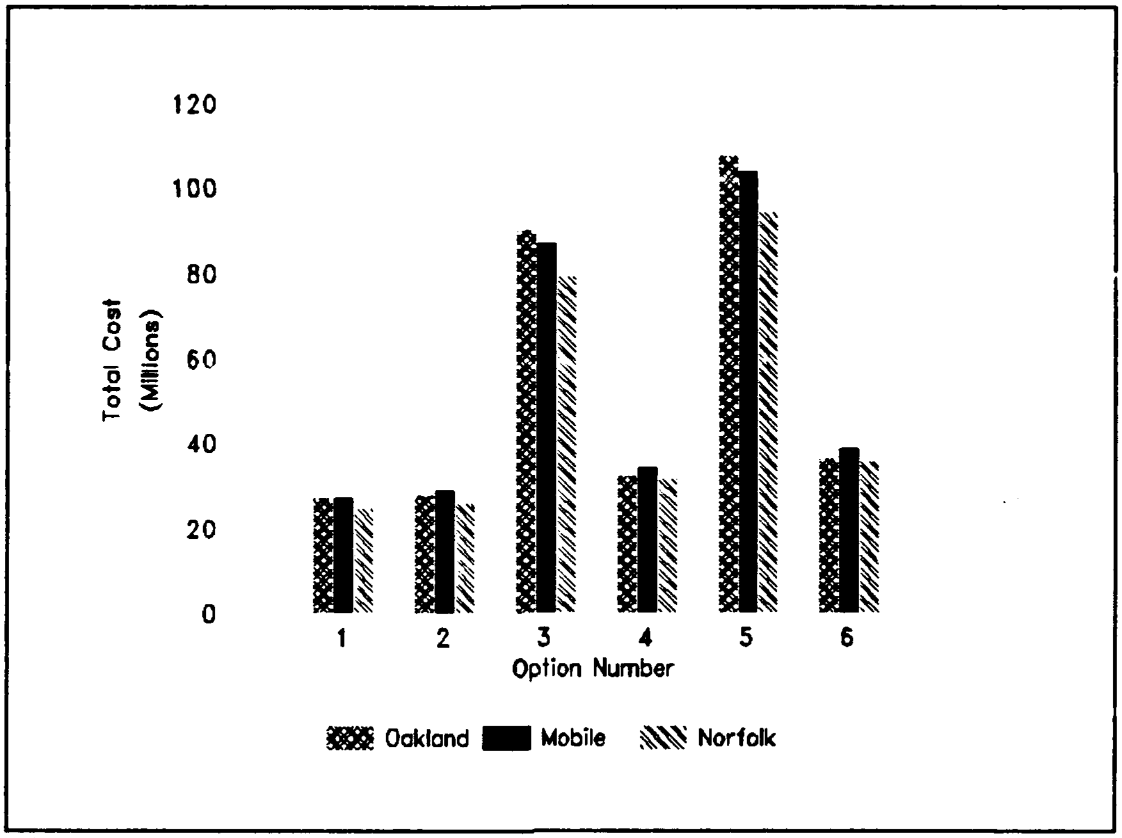

Figure 9. Comparison of the Total Costs per Option for the Deployment of an Armored Division from the Three Load Ports

The U.S. breakbulk can be used to show how the cost of a canal transit can make the cost per square foot more expensive if a unit is deployed from Mobile rather than Oakland. Table 23 shows cost per square foot for per diem and the applicable voyage costs. As costs are calculated they are cumulated in the column to the right of the individual cost. Table 23 shows that, while per diem and fuel costs for a commercial breakbulk deploying from Oakland are higher than a like vessel from Mobile, once the canal fee is added it becomes more expensive to deploy this type vessel from Mobile. The same holds true for the FSS and other commercial vessels.

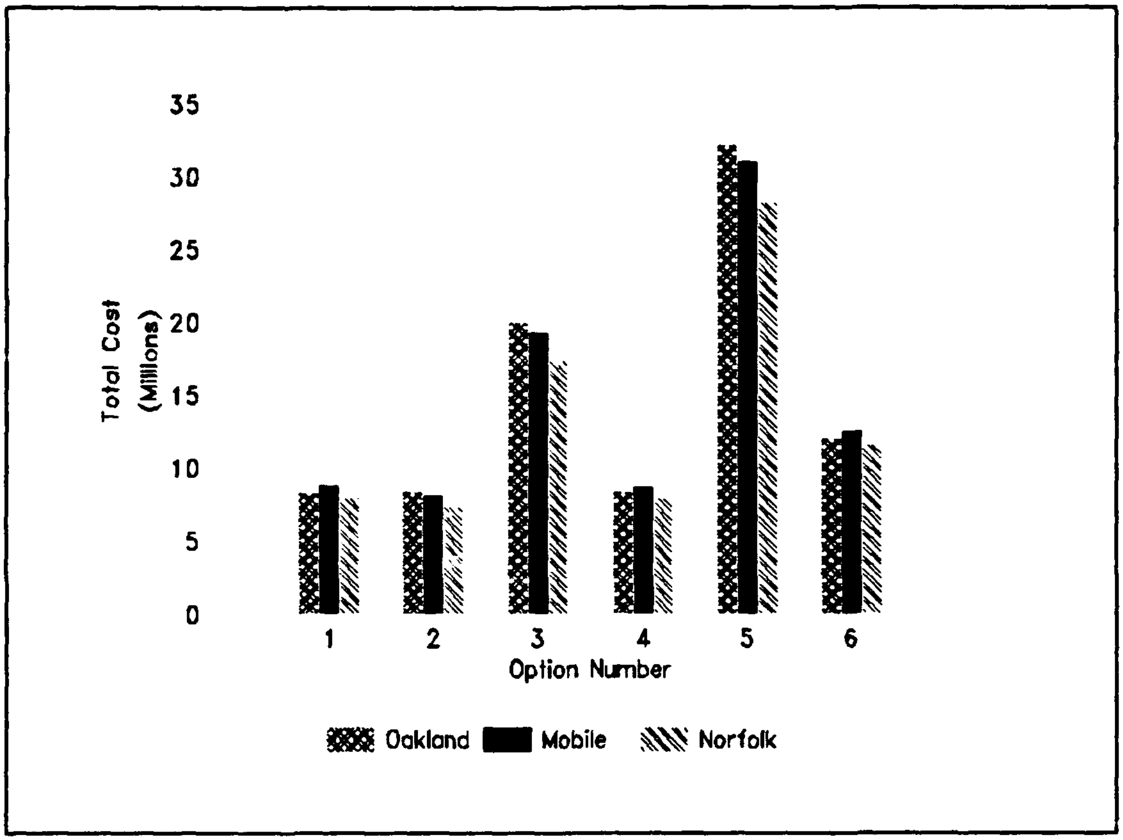

Figure 10. Comparison of Total Cost per Option for the Deployment of a Light Infantry Division from the Three Ports

TABLE 23. SQUARE FOOT PER DIEM AND VOYAGE COSTS FOR A U.S. BREAKBULK DEPLOYING FROM OAKLAND AND MOBILE

Cost	Oakland Cost per Square Foot	Oakland Cum. Total	Mobile Cost Per Square Foot	Mobile Cum. Total
Per diem	$17,044	$17,044	$14,947	$14,947
Fuel	$5,744	$22,788	$4,985	$19,932
Canal	$0	$22,788	$4,000	$23,932
Port	$578	$23,336	$578	$24,510
Overhead	$117	$23,483	$123	$24,633

The following equation can be used to determine at what total voyage length, measured in days, a vessel sailing on a route through the Suez Canal will have costs equal to the same vessel deploying from Oakland:

$$D=\frac{TCO+DI(FU+FI)-C}{PD+FU}$$

where: D = total voyage days
TCO = total cost Oakland
FU = fuel cost per day underway
DI = total voyage days inport
FI = fuel cost per day inport
C = Canal Cost
PD = per diem cost

Using this equation it can be determined that any round trip voyage of a U.S. breakbulk greater than 54 days that requires a Suez Canal transit will cost more than deploying the same vessel from Oakland.

E. THE IMPACT OF ACTIVATION AND DEACTIVATION COSTS

The activation and deactivation fee is allocated across all the voyages that a ship is expected to make in an arbitrary time frame of 255.5 days. Therefore the activation and deactivation fee is dependent upon voyage length (distance). In addition to analyzing the impact of the fee calculated in this manner, it is important to consider two other ways of allocating this fee. The first is to do as was done during Desert Shield and have the Navy pay the fee with no cost to the user. The second is to assume the user is the first user of the RRF vessel and therefore charge him the entire cost of activation, $1.5 million.

1. Activation and Deactivation Fee Based on Voyage Length (Distance)

As previously discussed the costs of a Suez Canal transit can significantly impact the total cost of a vessel. In the case of the FSS and commercial vessels, if the same vessel is deployed from each of the three ports, the deployment from Mobile will be the most expensive. Table 20 shows that the cost per square foot for these vessels is less when deployed from Oakland than Mobile. However, Table 20 also shows that the RRF vessels cost the most per square foot when deployed from Oakland. This is because the savings from not paying a canal fee when deploying from Oakland are offset by the relatively large activation and deactivation fee for vessels sailing from Oakland.

As discussed in Chapter III, the activation and deactivation cost is dependent upon the length, measured in distance, of the deployment. For the same RRF vessel the total deployment distance from Oakland is greater than the deployment distance from the other two ports. Therefore the activation and deactivation cost is higher for the same vessel sailing from Oakland.

Once again the measure of square foot is used to analyze the various costs. The CAPE H class will be used to show the impact of the activation and deactivation fee. The cumulative costs per square foot for deploying a CAPE H from the three ports is in Table 24.

TABLE 24. CUMULATIVE (CUM) SQUARE FOOT (SQ FT) COSTS FOR CAPE H

Cost	Oakland Cum. Cost per SQ FT	Mobile Cum. Cost per SQ FT	Norfolk Cum. Cost per SQ FT
Per Diem	$8,201	$7,194	$6,475
Fuel	$11,631	$10,165	$9,099
Port	$11,798	$10,332	$9,266
Canal	$11,798	$12,167	$11,101
Overhead	$11,997	$12,360	$11,275
A & D	$20,081	$19,449	$17,610

Looking at the cumulative figures it can be seen that as costs are added for the CAPE H vessel, it is initially more expensive to deploy from Oakland. Once the canal costs are added it becomes more expensive to deploy from Mobile. Finally, when the activation and deactivation fee is added it becomes, once again, more expensive to deploy from Oakland.

2. No Activation and Deactivation Fee

Table 25 and Figure 11 show the total cost per option for each of the three ports with no activation and deactivation fee. Without this fee, for each vessel type, Mobile has the highest total cost among the three ports. As can be seen in Table 25 and Figure 11, because the activation and deactivation fee no longer offsets the impact of the canal transit fee, Mobile becomes the most costly of the three ports to deploy from.

TABLE 25. TOTAL COST FOR DEPLOYMENT OF A LIGHT INFANTRY DIVISION WITH NO ACTIVATION AND DEACTIVATION FEE

Option Number	Oakland	Mobile	Norfolk
1	$8,275,053	$8,778,817	$7,940,030
2	$5,006,015	$5,153,432	$4,695,140
3	$8,232,947	$8,446,238	$7,726,031
4	$8,335,263	$8,656,132	$7,947,397
5	$18,330,558	$18,773,725	$18,254,261
6	$11,983,658	$12,569,619	$11,602,135

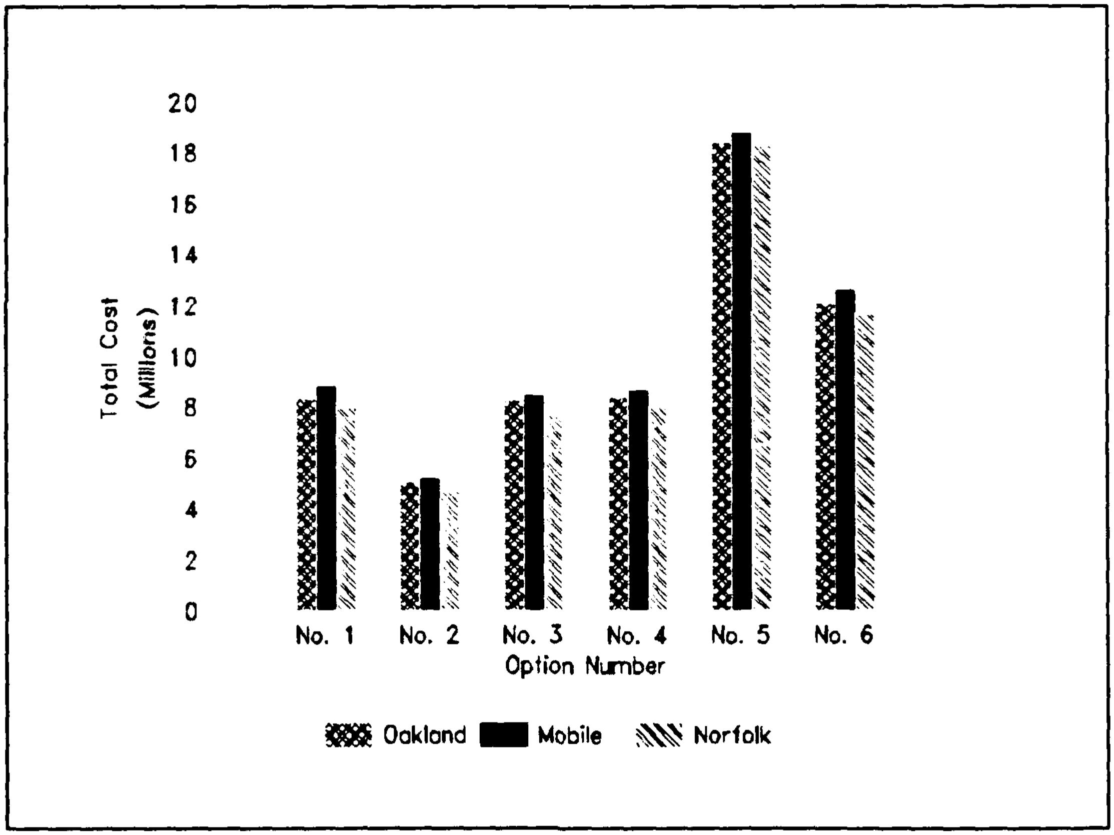

Figure 11. Total Cost for Deployment of a Light Infantry Division, per Option, with the User Paying no Activation Cost

3. Impact of Total Activation Fee Only

When the assumption is changed so that the user pays the entire activation fee of $1.5 million the results are presented in Table 26 and graphically displayed in Figure 12. As can be seen the cost of the activation fee, because it is not dependent on voyage length, does not offset the canal transit costs. Therefore because a constant figure is added to each of the options, once again the options are more expensive from Mobile than Oakland. Using Figures 10, 11 and 12, the effect of different activation and deactivation allocation schemes can be compared with respect to both vessel assignment options and ports.

TABLE 26. TOTAL COST, PER OPTION, FOR THE DEPLOYMENT OF A LIGHT INFANTRY DIVISION WITH THE USER PAYING THE ENTIRE ACTIVATION FEE

Option Number	Oakland	Mobile	Norfolk
1	$8,275,053	$8,778,818	$7,940,031
2	$9,535,865	$9,683,282	$9,224,990
3	$22,2283,722	$22,549,176	$21,241,400
4	$8,335,263	$8,658,132	$7,947,396
5	$35,510,658	$35,953,825	$34,406,578
6	$11,983,568	$12,569,619	$11,602,135

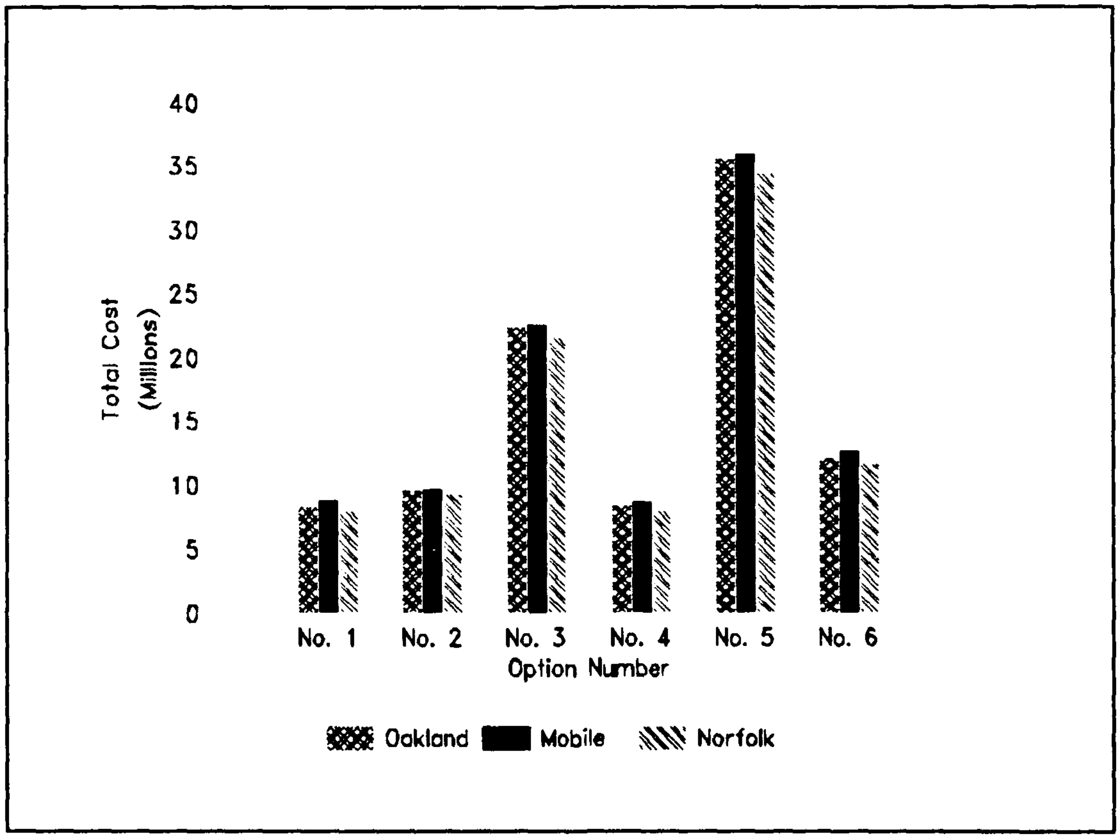

Figure 12. Total Cost, per Option, for the Deployment of a Light Infantry Division with the User Paying the Entire Activation Fee

F. PORT LOADING CAPABILITY AND ITS IMPACT ON TOTAL DEPLOYMENT TIME.

Load port can significantly impact total deployment times. The number of vessels a port can handle per day helps determine how long it will take to deploy a unit. Oakland can handle more vessels at one time than the other two ports. Option 3 for the movement of an armored division requires 37.88 breakbulk vessels. Table 27 shows the number of breakbulks which can be accommodated at one time per port and the total days inport required to load and discharge an armored division. It was previously assumed that Ad Dammam is able to accommodate as many vessels as the load port can. In other words, if Norfolk can load three breakbulks at one time, Ad Dammam will discharge three breakbulks at one time. However if Oakland loads six breakbulks at one time Ad Dammam will discharge six breakbulks at one time.

TABLE 27. PER PORT THE NUMBER OF BREAKBULKS HANDLED AT ONE TIME AND TOTAL DAYS FOR DEPLOYMENT OF AN ARMORED DIVISION USING OPTION 3

Port	Number of Breakbulks Handled at One Time	Total Days Inport for Deployment
Oakland	6	56
Mobile	5	64
Norfolk	3	104

As can be seen, Oakland can load twice the number of breakbulks Norfolk can at one time. As a result these vessels are loaded in approximately half the time it would take to load a unit in Norfolk.

G. TRADE-OFFS AMONG VESSEL MIXES

Not only are there trade-offs among the vessel classes but there are trade-offs among the vessel mixes. This becomes evident when comparing in Table 25 the total costs of options 1 and 4 for deployment of a Light Infantry Division from Mobile and Norfolk. When deploying a division from Norfolk, option 1, with 2.97 FSS, is the third least expensive and option 4, with 6.50 U.S. breakbulk and one U.S. RORO, is the fourth least expensive. The opposite is true for Mobile with option 4 being the third least expensive and option 1 being the fourth least expensive.

Table 28 shows the cumulative total costs for options 1 and 4 from Mobile and Norfolk. Table 29 shows the percent of the total cost accounted for by the five cost categories: per diem, fuel, port, canal and overhead. Figure 13 graphically presents the cumulation of costs for the two options from the two ports.

TABLE 28. CUMULATIVE TOTAL COSTS FOR OPTION 1 AND OPTION 4 FOR A LIGHT INFANTRY DIVISION DEPLOYING FROM MOBILE AND NORFOLK

Cost	Mobile Option 1	Mobile Option 4	Norfolk Option 1	Norfolk Option 4
Per Diem	$2,434,078	$5,522,630	$2,139,039	$4,997,980
Fuel	$7,034,960	$7,104,353	$6,212,619	$6,397,159
Port	$7,121,684	$7,286,053	$6,299,343	$6,578,859
Canal	$8,615,053	$8,613,052	$7,784,343	$7,907,859
Overhead	$8,778,817	$8,656,128	$7,940,030	$7,947,398

TABLE 29. COST CLASSIFICATION PERCENTAGES OF TOTAL COSTS FOR OPTIONS 1 AND 4 FOR A LIGHT INFANTRY DIVISION DEPLOYING FROM MOBILE AND NORFOLK

Cost	**Mobile Option 1**	**Mobile Option 4**	**Norfolk Option 1**	**Norfolk Option 4**
Per Diem	27.73%	63.80%	26.95%	62.89%
Fuel	52.40%	18.27%	51.31%	17.60%
Port	1.00%	2.10%	1.09%	2.29%
Canal	16.93%	15.33%	18.71%	16.7%
Overhead	1.94%	.50%	1.94%	.50%

Using Tables 28 and 29 and Figure 13, comparison of the options highlights a number of trade-offs previously discovered and how they can be applied to vessel mixes. The trade-offs between speed and fuel and per diem can be seen by comparing options 1 and 4 for each port. Both options 1, with the faster FSS's, show that the faster ship has the majority of its costs allocated to fuel (52.4% for Mobile and 51.31% for Norfolk). The slower option, option number 4, has the majority of its cost allocated to per diem (63.8% for Mobile and 62.89% for Norfolk). This confirms our intuition that speed and per diem costs are inversely related while speed and fuel costs are directly related.

When comparing the total costs of the different options we can compare the effect of using different ships and their associated differing costs. Not only do the ships have different per diem and fuel costs but they also have differing port, canal and overhead costs. As the costs for

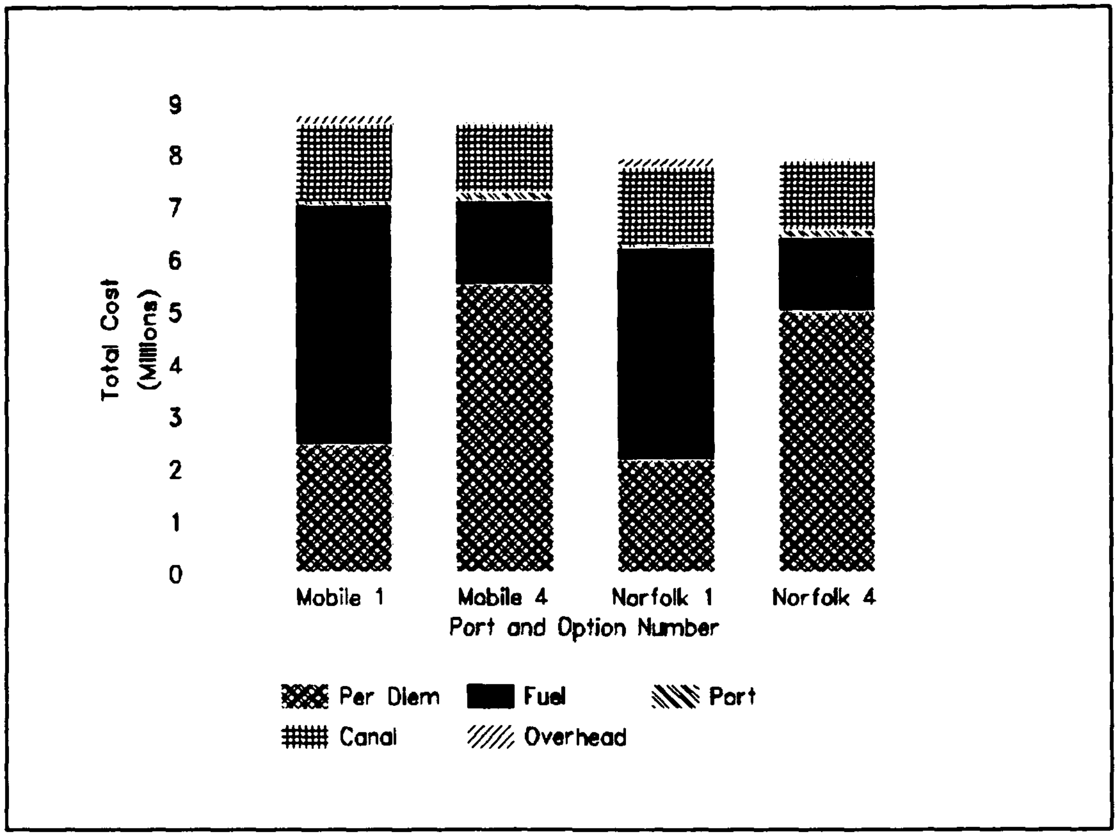

Figure 13. Cumulative Costs for Options 1 and 4 from Mobile and Norfolk

the different vessels making up an option are totaled the option rankings based on cost change.

For example, after fuel and per diem costs are totaled in Table 28, from both Mobile and Norfolk option 4 is more expensive than option 1. After port costs are added in this remains true. However once canal costs are added, option 1 becomes more expensive than option 4 when deploying from Mobile, but when deploying from Norfolk option 4 is still more expensive than option 1.

From this it can be concluded that at some voyage distance the cost of per diem and fuel offsets the impact of the canal costs. This breakeven point can be determined by setting the two options equal to each other and solving for distance. In the case of this example the breakeven point would fall between the round trip distances of Norfolk, 16,848 nautical miles and Mobile, 19,160 nautical miles.

As costs are cumulated and their impact upon total cost is assessed it is important to also compare the time to complete deployment for each option. As shown in Table 18, from Norfolk option 1, the fastest means of deployment with a total deployment time of 20.5 days, is slightly cheaper than option 4, the fourth ranked with a deployment time of 41.77 days. However Table 17 shows that from Mobile option 4, with the fourth ranked deployment time of 40.6 days, is somewhat cheaper than option 1 with the fastest deployment time of 22.19 days.

While Norfolk has a shorter underway time for all vessels, for options one and four total deployment time is longer than the options deploying from Mobile. This can be attributed to port capability and the number of vessels which can be loaded at one time. As seen in Table 27, Norfolk can handle fewer vessels at one time than Mobile. Therefore total deployment time for some vessel mixes is longer from Norfolk than Mobile, a port which requires more time underway.

This chapter has shown that to fully understand trade-offs one must first understand how costs are assigned. Once costs are defined and calculated they must be analyzed both individually and as a total. By comparing the impact each cost classification has on the total cost, the trade-offs among vessel type, route selection, load port and speed of deployment can be seen. This trade-off analysis then becomes important in ensuring the most efficient use of resources when making sealift vessel assignments.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

While the trade-offs discussed in this thesis are just some of those to be considered when assigning sealift, they highlight the importance of trade-off analysis. It is clear that trade-offs must be considered so that the most efficient use of resources will be realized. Although DOD, due to numerous government regulations, does not have the freedom the commercial world does in acquiring sealift, it still can utilize trade-off analysis. In fact, due to these regulations, trade-off analysis is more important because of the uniqueness of some of the costs involved.

This thesis has emphasized some important trade-offs. Intuition has proven correct and the faster ships do have higher fuel costs. However, faster ships do mean lower per diem charges. In most cases though the lower per diem charges do not offset the increased cost of fuel.

Vessel route also impacts cost. A deployment from the West Coast of the United States, with a greater distance to travel then the same deployment from East and Gulf Coast ports, will not necessarily cost more. The Suez Canal transit fees are steep and can offset the cost of traveling an extra

1500 nautical miles. For an exercise or redeployment, consideration should be given to the economic feasibility of canal transits. Possibly a trip around the Cape of Good Hope, while adding days to the journey, could save money. Another possibility could be deploying a unit from a West Coast port rather than an East Coast port assuming inland transportation charges do not offset these savings associated with avoiding the canal transit. Once again another trade-off.

The allocation of activation and deactivation fees for RRF vessels can greatly impact the total cost of deployment. It may seem rational to assign costs proportional to the length of time the vessel was used. However, this represents an arbitrary allocation of fixed costs which has no inherent advantage with respect to other means of allocation. Because price should be equal to variable costs, DOD should pay the entire fee. If not, users in the name of fiscal conservatism, would use any means possible to avoid having their cargo transported on relatively expensive RRF vessels.

While the variance in the number of ships a port can handle at one time may not change the total price of a deployment, it can add to or subtract from the total deployment time. While this can not be the sole determinant of load port it should be given consideration when planning a multi-ship deployment. It should be noted that this thesis assumed the piers presently available at the three ports would be used. In a time of war, commercial and empty military berths would be made available. However, the manpower constraint could still exist. Further analysis of sealift trade-offs should include a study of different throughput capabilities for each port.

As vessel mixes are considered for a deployment the trade-offs between vessel types should also be considered. When viewed alone, one type of ship among the available types of vessels may have the least expensive total deployment costs. However, due to vessel capacity and cost structure, using only this one type of vessel does not necessarily yield the cheapest total deployment cost for a unit. As vessel types are combined for deployment of a unit, their individual capacities and cost structure will be reflected in the total deployment cost of a unit.

This thesis has also shown that a faster means of deployment, such as with the FSS, does not necessarily cause a higher total deployment cost. This needs to be considered when allocating transportation dollars. While it makes sense to assign high priority cargo to the faster ships, such as the FSS, it also makes sense to allocate more money for the movement of this high priority cargo. However, Chapter IV has shown that the use of smaller, slower breakbulks to move either a Light Infantry Division or Armored Division is more expensive than using the faster ROROs. Therefore, when allocating transportation dollars, consideration should be given to the fact that the movement of low priority cargo may in fact cost more if the slowest options which employ breakbulks are used. If sufficient funds are not allocated to move cargo assigned to the more costly breakbulks, commanders will not be able to afford to move their entire unit.

B. RECOMMENDATIONS

This analysis of trade-offs is by no means complete. When deploying a unit, sealift is not the only means of transportation to be used. Inland units must be transported to the port. The costs and capabilities of land transportation must be compared to sealift costs from each port. Once again trade-offs will occur. To fully understand the trade-offs of a deployment, inland and sealift cost must be analyzed together. Analysis of inland cost in a manner similar to that used in this thesis could be used to identify and compare the trade-offs among all phases of transportation.

For a better understanding of the trade-off between speed and fuel, fuel consumption data over different ranges of speed for each vessel type, and if possible each vessel, should be collected. While this could be costly and almost impossible to accomplish in the commercial world, for the government-owned or controlled vessels this could be accomplished during exercise deployments or RRF breakouts.

From this data, fuel consumption curves could be built and more accurate estimates of costs could be determined when a change in vessel speed is being considered. With this information, the trade-offs between cost and operational considerations could be better analyzed. An example of such an operational consideration is whether a ship's speed should be increased so that it can make the next canal transit or arrive within the tide window on Thursday vice Friday,

Further analysis of the trade-offs within and between vessel types should be accomplished to ensure an accurate understanding of costs. Collecting cost data and developing a data base from which this analysis can be done is necessary. This data base would include all transportation costs including per diem, fuel, port charges, canal fees and overhead. The data base would provide a better understanding of costs and aid in making the best vessel acquisition and assignment decisions possible.

C. FINAL NOTE

As budgets shrink and commanders are given increased responsibility for their decisions and the associated costs, it is important that commanders understand the trade-offs they face. These trade-offs consider operational commitment, measured in time, and fiscal resources, measured in dollars. The best decision is not necessarily that which is cheapest; instead it is the one which optimizes the trade-offs. In other words, the commander deploys his unit in a manner which not only meets the CINC's priorities but which makes the most efficient use of his resources and meets the fiscal constraints of both his budget and applicable regulations. At this point no other allocation of available resources can improve the exchange between trade-off factors and optimization has been achieved. This is when the commander makes the most fiscal and operationally responsible decision.

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