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Analysis of Pacific Fleet Underway Replenishment data

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NAVAL POSTGRADUATE SCHOOL
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THESIS

ANALYSIS OF PACIFIC FLEET UNDERWAY
REPLENISHMENT DATA

by

Timothy E. Conley

September 1988

Thesis Advisor: W. P. Hughes

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Analysis of Pacific Fleet Underway Replenishment Data

by

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Lieutenant, United States Navy
B.S., University of Missouri, 1975

Submitted in partial fulfillment of the
requirements for the degree of

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September 1988

ABSTRACT

A data analysis is conducted on approximately 3900 underway replenishments in the Pacific Fleet between January 1984 and June 1985. The data was reported in accordance with COMNAVSURFPACINST 3180.2E. There are four results obtained in the study. The first result is that refueling transfer rates in NWP-14C, *Replenishment at Sea* compare favorably with the observed data for average value events. Secondly for single station conventional replenishment (CONREP) of ammuntion and stores, short tons per hour as a transfer rate measure (the transfer rate in NWP-14C) is not a significant predictor of the required transfer time. Therefore the study recommends measuring conventional replenishment transfer rates in minutes per lift. Third a simple linear regression model is proposed to describe single station refueling and CONREP transfer rates. And finally a logarithmic multiple regression model is proposed to describe the total time required for an underway replenishment, for situations in which several commodities are transferred.

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ABBREVIATIONS AND VARIABLE NAMES

AE--Ammunition Ship

AFS--Combat Fleet Stores Ship

ALIFT--Observed Number of CONREP Ammunition Lifts

AMO--Ammunition Transferred During CONREP

AO--AO-177 Class Fleet Oiler

AOE--AOE-1 Sacramento Class Multiproduct Ammunition/Oiler

AOR--AOR-1 Wichita Class Fleet Oiler

ATIME--Observed CONREP Ammunition Transfer Time

AXB--Combination of AO, AOE, AOR, and TAO Data

AXL--Combination of AE and AFS Data

BB--Iowa Class Battleship

CG--Conventional or Nuclear Cruisers Excluding CG-47 Class

CINC--Commander in Chief

CLF--Combat Logistics Force Ships

COMNAVSURFPAC--Commander Naval Surface Forces Pacific Fleet

CONREP--Conventional Replenishment (Stores and/or Ammunition)

CSTA#--Number of CONREP Stations Used Per UNREP

CTIME--Observed CONREP Transfer Time (Either Ammunition or Stores)

CV--Conventional or Nuclear Air Craft Carrier

DANT--Day = 1, Night = 0

DD--Spruance Class Destroyer and Kidd Class Guided Missile Destroyer

DDG--Adams Class Guided Missile Destroyer

DFM--Quantity of Diesel Fuel Marine in Barrels or Mbbl

FAS--Refueling at Sea and Variable to Control for Refueling During CONREP

FF--Frigates FF-1037 and Above

FFG--Guided Missile Frigates FFG-1 and Above

FSTA#--Number of Fueling Stations Used Per UNREP

FUEL--Either DFM or JP5 Depending on Usage

JP5--Quantity of JP5 Transferred Per Hose in Barrels

LIFT--Observed Number of CONREP or VERTREP Transfer Lifts

Mbbl--1000 barrels (42,000 gallons)

MULT--Multiple UNREP = 1, Single UNREP = 0

NSWSES--Naval Ships Weapons Systems Engineering Station, Port Hueneme, CA

NWP--Naval Warfare Publication

OPLAN--Operational Plan as Defined in NWP-11E

PTIME--Observed Fuel Pumping Time

SLIFT--Observed Number of CONREP Stores Lifts

STAT--(Sea State > 3) = 1, (Sea State ≤ 3) = 0

STIME--Observed CONREP Stores transfer time

STO--Stores Transferred During CONREP

STREAM--Standard Tensioned Replenishment Alongside Method

TAO--TAO-105 and TAO-143 Class Fleet Oilers (USNS)

TTIME--Total time of the UNREP from Approach to Breakaway

UNREP--Underway Replenishment; Refueling, CONREP, or VERTREP

VERTREP--Vertical Replenishment (Stores, Ammunition, Personnel)

I. OPERATIONAL LOGISTICS AND UNDERWAY REPLENISHMENT

A. USING AVAILABLE DATA TO IMPROVE UNREP MODELS

This research is an analysis of Pacific Fleet Underway Replenishment (UNREP) data from January 1984 through June 1985 to provide an input to replenishment models and existing wargames. The study provides a comparison of observed replenishment data to the published rates in NWP-14C (Naval Warfare Publication-14C *Replenishment at Sea*), which is doctrine for conducting the alongside portion of underway replenishment. The publication provides a planning estimate for replenishment rates and some description of possible external factors which can affect transfer rates. The data for this analysis was reported in Commander Naval Surface Force Pacific Fleet (COMNAVSURFPAC) Report 3180-1 and in accordance with COMNAVSURFPACINST 3180.2E (*Pacific Fleet Replenishment Guide*). Records kept at the Naval Ships Weapons Systems Engineering Station (NSWSES), Port Hueneme, CA indicate the data was reported for more than twenty years, but the reporting requirement was cancelled in December 1987. Analysis of the reported data was conducted monthly but restricted to monthly summaries and yearly cumulative averages. The variability and observed external effects in the data which were not considered in the monthly reports will be studied in some detail over an eighteen month period of operations to support the original goal of collecting the data. Specifically, CNSPINST 3180.2E states: "The purpose of the Fleet Underway Replenishment Evaluation System is to provide statistical information for planning and to foster improvement in replenishment operations" [Ref 1: Part III para 3.1]. The following advice given during World War II describes the importance of using available data to understand operational problems.

> When embarking on a new problem of operational research, the first step is usually to collect as much numerical data about the operation as possible. But many data may remain unavailable, either because no records exist or because their collection is impracticable. Thus, a very incomplete numerical picture, in the form, perhaps of tables or curves representing some results of the operations as a function of some few variables is all that can usually be obtained.
>
> The first step alone maybe of the greatest importance and lead to practical conclusions of great value. For suitable presentation of the actual facts of past operations, without any interpretation, may be so striking as alone to compel reconsideration of tactics and methods.

But to go further, it is clearly necessary to relate these observed results to the actual tactics employed. In other words, the object is to find a scientific explanation of the facts. Only when this is done can the two main objects of operational research be attained. These are the prediction of the effects of new weapons and tactics. [Ref. 2: p. 25]

Earlier in Chapter 1 of Professor Waddington's history of the Operational Research Section in World War II, he quotes Professor Blackett in a 1941 report on the goals of the Operations Research Section for the Royal Air Force.

Value of Scientific Confidence and Numerical Thinking

The scientist in considering an operational problem very often comes to the conclusion that the common sense view is the correct one. But he can often back the view by numerical proof and this gives added confidence in the tactics employed....In fact the scientist can encourage numerical thinking on operational matters and so can help to avoid running the war by gusts of emotion. [Ref 2: p. 7]

B. CONCEPTS IN UNDERWAY REPLENISHMENT

1. Fleetwide and Battle Group Logistics Planning

Operational Logistics provides the planning necessary to maintain the readiness of battle group forces. Underway replenishment is one of the methods used in operational logistics to support operating forces. At the theatre and fleet level, the Operational Plan (OPLAN) from NWP-11E (Naval Warfare Publication 11E *Naval Operational Planning*) assigns responsibilities for specific levels of command to support the operational logistic requirements of notional forces. The Logistics Annex described in Chapter 12 of NWP-11E predicts requirements to support the operating forces. Adequate material (POL/Ammunition/Stores) must be available to support required operations or the mission must be changed. If, however, too much or incorrect resupply material is forwarded to the battle group, the station ship may not be able to store excess material, and thereby reduce battle group resupply efficiency.

A battle group commander is assigned the logistics responsibility for his fighting forces and each unit commander is delegated the responsibility for his unit. From NWP-11E [Ref. 3: para 4.2.3] and OPNAV Instruction 4000.85 (*Navy Logistics System,*) [Ref. 4: encl 1, p.6] there is a level of uncertainty in planning for logisitic support between Fleet CINC planning and the Battle Group Commander. Planners for battle group operations at unified and numbered fleet commands use notional planning factors to estimate the force requirements. The Battle Group Commander and his unit commanders develop resupply requirements on actual usage data. This process presents problems in different requirements generated by "push" systems of the numbered fleet commander and "pull" requirements of the unit commander. "Push and pull" describe the difference in requirements between fleet planners, who predict battle group requirements and "push" supplies to fill predicted usage and the battle group planner trying to "pull" essential and often limited supplies to meet specific and possibly unpredictable requirements [Ref. 5: p. 701]. The Combat Logisitics Force (CLF) ships in the shuttle and station ship assignments operate as warehouses adjusting continuously to balance this "push and pull" effect.

2. The Evolution of UNREP

Prior to World War II, underway replenishment systems were designed for specific delivery and receiving ships. Often the transfer rigs were simple modifications to the cargo booms and rigging of merchant vessels. Transfer of the deck plate knowledge and experience was not universal and many lessons had to be relearned over the past 80 years of UNREP. At the conclusion of World War II, the U. S. Navy had developed a significant capability to replenish fuel and ammunition at sea. Task Force 58 maintained a moving supply train in the North Pacific to support the naval assault on Japan. Following the war, the requirement for underway replenishment disappeared as did much of the experience and technology developed during the war. In the early 1950's, the Navy again needed underway replenishment to support Korean operations. The World War II and Korean War underway replenishment experience was primarily from single product ships. In 1954 successful fleet operational tests of a multiproduct transfer ship (a war prize taken from the Germans) were completed [Ref. 6: pp. 4-6]. Following these tests, the concept for the AOE (multi-product ammunition and oiler replenishment ship) was defined in 1954 [Ref. 7: pp. 13-17]. About the same time, tests were being conducted for Vertical Replenishment at Sea [Ref. 8: p. 52].

A careful evolution of underway replenishment systems, standardized equipment with proven reliability, give today's Combat Logisitics Force versatility to meet a wide variety of transfer and shuttle ship requirements. Transfer equipment is modularized for installation on merchant vessels to augment Combat Logisitic Forces [Ref. 6: p. 25]. For example equipment to transfer material at sea in today's fleet is capable of transferring a pallet of eggs, then on the next lift a "six-pack" of MK82 500lb bombs.

3. Three Types of UNREP

There are three types of underway transfer systems: Fueling at Sea (FAS), Conventional Replenishment (CONREP), and Vertical Replenishment (VERTREP). The process of transferring fuel has been the mainstay of UNREP since World War II.

Much of the technology developed in World War II was the result of work conducted as early as 1898 to resupply battle ships from merchant colliers [Ref. 6: p 2]. Today's transfer systems rely on the years of practical experience since World War II. Liquid transfer is predominately fuel for ship's main engines (DFM) and aircraft fuel (JP5). The physical process of supporting a hose between two ships is limited by the height of the hose above the water line, the separation of the two ships, the ability of the supporting stucture to compensate for relative ship movement, the ability to establish a fluid tight path, and the capability to control pumping fuel. In 1974, Commander Naval Ship Systems Engineering Station, Philadelphia, PA sponsored a study to create a computer program to simulate the underway replenishment-at-sea fueling rig system [Ref. 9: Abstract].

The second principle method of transfer, Conventional Replenishment, transfers dry cargo between ships (mail, personnel, repair parts, food, and for war time operations possibly the most important ammunition). Through World War II and the Korean Conflict, ammunition transferred at sea was often accomplished using converted merchant ships [Ref. 6: p. 5]. Since the mid 1950's, design of the transfer equipment and material handling on the delivery ship has been given the highest priority. In 1964, the Office of Naval Research directed a study to simulate the movement of dry cargo between ships engaged in replenishment at sea [Ref. 10: Abstract]. Equivalent effort to improve cargo handling on the receiving ship is not always included in combatant ship design. For instance, today's Vertical Launch Systems use manpower intensive methods to resupply missiles at sea on the receiving ship resulting in slow transfer rates [Ref. 11].

Cargo is transferred between ships using STREAM (Standard Tensioned Replenishment Alongside Method) equipment This system uses a trolley on a tensioned highline between ships to support cargo transfers. The highline maintains a constant tension using a high pressure air cushioned ram to allow pay in and out of the highline through a block on the ram and an anti-slack device to compensate for ship movement. The trolley is then pulled between the ships with inhaul and outhaul winches on the delivery ship. Engineering advances over the past thirty years in material handling and stowage make the process of underway replenishment considerably less dangerous and more reliable. [Ref. 6: p. 12]

The third method of transferring cargo between ships underway is called vertical replenishment (VERTREP), which uses helicopters to lift cargo between ships. This process eliminates direct connections between two ships and instead uses the precise control of the H-46 helo to lift and move cargo. Today VERTREP is another of the important intra battle group operational logisitics tools available to the battle group commander.

4. CLF Employment in Peacetime and During Warfighting

Because fuel, spare parts, food, and general stores are consumed when ships are underway in peacetime and at war, it is often considered the mission of CLF will be little different in the event of hostile action. The same personnel and equipment will be moving much needed fuel and ammunition. There are unanswered questions involving the employment CLF ship's in the event of hostilities. For high speed transit only the AOE is designed to keep pace with a battle group. For extended operations in a designated area removed from a support base the support ships may spend more time in a shuttle role than on station with the battle group. The period of time logisitic support ships are not directly protected by the battle group may require protection not normally assigned in peace time operations. At the heart of the logistics problem, the rigs between ships and the men to operate the rigs will be the same in peacetime and in war. During the initial hostilities and war fighting, the ability to move material will depend on the expertise demonstrated in day-to-day peacetime operations.[1]

C. THE PROCESS OF UNDERWAY REPLENISHMENT

1. UNREP Step by Step

NWP-14C provides a step by step procedure to safely conduct transfer operations. This document is updated by senior enlisted personnel knowledgeable in Underway Replenishment, who recommend changes to COMNAVSURFPAC for approval by OP-375 (Assistant Chief of Naval Operations (Surface Warfare) Combat Logistics Force Branch). The process of passing the fueling rigs, or cargo rigs is precisely defined with safety requirements and "best ways" to conduct an UNREP. Likewise VERTREP procedures are defined in NWP-14C Chapter Nine. Once the rigs are in place or the VERTREP is ready, the control of moving material often transfers to the department responsible for the cargo. Engineering department personnel control the pumping of fuel, gunner's mates transfer the bullets the supply department handles repair parts, sodas and food, but only the Postal Clerk can receive mail. The doctrine of

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1 The historical background presented here is heavily dependent on the research of Mr. Marvin Miller and Mr. John Hammet at NSWSES, Port Hueneme, CA.

moving material between ships is established, however the procedures to control the material moved is not necessarily a uniform process throughout the fleet.

2. Refueling and Conventional Replenishment

Underway replenishment can generally be divided into a beginning, middle and end. The beginning of fueling and conventional replenishments are much the same. The delivery and receiving ships maneuver into position and prepare to "come alongside." The receiving ship starts the approach from about 300 yards astern of the delivery ship and advances into position 100-150 feet off the beam of the delivery ship. Once alongside, a shot line is fired from the delivery ship to the receiving ship. When the shot line is in hand on both ships, the high line, inhaul and outhaul lines, attaching gear and "phone and distance line" (a nylon line with sound powered wires interweaved) are manually pulled between the ships. When the highline is attached and ready to be tensioned and either the fueling rig is seated and ready to pump fuel or the cargo rig is tensioned, tested and ready to transfer cargo, the beginning of the UNREP is complete.

For refueling, the middle of an UNREP is a continuous process. Engineering department personnel on each ship communicate to control the starting, stopping and operating pressure of the fuel transfer pumps. Personnel on deck, at the transfer station, maintain the safety of the rig, monitor the UNREP gear and stand ready to disconnect the rig in the event of an emergency. Engineering personnel, during a fueling, are stationed at control valves, tank sounding stations and in a central area to control the safe transfer of fuel. When all tanks on the receiving ship are full, the pumping stops and control of the ship refueling returns to the transfer station.

For conventional replenishment the middle of the UNREP is a series of discrete events. Each lift must be moved to the transfer station on the delivery ship and then moved away from the transfer station on the receiving ship before the next lift can be transferred. Material transferred may be cannisters of missiles, cargo slings of stores, pallets of projectiles or powders, coaling bags of repair parts or perhaps a boatswain's chair for personnel transfer. Virtually anything that can be attached to the transfer trolley can be transferred at sea. The current limitation is in the neighborhood of 8,000-10,000 pounds. [Ref. 12: p. 4-66]. Aircraft engines weigh about 8,000 pounds and aircraft carrier arresting gear cables weigh about 9,000 pounds. During CONREP, material handling can become the time critical factor in transferring cargo. The problem of cargo handling on the combatants is a known problem, receiving considerable attention by engineering personnel at the NSWSES UNREP Group [Ref. 13]. Additionally an effort is being made to improve handling procedures to rearm Vertical Launch Systems. From an analytical perspective, several studies were conducted in the mid 1960's and early 1970's to create computer models of specific aspects of underway replenishment. One of the models was the subject of an Operations Research Master's Thesis at the Naval Postgraduate School in 1969 by John W. Hilt LCDR USN. His thesis developed a three server queuing model in an attempt to model intra ship cargo handling procedures [Ref. 14: Abstract]. For the delivery ship, the correct material must be staged at the transfer station. For the receiving ship, either material handling equipment or plenty of manpower is required to move cargo away from what is generally a very small deck area around the transfer station. Today's STREAM gear is capable of moving several tons of cargo per lift. Once the cargo rig is in place and ready, the transfer is a rapid process. Speed limitations are primarily safety and material handling capabilities on each ship.

The end of the UNREP is a sequence of steps to safely disconnect the transfer rig and return the rig, and transfer lines to the delivery ship. Once all lines are clear, the receiving ship speeds up and "breaks away" to return to station.

3. Vertical Replenishment

VERTREP can also be separated into a beginning, middle and ending, but several ships may be receiving helo services simultaneously. On the delivery ship, getting an H-46 helo ready to fly is controlled by the Air Detachment on the ship. For the purpose of studying Vertical Replenishment, no measured time is available in the COMNAVSURFPAC data to describe the beginning and end of the VERTREP. Critical steps in preparation for VERTREP include staging material for transfer, adequate ship to ship communication and a pre-planned schedule of transfer. As with CONREP, once the delivery and receiving ships are prepared, VERTREP becomes an versatile tool to support battle group supply readiness. When the VERTREP is complete there is no break away requirement and the delivery and receiving ships end the VERTREP separately. Procedures for VERTREP are defined in NWP-14C Chapter Nine.

D. BATTLE GROUP MODELS

The results of this analysis may be suitable for use in some of the current battle group war games and simulation models. Five of the current models are discussed.

1. Enhanced Naval War Gaming System ENWGS
2. Research Evaluation Systems Analysis RESA
3. Battle Force Operational Readiness Model BFORM

4. Naval Postgraduate School Planning Model PROLOG
5. Replenishment at Sea Model RASM

The Enhanced Naval War Gaming System models underway replenishment as a logical process. As the game is played. fuel, ammunition, and stores are decremented and then, when scheduled, an UNREP event occurs as a logical [0,1] event. That is, the replenishment occurs instantaneously to a specified level of capacity. If required, ENWGS can support detailed modeling of UNREP sequences [Ref. 15].

RESA (another large computer war game model), does not have a specific capability to model underway replenishment, according to the scenario analyst at the Naval Postgraduate School [Ref. 16]. In RESA. extensive modeling is done to provide reasonable aviation fuel demand and ammunition consumption, but most scenarios in the game model only short periods of time and the likelihood an UNREP would be required is quite small.

The Johns Hopkins University Applied Physics Lab has developed the *Battle Force Operation Replenishment Model (BFORM)* This model is under development for OP-814. The model is a simulation which allows the user to input battle group forces (air and surface) with consumption rates for fuel, ammunition and stores. *BFORM* then simulates required replenishment requirements to sustain given levels of performance over an extended period of time (about two weeks). The model conducts UNREPs as necessary to maintain fuel percentage and ammunition levels at some defined percentage. During the simulation *BFORM* compiles records of replenishment data to generate a summary report [Ref. 17: p. 3-15]. The simulation is designed to allow interactive input of demand and transfer rates. For test purposes, the model uses average fuel transfer rates from NWP-14C, demand rates as given in NWP-11-1 *Surface Ship Characteristics* and ammunition transfer rates used by Commander Service Group Two [Ref. 18].

PROLOG is a user interactive computer wargame developed at the Naval Postgraduate School. This war game is specifically designed to model operational logistics requirements of an aircraft carrier battle group. *PROLOG* models the replenishment requirements for ammuniton, fuel and Carrier Onboard Delivery (COD) during a three to four week power projection strike. The battle group operates over 1000 miles from the support base, making battle group resupply at sea essential [Ref. 19: p. 6]. Transfer rates in *PROLOG* are taken from NWP-14C. Some of the variables modeled in the process of underway replenishment are:

The approach and breakaway between the delivery and receiving ship.

Firing of the shot line

Transfer of rigging gear

Seating of the fuel probe

Possible failure of the rig during the UNREP

Taking fuel samples during the refueling

Tightlining of the highline

Allowing ships along side port and starboard simultaneously

The Center for Naval Analyses developed *The Replenishment at Sea Model (RASM)* in 1986. As described in the cover letter,

> *The Replenishment at Sea Model* permits rapid evaluation of the distribution of fuel, ordnance, and supplies by a combination of MLSF ships operating within a moving or stationary battle force. The user controls battle force components, formations and activity and MLSF forces, speeds, products and mode of operation through a comprehensive input. [Ref. 20: Appendix B p. 12]

Some of the underway replenishment variables in the model include:

DFM.RATE, DFM transfer rate in barrels per hour (7044 bbl/hr)

JP5.RATE, JP5 transfer rate in barrels per hour (7044 bbl/hr)

MISSILE.RATE, Missile transfer rate in missiles per hour (6/hour)

ORD.RATE, Palletized Ordnance transfer rate in tons per hour (156 tons/hr)

STO.RATE, Palletized Stores transfer rate in tons per hour (240 tons/hr)

These rates are in an auxiliary file of the program and are user input prior to running the model. The rates in parentheses are the default values in the program. No documention to reference the source of the rates is given.

E. WHEN IS DETAILED MODELING REQUIRED?

Having discussed some of the current models capable of describing battle group replenishment, when would it seem reasonable to model the specifics of underway replenishment? The model should increment time in something less than one hour intervals. Longer time increments will completely encompass most UNREPs and in those cases a simple [0,1] decision would be sufficient. For instance if the game increments in three to six hour time periods, all the variables in UNREP would be masked since very few events exceed two or three hours even for carrier UNREPs. If however, the battle group model only describes short intervals of time (12 to 24 hours), probably the interest of the study is in battle group tactics. For virtually any tactical situation, UNREP will be scheduled "some other time" and the CLF ship will simply become another ship in the battle group. UNREP transfer rate models may be useful when the complete wargame model or simulation uses small increment time steps (one minute to fifteen minute time steps) and models a significant period of time (seven days or more). For simulations greater than five to seven days, the battle group will require some form of resupply, be it from shore facilities or organic CLF ships.

The importance of battle group resupply should not be understated, but a very small percentage of the battle group operating time is spent conducting underway replenishment. Lt. Steve Barnaby, a student at the Naval Postgraduate School, using the *BFORM* model has shown resupply of battle group ships requires the combatant ship to be off station less than five percent of the total operating time to maintain adequate onboard fuel percentages [Ref. 21]. Small combatants require less than two percent of their operating time to refuel and the aircraft carrier requires little more than three percent. If only single ship UNREPs are allowed during battle group operations, the scheduling problem may be insignificant in overall battle group planning. However, a substantial block of time may be required to schedule one UNREP time period for an entire battle group. (It will be shown in the analysis that the time required for an UNREP is not symmetrically distributed around the average predicted time, which can perturb the scheduling problem.)

II. DESCRIPTION OF THE PACIFIC FLEET DATA BASE AND NWP-14C

A. DATA ANALYSIS

The data analysis of Pacific Fleet underway replenishments proceeds in three parts. First, a test is conducted to determine if the hypotheses that the transfer rates of cargo from ship to ship equal the rates published in NWP-14C. The rates published in NWP-14C are used throughout the Navy for battle group planning. Comparing the observed data with the predicted rates will give some confidence that the published rates predict the average times for underway replenishment.

Second, simple linear and multiple regression models are created to predict average single station transfer times given the quantity of material to transfer. External factors are added as possible conditioning variables to help improve the estimate of required transfer times. The quantity of material transferred is defined as the independent variable and the required transfer time is the dependent variable. Most often the battle group logistics planner will know how much fuel, ammunition or stores need to be transferred and will need to predict the time required for the transfer. Models are created for different classes of receiving ships such as aircraft carriers, cruisers and destroyers. For wargaming analysis or simulation, the single station models could be used to create a complete UNREP by adding more than one station to an event plus the added time estimated for the beginning and ending of the event. The purpose of the multiple regression model is to determine how environmental factors, such as delivery ship type, day or night events, multiple or single ship events, and sea state affect the transfer times.

The third part of the analysis creates models to describe the total amount of time required for an underway replenishment given several simultaneous transfer requirements. For instance, an aircraft carrier may require 12,000 barrels of DFM, 10,000 barrels of JP5, 100 lifts of ammunition and 50 lifts of stores. If these requirements are scheduled for the same UNREP, the total time will be at least as long as the longest single station event. The regression models attempt to predict the total time required using any or all of the transfer requirements. At this level of aggregation, the predictive ability of the model is limited by the large standard deviation in the observed data which cannot be explained by observed external factors. However some insight of time controlling factors may be gained.

B. THE DATA BASE

A description of the reporting requirements and type of information collected from underway replenishments in the Pacific Fleet highlight strengths and weaknesses of the data. Information in each transfer station report included the delivery ship, receiving ship, date of transfer, total alongside time, sea state, day or night, rig and unrig times, quantity of fuel transferred, pumping time at each pumping station, number of stations used, delay time, and if the event involved more than one ship alongside simultaneously. For CONREP the report also required total short tons of ammunition or stores transferred, the number of lifts required, total time of the CONREP and number of stations engaged. Each VERTREP was reported with the number of short tons of ammunition or stores, the number of lifts, the distance between the ships during transfer, the total time of the VERTREP and the number of helos used.

Reporting the UNREP data was the responsibility of the delivery ship. Separate data were collected for each transfer rig used. The transfer reports were forwarded to COMNAVSURFPAC for monthly consolidation, then forwarded for automatic data processing. Monthly summaries reported delivery ship UNREPs and receiving ship class performance. The reports were distributed to the following commands: Commanding Officer Military Sealift Command, Commanding Officer Military Sealift Command, Pacific Fleet, Commander Service Group One, Commanding Officer Naval Ships Weapons Systems Engineering Station, Port Hueneme, CA, and Commander Naval Surface Forces Group Western Pacific.

Some subjective factors in the data should be noted. Part of the output from the collected data was the "Evaluation Summary," which was by definition a critical summary. Specifically the instruction states:

> While the intent of the summary is constructive, it is essentially critical in nature. Except in rare cases, no remarks are included about the many replenishments which are well conducted. The purpose of noting the errors, oversights and mistakes made by others is to avoid their recurrence and to provide information on proper underway replenishment procedures [Ref. 1: para 3.4].

The fact that the reported data was used as a critical tool, possibly reduced the objectivity of the reported information. The monthly reports of underway replenishment were collected without the benefit of feedback to the fleet. Distribution of the data was not directed to the shipboard personnel who collected the data so there was only limited fleetwide knowledge of the content of the reports. The primary feedback to the fleet reporting units were the critical reports of operational errors while ships were alongside.

Another source of error was data entry into the computer data base and error checking of the generated reports. Reported data for refueling was especially prone to error. Many of the data points for quantity of fuel delivered exceed the fuel storage capacity of the receiving ship. Additional data entry error is introduced since this analysis is conducted from paper copies of the data requiring manual input to a data base prior to analysis. To conduct a consistent screening of the data several simple rules were set down to accept or reject observed data prior to analysis. These rules are listed in Appendix A along with tables listing the samples sizes for receiving ship classes and the percentage of data deleted.

Information external to the data base was located to investigate possible effects of operating environment on the observed data. Operating schedules for 1984 and 1985 were obtained from Commander Service Group One in an effort to determine if transfer rates during deployments,fleet exercises or training were significantly different. The only model attempted using the operating schedules compared the transfer rates of two similar TAO-143 class oilers to Spruance class destroyers. One oiler was operating near San Diego, CA and the other operated in the Indian Ocean. The results did not indicate a significant difference in transfer rate but the standard error term of the regression model was considerably larger for the Indian Ocean operations. Certainly a great deal of information is available to compare UNREP data to the operating schedules, however there was insufficient time to pursue this analysis and the UNREP data was not complete for many of the exercises preventing adequate analysis of fleet exercises.

C. NWP-14C TRANSFER RATES

NWP-14C is doctrine for Underway Replenishment. The transfer rates listed in the current revision published in 1985 are unchanged from the original publication in 1977. Figure 1 is the matrix of transfer rates considered in this report. In 1977 only nine DD-963 Spruance class destroyers had been commissioned. Five were commissioned prior to 1977 and four were commissioned in 1977 [Ref. 22: p. 746]. Neither the FFG-7 Oliver Hazard Perry class guided missile frigates nor the CG-47 Ticonderoga class cruisers were in the fleet in 1977. Also since the original publication the BB-61 Iowa class battleships have been decommissioned and recommissioned. Even though the types of ships in the fleet have changed considerably in the past eleven years, the published rates on practical grounds appear to be reasonable. If the published values were grossly incorrect battlegroup planners, OPNAV sponsors or wargaming modelers would have searched for a better alternate source. To date, no agency has seen a requirement to improve the NWP-14C rates. In fact it will be shown that for average transfers under average conditions, the doctrinal rates for refueling are quite good.

There was no formal analysis conducted to establish the rates published in NWP-14C. Using common sense fleet experience, an estimate of equipment operating characteristics and expert judgment, the rates in NWP-14C were set to provide a conservative estimate of intership transfer capability [Ref. 11]. The estimated transfer rates in NWP-14C are given in four classes, liquid fuel (F76 and F44 are the NATO equivalents for what in this study are referred to as DFM and JP5 respectively), palletized ordnance, missiles and boosters in dollies, and stores and provisions. The transfer rate for fuel is reported in barrels per hour (one barrel equals 42 gallons). Palletized ordnance, stores and provisions transfers are listed in short tons per hour. When the rates were established, short tons per hour was a reasonable unit of measure for cargo. The transfer of cargo between ships was most often constrained by the weight of the pallet. Additionally battlegroup planners estimate requirements in short tons rather than in pallets or unit loads [Ref. 11]. Missiles transfers are listed in loads per hour. VERTREP transfers rates are listed in short tons per hour to be consistent with CONREP. VERTREP is separated into transfers of less than 2000 yards and greater than 2000 yards to account for the decreased transfer rate as the distance between ships increases.

NWP-14C refueling rates vary from 2070 barrels per hour for DD/DDG's up to 2600 for CV's. The maximum fueling rate for fleet oilers is approximately 4300 barrels per hour [Ref. 12: p. 3-3]. Compared to maximum possible capacity for refueling in barrels per hour, the published transfer rates vary from 50 to 60 per cent of system capacity. Since the early 1970's there has been no major increase to the maximum pumping rate of fleet oilers. (Major improvements have been made to simplify operations and make refueling much safer.) [Ref. 6: p. 16]

For conventional replenishment, NWP-14C transfer rates vary from 20 tons per hour for FF/FFG's up to 35 tons per hour for CV's. This wide shift no doubt reflects the cargo handling capability differences between small combatants and the large deck carriers. It is interesting to note the rates listed in NWP-14C for vertical replenishment are the same for all classes of receiving ships.

For current operations, reporting fuel transfers in barrels per hour or its reciprocal as used in this study continues to be the logical measure of transfer. However, with the

PRODUCT	SHIP SEPARATION IN YDS (m)	UNIT OF MEASURE	UNIT OF TRANSFER	CV	BB	CG (18, 26 CL)	DD/DDG	FF/FFG
F76	ALONGSIDE	BARRELS (CUBIC METERS)	1-HOSE	2820 (447.9)	2238 (355.8)	2238 (355.8)	2070 (329.1)	2200 (349.7)
F44 (JP 5)	ALONGSIDE	BARRELS (CUBIC METERS)	1-HOSE	2970 (472.2)				
ORDNANCE PALLETIZED	ALONGSIDE	SHORT TONS (METRIC TONS)	1-RIG	35 (31.7)	24 (21.7)	24 (21.7)	20 (18.1)	20 (18.1)
	-2000 (1,828.8)	SHORT TONS (METRIC TONS)	1-HELO/ 20 TRIPS	30 (27.2)	30 (27.2)	30 (27.2)	30 (27.2)	30 (27.2)
	+2000 (1,828.8)	SHORT TONS (METRIC TONS)	1-HELO/ 8 TRIPS	12 (10.8)	12 (10.8)	12 (10.8)	12 (10.8)	12 (10.8)
MISSILE OR BOOSTER IN DOLLY	ALONGSIDE	LOADS	1-RIG			(Note 1) 10 5	(Note 1) 10 5	5
STORES AND PROVISIONS	ALONGSIDE	SHORT TONS (METRIC TONS)	1-RIG	21 (19.0)	13 (11.7)	17 (15.4)	13 (11.7)	13 (11.7)
	-2000 (1,828.8)	SHORT TONS (METRIC TONS)	1-HELO/ 20 TRIPS	20 (18.1)	20 (18.1)	20 (18.1)	20 (18.1)	20 (18.1)
	+2000 (1,828.8)	SHORT TONS (METRIC TONS)	1-HELO/ 8 TRIPS	8 (7.2)	8 (7.2)	8 (7.2)	8 (7.2)	8 (7.2)

NOTE 1: HIGHER TRANSFER RATE TO SLIDING PADEYE, LOWER RATE TO FIXED PADEYE

Figure 1. NWP-14C Figure 1-2 Average Transfer Rates

transfer capacity available in today's cargo transfer systems, CONREP delivery rates are seldom limited by the weight of the lift. Like missiles transfers, all CONREP today appears to be limited by the ability to move material to and away from the transfer station. Another problem with using short tons per hour as a unit of measure is that the density of lifts can vary considerably. A pallet of bomb fins or sonobouys is considerably lighter than a pallet of 2000 lb bombs, but using short tons per hour the transfer of bombs would indicate a much larger transfer rate even though the number of lifts may be the same. Unfortunately the information in the UNREP data available does not adequately discriminate the types of cargo, so the actual interaction of cargo density with transfer rate in lifts per hour cannot be described. For estimating transfer rates, a better time estimating unit should be minutes per lift or lifts per hour. The term lift is used to indicate moving the transfer hook and attached cargo from one ship to the other. Often several pallets of cargo are transferred in one lift using special cargo handling equipment.

D. STATISTICAL COMPARISON OF NWP-14C RATES WITH THE OBSERVED DATA.

1. Refueling Rates in NWP-14C

The first question for analysis is to determine if the transfer rates observed in fleet operations are the same as the predicted rates in NWP-14C. If you assume average transfer rates are a linear function of delivery time alongside and are normally distributed around some mean value with a predictable variance, then a standard *t* test of the data should be sufficient to determine if the observed rates equal the published rate [Ref. 23: p. 485]. For fuel, ammunition and stores the *t* test does not reject the hypothesis that the observed rate equals the predicted rate. Table 1 lists the observed average rate and estimated standard deviation along with the NWP-14C estimate and the calculated *t* statistic value. For the size samples considered, any "*t*-value" less than two is not rejected. Some consideration is given to the rather large standard deviations in the data during the regression analysis. The average observed transfer rates for refueling range from about 2500 to 3000 barrels per hour, and the standard deviation in the observed data was generally $\pm$500 to 800 barrels per hour. This amounts to a possible 30 to 50 percent shift in the predicted rate. Before accepting the NWP-14C rates, it is important to note the transfer times and transfer quantities are both always positive and do not always fit a normal distribution. Since the transfer rate is a function of both the time and quantity of material transferred it is unlikely the transfer rates are distributed normally. The *t* test may not be appropriate to test the transfer rates. Summary statistics for single station transfers are listed in Appendix B.

Table 1. AO, AOE, TAO REFUELINGS FROM JANUARY 1984 TO JUNE 1985

Ship Type	NWP-14C Rate	Observed Average	Std Deviation	Std Error	t-value	Sample Size
CV	2600	3036	673	33	.65	411
CV JP5	2970	2993	763	44	.03	297
CG	2238	2536	759	31	.39	582
DD	2070	2557	793	39	.61	717
DDG	2070	2654	806	33	.78	567
FF	2200	2784	881	34	.62	662
FFG	2200	2552	866	34	.41	322

2. CONREP VERTREP and Missile Transfers

Similar tables for CONREP and VERTREP are not provided since NWP-14C uses short tons per hour as the transfer rate. Using the observed data to compute the short ton per hour rate, the standard deviation of the observed data is approximately two times the average value making most any conventional statistical test insignificant.

Missile transfers are not specifically identified in the available data, so no definite estimates of missile transfer rates are possible. Because missile transfer rates are important, the observed data was sorted to find ammunition transfers from AE or AOEs to CG or DDGs with four or less lifts for the entire UNREP. These parameters at least approximate the characteristics of a missile transfer at sea to a small combatant. In the eighteen months of data, nine UNREPs meet the criteria. For the nine events the average time alongside was 72 minutes to transfer three lifts. NWP-14C cites five lifts per hour for missile transfers. The calculated t statistic of these nine data points is 6.2 which would reject the hypothesis that five lifts per hour equals the observed rate. Because the events are not documented as missile transfers and the sample size is extremely small, no significance is placed on these results.

3. Rig/Unrig Times

NWP-14C predicts ten to twelve minutes to rig and unrig transfer stations. The available data are summarized in Appendix C. From the observed data an aircraft carrier requires twenty minutes to rig and unrig any type of UNREP station and CLF ships require fifteen minutes. Small combatants use twelve minutes to rig/unrig fueling stations and 20 minutes for CONREP stations. The data are normally distributed around the mean. Some increase in rig/unrig time can be observed at higher sea states, but the available sample sizes for comparison in heavy seas are small and difficult to compare with calmer conditions.

III. DESCRIBING HOW THE REGRESSION MODELS WORK

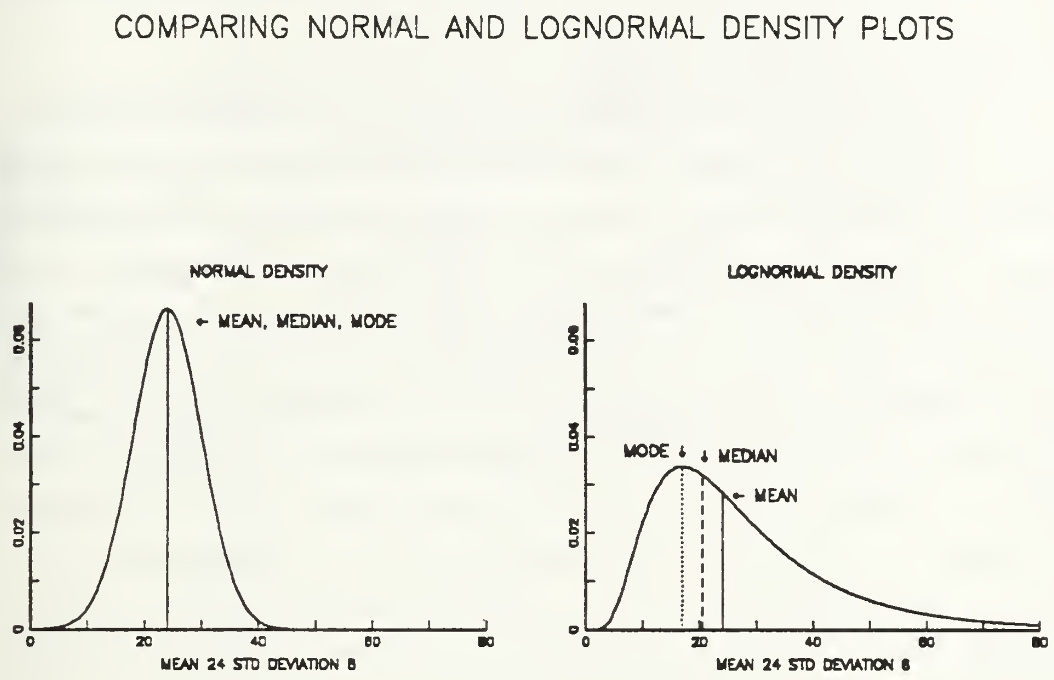
A. USING MULTIPLE LINEAR REGRESSION TO MODEL UNREP

1. Changing the Scale of Measuring Transfer Rates

This study is attempting to predict the amount of time required to transfer a given quantity of material. The rate of transfer for this type model is best described in terms of time per unit of cargo transferred, which is simply the reciprocal of the transfer rate in NWP-14C. Through the rest of the study (except where specifically noted) transfer rates will be cited in minutes per thousand barrels (Mbbl)of fuel for refueling and minutes per lift for CONREP. One draw back conceptually is that large rate coefficients will indicate slow transfer rates and small numbers represent faster transfers. As an example 15 minutes per thousand barrels equates to 4000 barrels per hour while 20 minutes per thousand barrels equates to 3000 barrels per hour. So if speed is important, smaller is better.

2. Normal Data vs Lognormal Data

During the exploratory data analysis it was determined that transfer rates, when measured in minutes per thousand barrels, generally did not fit a normal distribution, but were similar to a lognormal distribution using a Kolmogorov-Smirnov test [Ref. 23: p. 554]. Random variables in a lognormal distribution are all greater than zero which is not the case for normal random variables. If the transfer rates follow a lognormal distribution then the natural log of the transfer rates are normal. Under this assumption a second t test is conducted using logarithmic transformed data. Again the results do not reject the hypothesis that the log of the observed transfer rates equal the natural log of the published rates. If the data are distributed as lognormal then the "most likely" transfer rate will be the mode which is less than the mean value of a proposed distribution. Figure 2 shows two curves, the left curve is a density plot of a normal distribution and the right curve is a lognormal density plot. Each curve has a mean value of 24 and a standard deviation of six. A mean of 24 could represent the approximate observed transfer rate in minutes per Mbbl to a combatant, with a standard deviation of six minutes. The skewed nature of the lognormal distribution indicate the "most likely" transfer rate will be faster than the mean value but values much slower than the mean value will be more frequent than in normally distributed data.



Height of the curve indicates the relative frequency of values under the curve. For the lognormal case, values tend to be more spread out with many values much greater than the mean. In the right graph, the solid line represents the mean, the dashed line is the median and the dotted line indicates the mode of the distribution.

Figure 2. Normal and lognormal with equal means and variances.

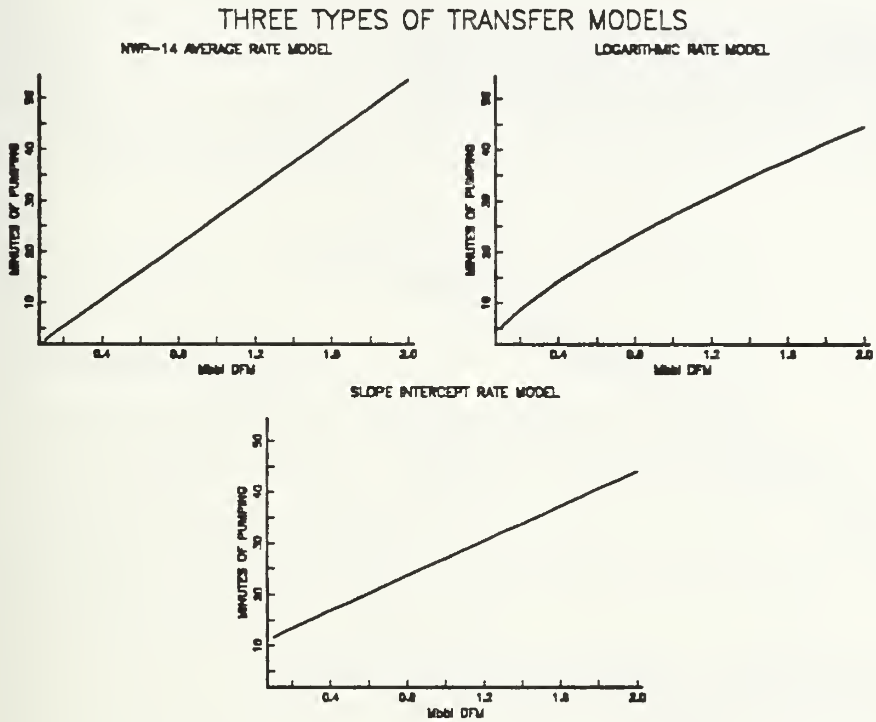
Because transferring material between ships takes time, one additional test was performed on the observed transfer rates. A test on the refueling data was conducted to find if the transfer rates were constant with respect to the pumping time. This is not a test if the pumping rate during a single event is constant but if separate events of different pumping times each have approximately the same pumping rate. Because the original data analysis indicated the rates were lognormal it was predicted this test would not accept the hypothesis that the transfer rates with respect to delivery time were equal. This indeed was the case for eleven of twelve samples tested.

3. Three Types of Prediction Models

Three graphs in Figure 3 demonstrate possible models to describe underway replenishment. The upper left graph is a linear model similar to the average rate models in NWP-14C. If pumping is linear, for short and long pumping times, the transfer rate is the same. The upper right graph represents a logarithmic transformation of the transfer rates. For a logarithmic model small quantity transfer rates will be slower than large quantity UNREPs. This is attributed to the real world effects of fuel sampling, and the initial problems encountered at the beginning of the UNREP which are smoothed out during longer events. Intuitively the logarithmic model is more appealing although considerably more difficult to use without computing equipment. The bottom graph in Figure 3 is slope intercept straight line approximation of the logarithmic model. For values not too close to zero on the X axis, representing the independent variable, the slope intercept model provides a good approximation and requires only one multiplication and one addition to find the desired value of the dependent variable on the Y axis.

The three different line models are introduced as a possible explanations of how separate transfer rate models predict transfer time. Figure 4. plots the same lines from the previous figure on one graph. The straight line passing through the origin has a slope equivalent to the NWP-14C transfer rate for a CG (26.8 min per Mbbl). The curved line represents the best fitting line of a log log transformation of the observed data from cruiser refuelings. The third line is the best fitting straight line simple regression of the same cruiser data. An additional box has been added to the figure. The area inside the box is bounded by the interquartile range of the observed quantities and times of transfer (Appendix B). The box generally describes the most likely amount of fuel and time required for pumping. All three lines pass through the most likely values and thus are reasonable predictors of average value events. As the amount of fuel transferred increases the NWP-14C model predicts considerably more time required than either of the regression models. It is this difference in predicting ability which will be useful in the regression analysis.

If the two *t* tests and the test for constant rate over time all had not rejected the hypothesis that the observed and published rates were equal the analysis could have ceased at this point for the refueling data. Multiple regression techniques will be used



Upper left straight line model similar to NWP-14C rates.

$$Minutes\ of\ Pumping = 26.8(Mbbl\ DFM)$$

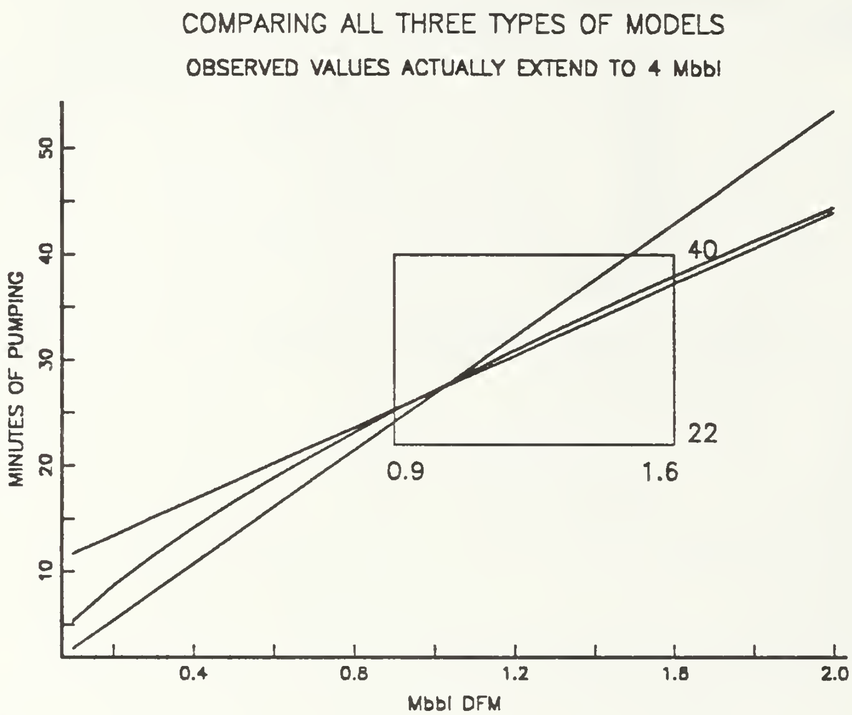
Upper right log log transformation model.

$$Minutes\ of\ Pumping = e^{(3.3+.713(\ln(Mbbl\ DFM)))}$$

Bottom slope intercept approximation to the log log model.

$$Minutes\ of\ Pumping = 10 + 17(Mbbl\ DFM)$$

Figure 3. Three possible transfer models



All three models predict well at or below average values, but the models diverge as the transfer quantities increase. The box represents the interquartile range of both the quantity of fuel and the required pumping time observed in the cruiser refueling data.

Figure 4. Overlay of all three models.

to describe some of the factors which affect refueling transfer rates and to develop models to describe CONREP.

B. DESCRIPTION OF THE REGRESSION MODELS

1. Dummy Variables Which Shift the Model Intercept

Throughout the regression analysis of the single transfer station and total time UNREP models, several variables interact simultaneously. In all cases there is only one continuous independent variable, the amount of cargo to be transferred. (CONREP lifts are obviously discrete events, but will be treated as continuous.) There is only one dependent variable. the amount of time required for the transfer. Other [0,1] dummy variables are added to the model which indicate the presence or absence of some external factor [Ref. 24: p. 241]. For straight line regression models the dummy variables either shift the intercept or the slope of the line. Figure 5 demonstrates the effect of a dummy variable on the intercept point of the model. This type model is described mathematically as:

$$Y = \beta_0 + \beta_1 Z + \beta_2 X$$

Y = the dependent variable
Z = the dummy variable with possible values [0,1]
X = the independent predictor variable
β_0 = the zero intercept of the model
β_1 = the shift in the intercept due to the presence or absence of the dummy variable
β_2 = the slope (or rate) coefficient of X
Dummy variables of this type move the regression line up or down but do not change the slope of the line. For the UNREP data this effect may be observed in factors effecting cargo handling and delay times which do not directly relate to the cargo transfer rate. When the dummy variable Z equals one the regression equation becomes:

$$Y = (\beta_0 + \beta_1) + \beta_2 X$$

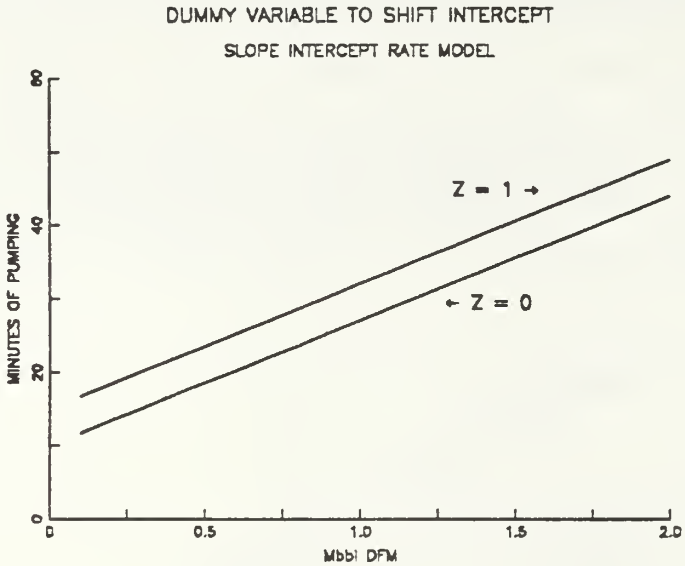
If the dummy variable Z is zero then the regression equation is:

$$Y = \beta_0 + \beta_2 X$$

The value of using dummy variables is that several factors can be considered simultaneously along with the independent variable [Ref. 24: p. 240].

2. Dummy Variables Which Change the Model Slope

The second influence possible using dummy variables is to change the slope of the regression line depending on the presence of the dummy variable. Figure 6 illustrates the effect of changing the slope of the regression line. Dummy variables of this type are used when a significant rate difference is expected between different environmental factors. This type variable could be used to demonstrate the difference in pumping capacity



Demonstrates the effect of a dummy variable on the intercept of a model. The shift can be positive or negative.

Figure 5. Varying the intercept of a regression model.

of the large fleet oilers and ammunition or stores ships which have much smaller transfer pumps. The general equation of this model is:

$$Y = \beta_0 + \beta_1 X + \beta_2 XZ$$

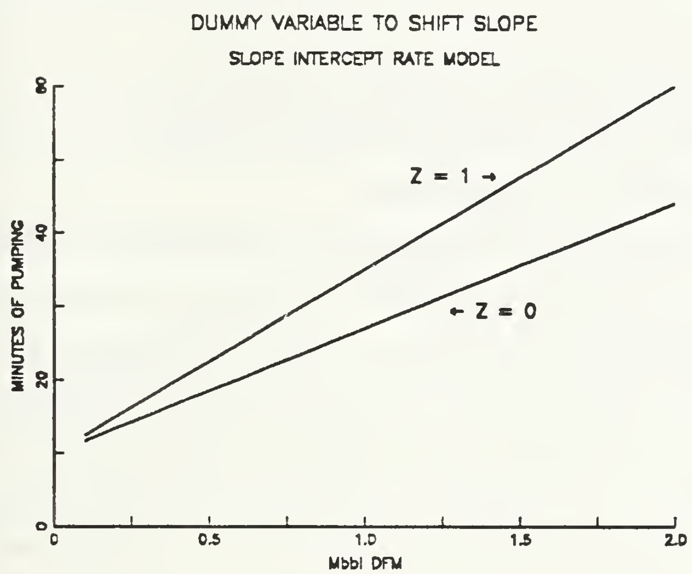
When the dummy variable Z equals one the equation is:

$$Y = \beta_0 + (\beta_1 + \beta_2)X$$

And when the dummy variable Z equals zero the equation becomes:

$$Y = \beta_0 + \beta_2 X$$

If necessary, dummy variables can be added to both the slope and intercept coefficients in the same model. However trial and error in this analysis indicates this procedure is not only computationally difficult, but leads to confusing and inappropriate results. During the analysis, if a model indicates both the intercept and slope are sig-



Demonstrates the effect of a dummy variable interacting with the slope of a model.

Figure 6. Varying the slope of a regression model.

nificantly different using dummy variables. separate models are created rather than using one larger model. The bulk of this analysis uses dummy variables to shift the intercept of the fitted lines. In regression texts this method is known as the analysis of covariance [Ref. 25: p. 297].

IV. SINGLE STATION UNREP MODELS

A. THE FULL MODEL AND SIMPLE MODEL FOR REFUELING

1. Models Are Created for Receiving Ship Classes

The analysis of single station transfer rates begins by searching for differences in transfer rates and finishes pointing out the similarities. Four types of cargo transfers are considered, DFM, JP5, Ammunition and stores. In NWP-14C the receiving ship is the principal concern, so in this analysis, separate models are created for different receiving ship types. Although dummy variables are added to the single station models, they do not significantly improve the amount of unexplained error in the data when compared to a simple linear model using only the transfer quantity and transfer time. The result of the single station transfer analysis is that a simple linear model using the quantity of material to transfer as the independent variable is the best model for single station transfer rates. This is not the case when trying to predict the total time required for an UNREP, where some of the external factors provide significantly better models of underway replenishment.

There are eight receiving ship models considered throughout:

1. Conventional and Nuclear Aircraft Carriers (CV)
2. Conventional and Nuclear Cruisers (CG)
3. Spruance/Kidd Class Destroyers/Guided Missile Destroyers (DD)
4. Adams Class Guided Missile Destroyers (DDG)
5. Fast Frigates (FF)
6. Guided Missile Frigates (FFG)
7. Fleet Oilers (AXB--B is for big)
8. Ammunition and Stores Ships (AXL--L is for little)

These classes each have significantly different hull forms, mission capabilities and possibly UNREP transfer rates.

2. Dummy Variables Are Added to the Full Model

Each of the combatant models uses dummy variables to condition for the delivery ship type and three additional environmental factors:

$$AE = \begin{cases} 1 \ \textit{if UNREP from an Ammunition ship} \\ 0 \ \textit{otherwise} \end{cases}$$

$$AFS = \begin{cases} 1 \ \textit{if UNREP from an AFS stores ship} \\ 0 \ \textit{otherwise} \end{cases}$$

$$AO = \begin{cases} 1 \ \textit{if UNREP from an AO} - 177 \ \textit{Class Oiler} \\ 0 \ \textit{otherwise} \end{cases}$$

$$AOE = \begin{cases} 1 \ \textit{if UNREP from an AOE} - 1 \ \textit{Class Multi} - \textit{product ship} \\ 0 \ \textit{otherwise} \end{cases}$$

$$AOR = \begin{cases} 1 \ \textit{if UNREP from an AOR} - 1 \ \textit{Class Oiler} \\ 0 \ \textit{otherwise} \end{cases}$$

$$TAO = \begin{cases} 1 \ \textit{if UNREP from a TAO} - 105 \ \textit{or TAO} - 143 \ \textit{Class Oiler} \\ 0 \ \textit{otherwise} \end{cases}$$

$$DANT = \begin{cases} 1 \ \textit{if the UNREP was during the day} \\ 0 \ \textit{otherwise} \end{cases}$$

$$MULT = \begin{cases} 1 \ \textit{if ships along both sides of the delivery ship} \\ 0 \ \textit{otherwise} \end{cases}$$

$$STAT = \begin{cases} 1 \ \textit{if sea state greater than 3 on the Beaufort Scale} \\ 0 \ \textit{otherwise} \end{cases}$$

In creating the refueling models, only fuel transfers from AO, AOE, AOR and TAO ships are considered. Although AE, AFS ships can and do refuel small combatants the fuel transfer capability is considerably less than the larger fleet oilers. Separate models are created to describe the delivery of fuel from an AE or AFS.

A description of the refueling models shows the relative complexity of the full model with the two variable simple linear model. The full model is:

$$PTIME = \beta_0 + \beta_1 AO + \beta_2 AOE + \beta_3 AOR + \beta_4 DANT + \beta_5 MULT + \beta_6 STAT + \beta_7 FUEL + E$$

PTIME = Observed single station pumping time
FUEL = Quantity of DFM (or JP5 for CV) transferred in Mbbl
E = Error between observed data and fitted model
The simple linear model is:

$$PTIME = \beta_0 + \beta_1 FUEL + E$$

In the full model β_0 (the constant term) represents fuel transfer from a TAO when other ship type dummy variables equal zero.

3. Selecting the Best Model for the Single Station Refueling

Using the "All Possible Regressions" program in *GRAFSTAT* [Ref. 26: p. 21] a model is computed for each of the receiving ship type. Each of the computed models for receiving ship single station transfer select the constant β_0 term and the independent variable for fuel, plus from one to five of the possible dummy variables to predict the transfer time. As a qualitative measure for comparison, the full model R^2 values range from .25 to .69 and the standard error from 9 to 18 minutes. An R^2 value of one is a perfect fit with positive or negative correlation and a value of zero indicates no correlation in the model. The standard error term generally indicates the observed value is within the range of the standard error about 65% of the time for average value transfers. [Ref. 24: p. 205]. Of the dummy variables taken into the model there is only one of the variables selected consistently. An additional 3 to 20 minutes is added to each model through the AOR variable. The AOR data throughout the analysis is suspect and a great deal of the AOR data is deleted. Because of AOR reporting problems in the data base this slower transfer time for AOR ships is disregarded. The AOR data has little impact overall since it accounts for only about 10% of all the observed refuelings.

The full model when compared to the simple linear model is considerably more complicated with extremely little increase in prediction accuracy. For the simple linear model, the six receiving ship model R^2 values range from .33 to .63 and the standard error varied from 10.2 to 20.3 minutes. So overall the full model provides virtually no improvement in predicting transfer times.

4. Recommended Single Station Refueling Models

The conclusion from the single station models is that apparently very few environmental factors affect the single station transfer rate. The following regression equation and coefficients listed in Table 2 provide a recommended fueling model for each class of receiving ship.

$$Predicted\ Transfer\ Time = \beta_0 + \beta_1 FUEL$$

Table 2. SINGLE STATION FUELING MODEL FOR DFM AND JP5

Receiving Ship Type	β_0 Minutes	β_1 Minutes per Mbbl	Avg Mbbl Transfer	Avg Pump Time
CV	15	17	3.9	80
CV JP5	20	15	4.3	85
CG DD	10	17	1.35	33
DDG FF FFG	7	17	1.1	27
AO AOE AOR TAO	42	13	10.0	172
AO AOE AOR/TAO JP5	54	10.5	8.6	145
AE AFS	19	16	1.3	55
JP5 to Small Combatants	β_0 Minutes	β_1 Minutes per Barrel	Avg Barrels Transfer	Avg Pump Time
CG DD DDG FF FFG AE/AFS JP5	12	.09	107	22

Each of these values is within the 95% confidence interval of the computed regression equations as shown in Appendix D. The standard error for the aircraft carrier model is eighteen minutes and twelve minutes for the small combatants. The grouping of receiving ships appears to be related to the overall ship size and fuel storage capacity. Based on the similarity in size, it is recommended to use the CG/DD transfer rates for CG-47 cruisers until better information is available. The average quantity and transfer time columns are provided for comparison with the model.

The separate analysis to transfer fuel from an AE/AFS results in an equation with zero intercept but a transfer rate approximately one half the rate for the larger fleet oilers. One equation is presented to model refueling of any small combatant from an AE or AFS.

$$PTIME = 36FUEL + E$$

There are 90 observations in the sample, the R^2 value is .62 with a standard error of 28 minutes.

5. Selecting the Best Single Station CONREP Model

For CONREP a simple regression model and a large multiple regression model are tested. The simple model is selected as the best model to describe the single station transfer. A large model conditioning for delivery ship type and environmental factors is processed using the "All Possible Regressions" program. The full model for CONREP is of the form.

$$CTIME = \beta_0 + \beta_1 AE + \beta_2 AO + \beta_3 AOE + \beta_4 AOR + \beta_5 TAO + \beta_6 DANT + \beta_7 MULT + \beta_8 STAT + \beta_9 AMO + \beta_{10} LIFT + E$$

CTIME = Observed single station CONREP time
LIFT = Number of Lifts, Ammuntion or Stores

$$AMO = \begin{cases} 1 \; if\; transfer\; was\; ammunition \\ 0 \; otherwise \end{cases}$$

For the CONREP model the base case is a transfer of stores from an AFS, so β_0 represents conventional replenishment from an AFS when the dummy variables for other delivery ship types are zero. For the simple linear regression model two separate equations are used to keep separate the transfer of ammunition and stores.

$$ATIME = \beta_0 + \beta_1 ALIFT + E$$

ATIME = Observed Single Station Ammunition Transfer Time
ALIFT = Number of lifts of ammunition transferred.

$$STIME = \beta_0 + \beta_1 SLIFT + E$$

STIME = Observed Single Station Stores Transfer Time
SLIFT = Number of lifts of stores transferred
The two equations allow for possibly different transfer rates and zero intercepts between ammunition and stores transfers. Table 3 provides recommended coefficients for the transfer of ammunition and stores.

$$Predicted\ Transfer\ Time = \beta_0 + \beta_1 LIFT$$

Table 3. SINGLE STATION CONREP MODEL FOR AMMUNITION AND STORES

Receiving Ship Type	β_0 Minutes	β_1 Minutes per Lift	Avg Ammo Lifts	Avg Ammo Time	Avg Stores Lifts	Avg Stores Time
CV Ammo or Stores	50	1.7	50	143	41	112
Ammunition to Small Combatants	20	2.4	7	40		
Stores to Small Combatants	15	2.3			12.3	42.5
Ammunition to CLF Ships	30	1.2	33	49		
Stores to CLF Ships	30	1.5			25	69

These predicted coefficients all are within the 95% confidence interval of the individual receiving ship type regression model. (The β_1 coefficient for ammunition varies from -2.5 to 3.2 for the FF model. Appendix D) The recommended standard error for Aircraft Carrier CONREP ammunition transfers is 60 minutes and 50 minutes for stores transfers. For all other small combatant UNREP the standard error should be 20 minutes.

Initially, significantly different transfer rates for refueling and CONREP were anticipated between the various receiving ship types. There may be significant differences, but the inherent error in the available data does not permit consistent isolation of differences at the single station level. It seems important to recognize the similarity observed in the data. The transfer rate is fairly constant between receiving ship types, with some variation in the amount of time during the transfer not attributable to the cargo.

V. TOTAL TIME UNREP MODEL

A. ADDITIONAL FACTORS ARE ADDED TO THE MODEL

1. Four Factors Add to the Complexity of the Model

The final section of this analysis creates a model to predict the total time required for an Underway Replenishment based on the quantity of material scheduled for transfer. Using the methods developed in the single station problem, four additional concepts are added to the total UNREP prediction models. The first addition is a logarithmic transformation of both the independent and dependent variable to improve the prediction of transfer times over a wider range of transfer quantities. The second concept is to create a decision rule to select one independent prediction variable from possible quantities of DFM, JP5 or the number of CONREP lifts. A third problem is to allow interaction between different types of commodities, that is, if fuel appears to be the controlling factor, does a simultaneous CONREP significantly effect the estimation. Interaction between multiple transfer stations is added as a the fourth additional external factor. Summary Statistics for Total Time UNREPs are listed in Appendix D.[2]

Using the log log model, the standard error of the regression does not significantly increase over the single station prediction model. For an average aircraft carrier UNREP of two and one half hours the standard error in the regression model is minus 35 minutes to plus 45 minutes. The standard error is not symmetric around the average value. The errors above the average value will tend to be greater than errors below the average value due to the skewed nature of the distribution of the data. For the log log transformation a simple linear equation can be evaluated using the least squares method of the following form:

$$lnTTIME = \beta_0 + \beta_1 \ln(Mbbl,Lifts) + E$$

or the direct prediction of total time:

$$TTIME = e^{(\beta_0 + \beta_1 \ln(Mbbl,Lifts)+E)}$$

TTIME = Total observed time of the UNREP

---

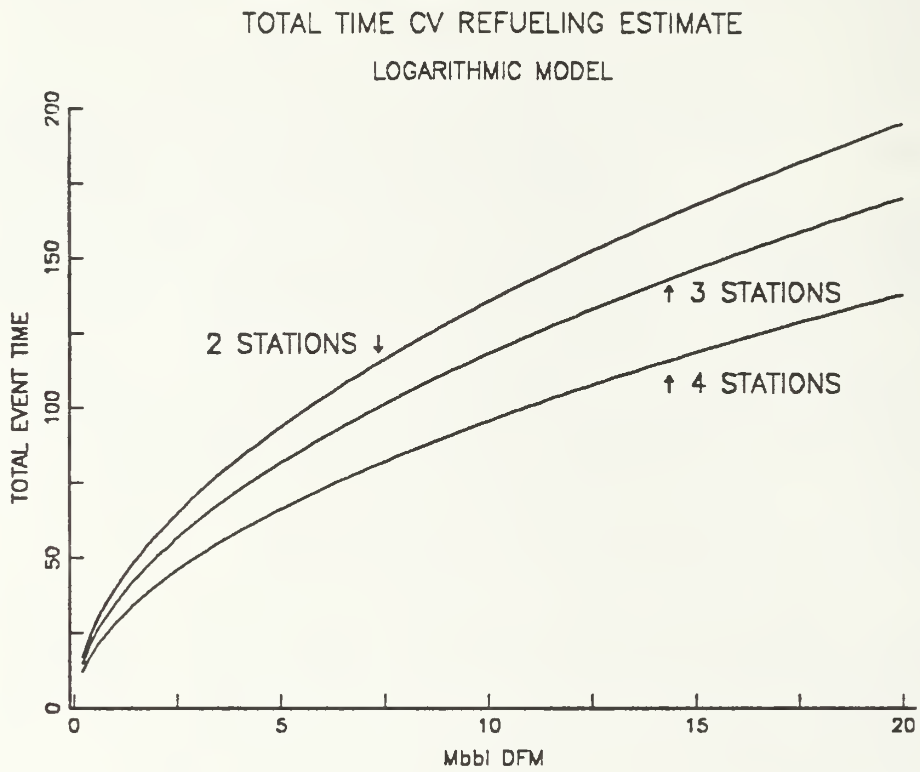
2 The single station data of the previous section is combined to determine the total transfer quantities during the UNREPs.

The first change in the model is a logarithmic transformation of both the quantity of material transferred and the time required for transfer. The straight line single station model used the observed data without transformation as a suitable approximation to the conceptually more accurate logarithmic model. To estimate the total event time, sufficient additional external factors impact on the model to warrant the additional difficulty of computing the regression equations with log transformed data. This simple regression equation is then expanded with [0,1] dummy variables to control for external factors. Figure 7 is a model comparing two three and four station carrier UNREPs. For values less than seven Mbbl the change in slope between the regression lines appears significant, but at 12 to 15 Mbbl the lines appear much more parallel.

The second additional consideration to the total time UNREP model is choosing the independent variable. For the single station model both the independent and dependent variables are given in the data and the problem is simply to fit a least squares line to the data. To estimate the total time required for an UNREP with multiple transfer stations and different commodities a decision is made to select the maximum quantity of fuel (DFM or JP5 for CV's) as the independent variable. Then dummy variables are added to condition for the number of transfer stations, different transfer rates between DFM and JP5 and distinguish refuelings which have simultaneous CONREP. If refueling is the controlling factor, the number of CONREP lifts is not considered. Sometimes it is obvious from the data that the total time of the UNREP is dominated by the number of transfer lifts. For this situation a second model is created which uses the number of lifts as the independent variable and then conditions for the presence or absence of refueling.

The third problem addressed, though unresolved, is to determine the cross over point where fueling or CONREP dominate the required time for an UNREP. An attempt is made to use the single station models to equate fuel and lifts to an equivalent transfer time, but is not seriously pursued. The selected regression equations show that when quantity of fuel is the independent variable the presence of any amount of CONREP adds time to the model, alternately in every case except for the aircraft carrier the presence of refueling when the independent variable is CONREP also add time to the model. These results give some indication of the amount of additional time required for complex replenishments.

The fourth consideration is controlling for the number of transfer stations. As shown in the Figure 7 there is a measure of improvement using additional stations, but



$$\hat{TTIME} = e^{(3.55+.137FSTA2-.206FSTA4-.089JP5+.530(\ln(\max(DFM,JP5))))}$$

Figure 7. Estimated carrier UNREP times using log log transformation.

four stations are usually not twice as good as two. An additional problem with multiple stations is that the reduction in total alongside time is a function of the amount of overlapping transfer time. When conducting the regression analysis, the proportion of simultaneous transfer time is considered as an average value for the number of stations during the UNREP. If the percentage of overlapping time is better than the average, the actual transfer time will be less than the regression model.

2. Establishing the Base Case for the Multiple Regression

For the regression models of total UNREP time, the base case for aircraft carriers is three DFM transfer stations, one station for small combatants and one station for fleet oiler consols. For aircraft carriers the average number of stations per UNREP is very close to three DFM stations and normally two simultaneous JP5 transfers. For small combatants, the average number of fueling stations varied from about 1.8 for CG's and DD's to slightly more than one (1.13) for FFG's. β_0 for the models using fuel to predict total UNREP time represents refuelings from TAO class oilers in the full model. β_0 for the models using CONREP to predict total UNREP time represent CONREP from an AFS.

3. VERTREP Data Did Not Produce Reasonable Results

Throughout this analysis VERTREP has not been discussed. Although an integral part of battle group logistics VERTREP seldom impacts the alongside portion of an underway replenishment. The data available for analysis is even more variable than the refueling and CONREP data. VERTREP is treated as a separate category with only limited success in describing the amount of time required to transfer cargo. Appendix B contains a summary of available VERTREP data.

B. FUEL QUANTITY AS A PREDICTOR OF TOTAL UNREP TIME

1. Full Model to Estimate the Total Time of Refueling

Using the modeling techniques described in building the regression models and the four additional constraints, the full total time refueling model is:

$$\begin{aligned} lnTTIME = {} & \beta_0 + \beta_1 AO + \beta_2 AOE + \beta_3 AOR + \\ & \beta_5 DANT + \beta_6 MULT + \beta_7 STAT + \beta_8 CONREP + \\ & \beta_9 JP5 + \beta_{10} FSTA2 + \beta_{11} FSTA4 + \beta_{12} \ln(\max(DFM, JP5)) + E \end{aligned}$$

$$CONREP = \begin{cases} 1 \text{ if } UNREP \text{ has simultaneous } CONREP \\ 0 \text{ Otherwise} \end{cases}$$

$$JP5 = \begin{cases} 1 \text{ if } Max(DFM, JP5) = JP5 \\ 0 \text{ Otherwise} \end{cases}$$

$$FSTA2 = \begin{cases} 1 \text{ if Number of pumping stations } = 2 \\ 0 \text{ Otherwise} \end{cases}$$

$$FSTA4 = \begin{cases} 1 \text{ if Number of pumping stations } = 4 \\ 0 \text{ Otherwise} \end{cases}$$

For each of the receiving ship classes, before the "All Possible Regressions" program is run, several of the variables are removed either because they are not significant during previous forward and backward stepwise regression or there are only a few occurrences of a particular dummy variable in the sample. Appendix D contains a table of all the coefficients calculated in the simple and multiple regression models.

2. Aircraft Carrier Total Time Refueling Model

The aircraft carrier total time model is:

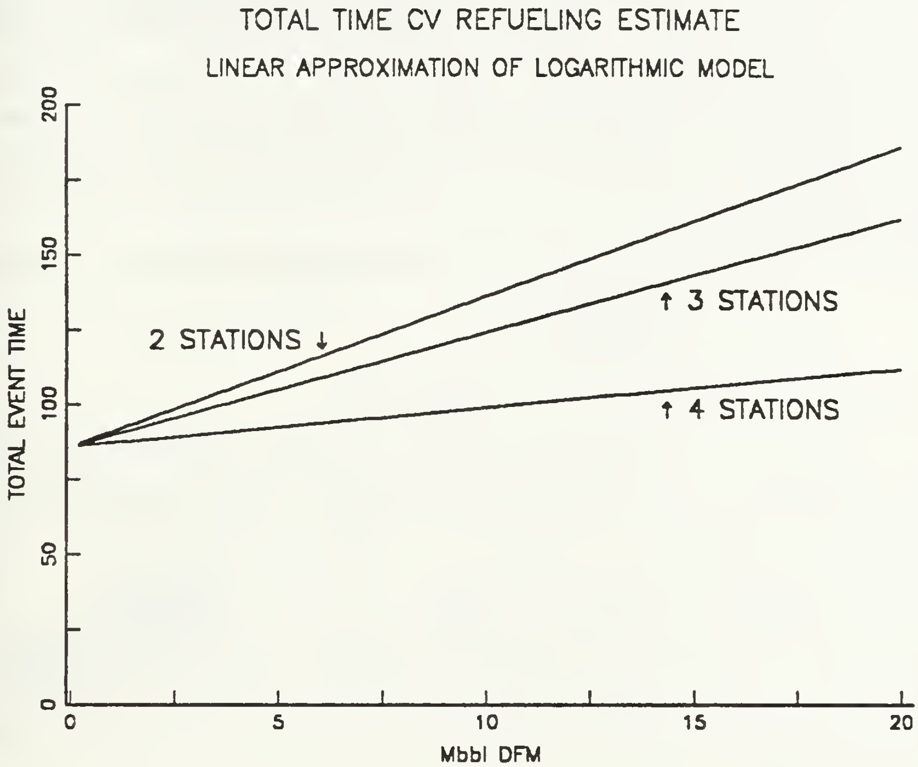
$$lnTTIME = 3.55 + .137FSTA2 - .206FSTA4 - .089JP5 + .530(\ln(\max(DFM,JP5))) + E$$

Figure 7 above is plotted using the values in this equation, however the JP5 term is set to zero to reduce the number of lines on the figure. The model is based on a sample size of 191 observations from any large fleet oiler (AO, AOE, AOR, TAO) to any aircraft carrier. The dummy variable for JP5 helps to account for a slightly different pumping rate when JP5 is the maximum fuel quantity. The coefficients chosen are within the 95 per cent confidence limits of the model. Although selected in the computed model the AOR dummy variable is again removed from the final equation. The R^2 value for the aircraft carrier model is .49 and the logarithmic standard error is .23 which equates to about minus 30 to plus 40 minutes near the average value transfers. The R^2 value indicates approximately half of the observed error around the mean value is explained by the regression equation.

The total time aircraft carrier and small combatant model regression equations are reasonably complex. To check if a simpler model would suffice, a non transformed model is computed using the full model with the aircraft carrier data. At least for aircraft carriers, the log log model provides a better response to the data over a wider range of values for the independent variable. For the linear model the intercept is at 86 minutes. This seems unreasonably large and always overestimates the time for shorter UNREPs. Figure 8 is a representation of the linear model allowing separate transfer rates. A better linear approximation could be achieved using separate models for the two three and four station UNREPs.

3. Small Combatant Total Time Refueling Models

For the small combatants two separate equations are presented representing a CG/DD model and a DDG/FF/FFG model. Sufficient similarities are again observed in the model coefficients to consolidate the larger hulled CG and DDs in one equation and the smaller DDG, FF and FFGs in a separate model. The coefficients of each equation fall within the 95 per cent confidence bands of the separate models. For the CG/DD model the recommended equation is:



$$\hat{TTIME} = 86 + 3.8DFM + 1.2(DFM)(FSTA2) - 2.5(DFM)(FSTA4)$$

The unreasonably high intercept could be reduced by allowing both the slope and intercept to vary with the number of transfer stations.

Figure 8. Linear approximation of Carrier refueling.

$$lnTTIME = 4.0 - .10DANT + .10STAT - .12FSTA2 + .15CONREP + .34(lnDFM) + E$$

The resulting equation for DD/FF/FFGs is:

$$lnTTIME = 3.90 - .07DANT + .10STAT - .20FSTA2 + .35CONREP + .43(lnDFM) + E$$

There are 293 observations in the CG model and 352 in the DD model. The R^2 values are .35 and .26 respectively and the standard error in both models is .27. These indicators of the quality of the model are not impressive, however graphically the model seems to fit the data. Figure 9 is a scatter plot of 150 Spruance class destroyer observations with the fitted values of the model. The second model has 308 DDG data points, 609 FF data points and 232 from FFGs. The R^2 values range from .24 for the DDG data to .47 for the FFG data. The standard error again translates to 30 to 40 minutes of probable error in prediction. The models are merely proposed as a starting point of modeling underway replenishment.

A separate model is created to describe refueling small combatants from an AE or AFS.

$$lnTTIME = 4.32 + .23AFS + .41AMO + .312(lnDFM) + E$$

There are 90 observations in the sample, the R^2 value is .34 with a standard error of .36. For this model β_0 represents a refueling from an AE because there were only 21 AFS refueling observations in the sample.

4. Total Time Refueling Models for CLF Ships

Two additional total time refueling regression models are provided. One is for large fleet oiler refuelings, normally known as consols. The second is a model for refueling AE/AFS CLF ships. These two models are significantly different from other models. For large fleet oilers:

$$lnTTIME = 4.29 - .23FSTA2 + .38(\ln(\max(DFM, JP5))) + E$$

This equation is based on 68 observations with an R^2 value of .78 and a standard error of .18. The model is apparently uneffected by external factors. For smaller CLF ships, AE/AFS the total time refueling model is:

$$lnTTIME = 3.50 + .57(\ln(DFM)) + E$$

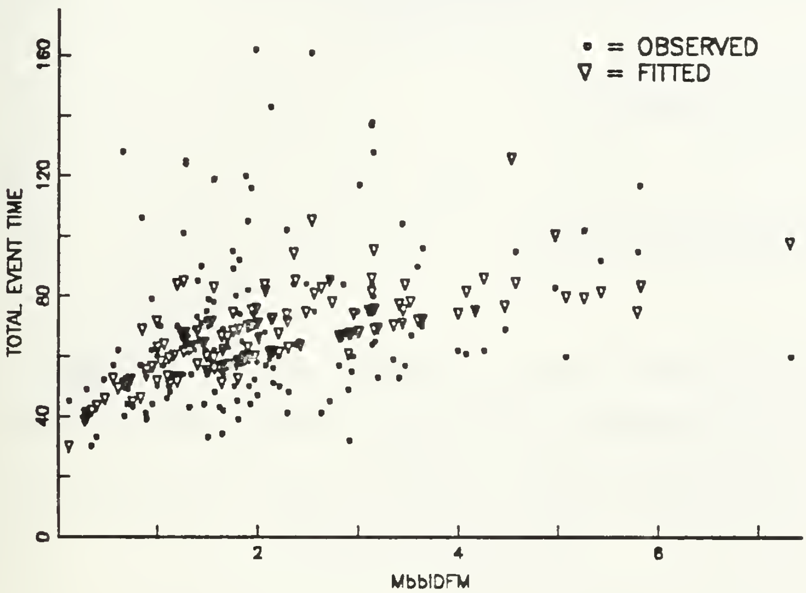
This equation is based on 144 observations with and R^2 value of .43 and a standard error of .26.

C. CONREP AS THE PREDICTOR OF TOTAL UNREP TIME

1. Aircraft Carrier Total Time CONREP Model

A separate set of models are presented for events either entirely CONREP or which at least appear to be dominated by CONREP. The receiving ship types are modeled separately, and then the results are combined into groups of equations as in the refueling models.

Spruance Class Destroyer Refueling Data Scatterplot



150 randomly selected refueling observations and fitted values. Note that error of observed values greater than fitted estimates tend to be larger than the observed error of values less than the fitted estimate. This effect can be attributed to the logarithmic transformation of the data.

Figure 9. Scatter Plot of Spruance Class DD refueling data.

The full model considered is:

$$
\begin{aligned}
lnTTIME = {} & \beta_0 + \beta_1 AE + \beta_2 AO + \beta_3 AOE + \beta_4 AOR + \beta_5 TAO + \\
& \beta_6 DANT + \beta_7 MULT + \beta_8 STAT + \beta_9 FAS + \\
& \beta_{10} AMO + \beta_{11} CSTA2 + \beta_{12} \ln(LIFT) + E
\end{aligned}
$$

$$
FAS = \begin{cases} 1 \ \textit{if UNREP has simultaneous refueling at sea from an AE or AFS} \\ 0 \ \textit{Otherwise} \end{cases}
$$

$$
AMO = \begin{cases} 1 \ \textit{if theCONREP transfers ammunition} \\ 0 \ \textit{Otherwise} \end{cases}
$$

$$
CSTA2 = \begin{cases} 1 \ \textit{if Number of CONREP stations} \ = \ 2 \\ 0 \ \textit{Otherwise} \end{cases}
$$

The model for aircraft carrier CONREP is based on 99 observations. The R^2 value is .34 and the standard error .30. It is interesting to note that the effect of simultaneous refueling does not factor into the equation for aircraft carriers.

$$
lnTTIME = 4.09 + .22(lnLIFT) + E
$$

2. Small Combatant Total Time CONREP Models

For CGs and DDs the recommended equation is:

$$
lnTTIME = 3.95 - .15DANT + .30FAS + .30(lnLIFT) + E
$$

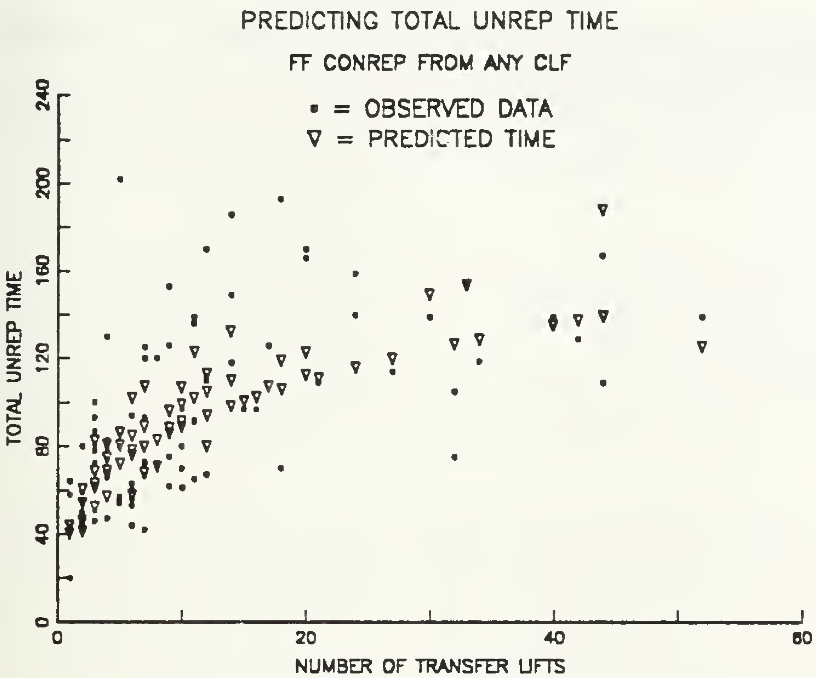
For DDG, FF/FFGs the regression model is:

$$
lnTTIME = 3.70 - .15DANT + .20FAS + .35(lnLIFT) + E
$$

The FAS variable is only to be used when the refueling is from an AE/AFS. For fleet oilers, although there were significant numbers of refuelings with simultaneous CONREP, the controlling factor for these events is virtually always the quantity of fuel. The refueling equation is more appropriate for fleet oilers. Figure 10 is a plot of the data and fitted values from the 112 CONREPs to Knox Class FFs.

3. CLF Total Time CONREP models

The equation for CLF CONREP is a composite of two models, one for the larger fleet oilers and one for AE/AFS CONREPs. The regression model uses a dummy



Plotting the observed and fitted data for CONREP transfers from CLF ships to Knox Class Frigates.

As noted in Figure 9, the observed error is larger for values greater than the fitted value, compared to observed values less than the fitted estimates. This tendency was described in Figure 2 as characteristic of lognormally distributed data.

Figure 10. Scatter Plot of Knox Class Frigate CONREP data.

variable (FAS) for simultaneous refueling at sea, which only applies to CONREPs involving AE/AFS.

$$lnTTIME = 4.05 + .18FUEL + .32AMO + .17(lnLIFT) + E$$

There are 148 observations in the sample. The R^2 value for both models was approximately .3 and the standard error was between .36 and .4.

VI. CONCLUSIONS

A. SIMPLE RULE OF THUMB PREDICTORS

A Surface Line officer can obtain two conclusions from this analysis.

1. An estimate of DFM pumping time through one hose is 10 minutes + 4 minutes per 10,000 gallons of DFM transferred (17 min per Mbbl).
2. For CONREP an estimate of the required transfer time is 25 minutes + 2 minutes per lift.

These two estimates have considerable variation throughout the observed data, but can be applied with some confidence to virtually any type of transfer. Using the simple linear regression models for single station transfers, error about the mean can be reduced 30 to 60 percent just using the quantity of material to transfer as the independent variable.

When more complex events are considered, (several transfer stations or more than one product transferred in a single UNREP) transformation of the data is required to obtain reasonable estimates of the average transfer rates. Although more complicated than the single station models, the logarithmic transformation model estimates can be solved using a hand held calculator. The inputs to the equations are simply the quantity of material to transfer and decisions concerning which dummy variables apply to the desired estimate. For complex events it must be born in mind that the statistical models derived, not only estimate average transfer times, but also the standard error from the mean can vary considerably. For UNREP planning, the single valued predictor (the mean) must be used with appropriate consideration for the standard error of the estimate. As an input to battle group models, the total time UNREP models may be appropriate. A summary of the proposed models are given in Appendix E.

B. ADDITIONAL POSSIBLE AREAS OF STUDY

If there is additional interest in describing underway replenishment, several topics remain open for research.

1. What type of model can describe VERTREP?
2. How do cargo handling techniques effect CONREP transfer rates?
3. Is there a method to quantify and then reduce what is apparently waiting time during an UNREP?
4. Is there a useful model to predict missile transfer times?

5. Using operational schedules, can significant differences be detected between operational events and training events?

Although considerably more historical data is available for analysis, monthly UNREP data reports are no longer required. Analysis of current operations would require special reporting requirements. Without a sponsoring command, acquiring additional data is unlikely. It was particularly dissappointing that a reasonable model for VERTREP could not be created from the data available.

C. A PROPOSED TABLE TO UPDATE NWP-14C

As a possible update to the transfer rates listed in NWP-14C the following table is suggested to estimate the total time required to conduct underway replenishments. Table 4 is developed for daytime UNREPs in sea state conditions less than four. The aircraft carrier estimates assume DFM is the controlling factor using three transfer hoses. The cruiser and destroyer estimate assumes two transfer hoses with similar environmental conditions. The smaller ship (DDG/FF/FFG) estimates are for one transfer hose. The estimate of time in the table is the total time required for the UNREP including the approach and rigging to the unrigging and breakaway. The predictions are given for the observed interquartile range of the Mbbl of DFM or number of CONREP lifts. The standard error term in the last column of the table gives some indication of the range of observed times. Because no reasonable VERTREP models were computed the VERTREP table simply lists the interquartile range values (25th 50th and 75th percentiles) for both the number of lifts and transfer times in the observed data. It is recommended CG-47 class cruisers use the CG/DD rates to estimate transfer times until observed data is available. The eighteen months of data analyzed had less than five battleship refuelings so it is recommended the equations for a two station carrier UNREP be used to model BB refuelings and the carrier model for CONREP should be used with the battleships.

D. COMMENT

Admiral Hooper in his book *Mobility, Support, Endurance* [Ref. 27: p. 52] lauded the efforts of the *USS Ponchatoula* for her "valiant" efforts during the Vietnam conflict. He cited one day in which the Ponchatoula transferred over 2.6 million gallons of DFM and 653,000 gallons of JP5 to some 20 ships and also conducted a consol to refuel.

Using average values from this study, today the *USNS Ponchatoula* would complete that same requirement in one day plus have eight hours available for transit plus two hours to eat lunch. It would be a busy day but certainly today's transfer rates can meet the requirements observed during Vietnam.

Table 4. ESTIMATING TOTAL UNREP TIMES

Estimate of REFUELING Times							
Receiving Ship	Short UNREP		Medium UNREP		Long UNREP		Est Error Min
	Qty Mbbl	Time Min	Qty Mbbl	Time Min	Qty Mbbl	Time Min	
CV	8.0	105	12.0	130	16.0	151	+45,-35
CG DD	1.2	47	2.5	60	3.0	64	+12,-10
DDG FF FFG	.8	41	1.2	49	1.6	55	± 10
Estimate of CONREP Times							
	Qty Lifts	Time Min	Qty Lifts	Time Min	Qty Lifts	Time Min	Est Error Min
CV	36	131	84	158	106	166	+60,-50
CG DD	5	72	15	100	20	110	+30,-20
DDG FF/FFG	5	61	10	78	15	90	+30,-20
Interquartile Values for VERTREP.							
	Qty Lifts	Time Min	Qty Lifts	Time Min	Qty Lifts	Time Min	
Ammo < 2000yds	3	24	6	38	34	75	
Ammo > 2000yds	2	15	5	25	12	30	
Stores < 2000yds	3	18	8	40	18	80	
Stores > 2000yds	1	15	3	25	10	55	

APPENDIX A. DATA MANAGEMENT

A. RULES FOR DELETING DATA

An attempt is made to use as much of the available data as possible. The following rules are applied as a consistent pattern of "cleaning up" the data.

1. Single station fuel transfers must be less than 40% of the receiving ships fuel storage capacity and greater than 100 barrels. The forty per cent criterion is selected for two reasons. Reasonable transfers of more than forty per cent are seldom noted in the available data and for most classes of receiving ships there is a natural break between believeable and unbelieveable transfer quantities at about forty per cent. Transfers less than 100 barrels are extremely rare.

2. Total Unrep Time fuel limits are set at approximately 50% of the ship type's total storage capacity.

3. For cruisers, destroyers and frigates, pumping times per hose are restricted to less than 100 minutes. For aircraft carriers, maximum pumping time per hose is 180 minutes. Refuelings of CLF ships are handled separately. Average pumping times are approximately one third of the upper limit.

4. Total UNREP times are limited to five hours for aircraft carriers and three hours for other combatants. For CLF UNREPs there is no preset time criterion to remove data.

5. AOR class data is considered questionable throughout the analysis. As much of the usable AOR data as possible is used, however if the data indicate a significantly different performance the results are disregarded.

6. For the major refueling models, no fuel transfers from AE, AFS, or TAE ships are allowed. These delivery ships have the capability to refuel combatants, however their fuel oil transfer pumps have considerably smaller capacity. Refuelings by AE, AFS and TAE are considered separately.

7. For DFM and JP5 transfer rates exceeding 4600 barrels per hour and less than 100 barrels per hour are considered unlikely and removed from consideration. NWP-14 lists 4330 barrels per hour as the maximum pumping capacity for a seven inch fuel hose at the maximum rated pressure. 4600 barrels is chosen as an upper limit to allow some flexibility in establishing the transfer rate upper limit.

8. For connected and vertical replenishment events with rates less than 2 tons per hour and rates greater than 200 tons per hour are deleted. This rule seldom eliminates feasible events and primarily identifies data entry errors.

9. For connected and vertical replenishment events with lift rates less than one per hour and greater than 70 per hour are disregarded. Again these limits seldom remove feasible transfers. Admittedly transfers of 70 lifts per rig per hour are possible but seldom reported in the data available.

B. USABLE OBSERVATIONS FROM THE DATA BASE

There are 6743 lines of data analyzed in this project. A line of data can any combination of a refueling, CONREP or VERTREP. The symbol AXB in the table represents AO/AOE/AOR/TAO data and AXL represents AE/AFS. The following tables list the amount of data deleted for both the single station models and the total time UNREP models.

1. Single Station Model Data Usage

		TOTAL	DFM	JP5	CONREP	VERTREP
CV	RAW	1198	595	386	170	164
	USED		411	297	169	162
	%DELETED		31	23	01	01
CG	RAW	1330	981	7	153	224
	USED		777	6	122	217
	%DELETED		21	14	20	03
DD	RAW	1046	805	128	121	107
	USED		717	89	121	103
	%DELETED		11	30	00	04
DDG	RAW	803	640	13	120	98
	USED		567	10	113	82
	%DELETED		11	23	06	16
FF	RAW	1151	775	157	102	200
	USED		662	135	102	188
	%DELETED		14	15	00	06
FFG	RAW	446	341	38	58	54
	USED		322	35	58	51
	%DELETED		06	08	03	06
AXB	RAW	396	301	92	CLF CONREPS	
	USED		162	91	WERE COMBINED	
	%DELETED		46	1		
AXL	RAW	495	250	52	203	222
	USED		197	30	196	204
	%DELETED		21	42	03	08

Amphibious Ship Replenishments and transfers to other ship types, including Coast Guard, Tenders, and foreign nations ships are not considered.

2. Total UNREP Model Data Usage

Total UNREP data was compiled by combining the information from single station data pertinent to a single UNREP.

		TOTAL	DFM/JP5	CONREP
CV	RAW	429	259	124
	USED		227	101
%DELETED			12	18
CG	RAW	557	396	109
	USED		349	92
%DELETED			12	16
DD	RAW	600	509	111
	USED		460	92
%DELETED			09	17
DDG	RAW	528	376	120
	USED		322	112
%DELETED			14	06
FF	RAW	880	664	101
	USED		635	97
%DELETED			04	04
FFG	RAW	368	301	58
	USED		223	48
%DELETED			26	0
AXB	RAW	265	71	84
	USED		68	78
%DELETED			04	07
AXL	RAW	267	164	75
	USED		150	71
%DELETED			09	05

APPENDIX B. SINGLE STATION SUMMARY STATISITICS

The tables are summaries of the data used in this analysis for the *t* test in Chapter II and the single station models of Chapter IV. The Q.5, Q.25 and Q.75 rows are the median, 25th and 75 percentiles of the observed data. S represents the observed standard deviation in the data. SSZ stands for the sample size of the statistics. SMLJP5 represents JP5 transfers to small combatants and AE/AFS.

A. REFUELING STATISTICS

FUEL IN BARRELS

STAT	AXB	CV	AXL	CG	DD	DDG	FF	FFG	CVJP5	AXBJP5	SMLJP5
AVG	10034	3892	2283	1322	1378	1048	1132	1019	4281	8609	107
Q.5	8985	3483	1972	1214	1281	981	1062	990	4155	7655	88
MODE	2672	3000	1667	1000	1000	1000	1357	230	2700	4774	48
S	6612	1557	1376	619	660	543	523	522	2173	4309	74
MIN	714	826	104	167	119	114	133	100	122	1347	3
MAX	35302	10395	7310	4260	4440	4550	4118	3661	10240	19471	440
Q.25	4960	2890	1250	904	901	690	750	630	2587	5380	49
Q.75	13468	4780	2862	1600	1700	1266	1424	1300	5523	11210	194

FUEL TIME IN MINUTES

STAT	AXB	CV	AXL	CG	DD	DDG	FF	FFG	CVJP5	AXBJP5	SMLJP5
AVG	172	80	55	33	34	26	27	26	85	145	22
Q.5	168	75	48	29	30	22	25	23	80	143	19
MODE	95	93	38	28	30	14	20	16	66	157	10
S	95	34	29	17	17	15	14	14	38	68	13
MIN	12	20	13	4	5	4	4	6	5	44	2
MAX	505	180	162	99	90	96	89	96	188	504	59
Q.25	99	57	35	22	22	15	17	16	59	93	12
Q.75	210	98	70	40	42	31	32	30	106	176	30

FUEL RATE IN BARRELS/HOUR

STAT	AXB	CV	AXL	CG	DD	DDG	FF	FFG	CVJP5	AXBJP5	SMLJP5
AVG	3464	3036	2506	2536	2557	2476	2506	2552	2993	3692	351
Q.5	3779	3061	2490	2571	2468	2697	2808	2631	3071	3812	281
MODE	2710	2940	2297	2289	2500	3000	3000	2640	2152	3842	240
S	997	673	772	760	793	806	881	866	763	1401	270
MIN	368	1254	218	443	460	435	231	133	480	467	25
MAX	4598	4545	4094	4578	4593	4547	4583	4571	4589	4580	1770
Q.25	2912	2534	2040	2080	1987	2075	2169	2029	2456	3177	190
Q.75	4187	3539	3032	2983	3102	3221	3399	3103	3526	4129	397
SSZ	162	411	197	582	717	567	662	322	297	91	305

B. CONREP STORES STATISTICS

CONREP STORES LIFTS

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	41.2	13.9	17.4	13.0	11.3	9.7	24.9
Q.5	34	8	7.5	10	7	6	17
MODE	6	5	2	2	2	3	12
S	32.8	13.5	11.8	11.1	11.3	11.1	25.4
MIN	1	1	1	1	1	2	1
MAX	138	85	47	58	52	61	138
Q.25	18	5	3	5	3	3	8
Q.75	53	21	19	19	15	11	34

CONREP STORES TIME (MINUTES)

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	112.8	45.9	43.4	41.9	41.6	32.6	69.0
Q.5	100	38	32	33	38	23	55
MODE	23	53	15	17	40	20	40
S	74.5	32.2	30.3	31.6	29.9	37.1	49.2
MIN	3	1	1	3	1	5	1
MAX	361	187	128	170	129	174	299
Q.25	59	23	18	19	18	15	33.5
Q.75	151	61	62	58	56	46	94.5

CONREP STORES RATE (LIFTS/HOUR)

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	21.8	17.4	16.7	18.4	15.9	18.0	21.1
Q.5	20	16.2	15.7	18	14.4	15.5	20.9
MODE	60	12	15	12	15	12	30
S	12.2	10.0	9.5	9.0	9.1	10.6	11.2
MIN	2.5	3.3	1.9	3.5	2.3	2.6	1.3
MAX	67.5	60	60	49.6	60	54.5	60
Q.25	14.3	9.8	10.2	12	10	10	13.1
Q.75	25.2	22.5	22.6	24	20	23	28.7
SSZ	135	95	102	97	85	55	172

C. CONREP AMMUNITION STATISTICS

CONREP AMMO LIFTS

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	50	6.1	6.5	12.1	6.6	3.3	33.5
Q.5	37	4	5	7	6	3	24
MODE	26	2	3	3	7	3	7
S	45.5	6.0	5.8	12.6	5.3	0.6	34.6
MIN	1	1	1	1	1	3	1
MAX	176	27	23	39	24	4	130
Q.25	19	2	3	3	5	3	7
Q.75	63	8	9	17	8	4	42.5

CONREP AMMO TIME (MINUTES)

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	143.8	64.9	27.7	61.9	37.5	15	49.4
Q.5	112	45	25	34	29	19	70
MODE	310	30	25	27	70	5	52
S	98.8	47.9	16.9	63.5	27.2	8.7	125.1
MIN	10	10	4	5	2	5	10
MAX	418	194	68	246	100	21	470
Q.25	66	33	15	18	22	5	52
Q.75	190	100	38	90.5	49	21	93

CONREP AMMO RATE (LIFTS/HOUR)

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	20.5	6.3	14.4	14.8	10.1	19.0	17.5
Q.5	20.4	4.2	13.8	12.2	7.5	11.4	18.4
MODE	30	4	13.1	6	5.4	9.5	20
S	9.7	4.9	7.6	11.0	5.8	14.8	9.1
MIN	2.5	1.5	1.8	2.5	4.9	9.5	4.7
MAX	36.8	21.4	35.4	48	25	36	33.5
Q.25	13.5	3.1	7.9	7.9	5.7	9.5	7.7
Q.75	30	9.7	18.7	17.6	15.2	36	24.2
SSZ	34	27	19	16	17	3	28

D. VERTREP AMMUNITION TRANSFERS LESS THAN 2000 YARDS

LIFTS

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	74	4.2	6.4	3	3.2	1	46.1
Q.5	57	4	6	1	3	1	31.5
MODE	8	4	3	1	1	1	118
S	1	2.7	5.2	3.5	2.3	0	47.1
Q.25	32	3	3	1	1	1	8
Q.75	97	5	8	7	5	1	83
MIN	8	1	1	1	1	1	6
MAX	216	10	15	7	7	1	111

TIME (MINUTES)

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	153	37	34	15.6	23	4.6	99
Q.5	126	24	32	10	28	5	61.5
MODE	126	20	31	4	40	2	20
S	127	21	20.3	15.3	15.8	2.9	102.6
Q.25	75	21	20	4	6	2	20
Q.75	160	49	45	33	40	6	172
MIN	45	20	5	4	1	2	15
MAX	615	75	75	33	42	10	270

RATE (LIFTS/HOUR)

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	31	7.1	12.3	11.2	15.4	18.6	27.1
Q.5	30	9	12	12.7	8.6	12	26.5
MODE	29	4.9	9.1	6	8.6	30	26.2
S	16	3.5	8	21.9	17.1	10.9	4.66
Q.25	19	4	5.8	6	4.5	10	25
Q.75	42	9.5	18	15	23.3	30	28
MIN	3.3	2.5	2.4	6	2	6	21
MAX	56.4	11.4	26.5	15	60	30	37
SSZ	19	9	9	3	11	7	8

E. VERTREP AMMUNITION TRANSFERS GREATER THAN 2000 YARDS

LIFTS

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	17.2	3.6	4		3.8		17.2
Q.5	12	3	4		4		9
MODE	11	3	4		5		3
S	12.5	2.7	0		1.3		21.7
Q.25	11	2	4		3		3
Q.75	16	5	4		5		19
MIN	8	1	4		2		1
MAX	39	9	4		5		54

TIME (MINUTES)

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	54	47.1	14		31.3		39.8
Q.5	57	20	14		32.5		33
MODE	30	20	14		45		30
S	32.8	73.1	0		23.5		21.1
Q.25	30	20	14		10		30
Q.75	70	32	14		45		34
MIN	15	6	14		4		25
MAX	98	212	14		64		77

RATE (LIFTS/HOUR)

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	24.3	8.5	17.1		14.5		20.3
Q.5	23.8	9	17.1		6.7		15.9
MODE	9.4	9	17.1		6.7		7.2
S	16.5	5.8	0		15.7		17.3
Q.25	9.4	3	17.1		6		7.2
Q.75	32	9.4	17.1		18		34.5
MIN	8.4	2.5	17.1		4.7		2
MAX	48	20	17.1		45		42.1

SSZ	5	7	1	0	6	0	5

F. VERTREP STORES TRANSFERS LESS THAN 2000 YARDS

LIFTS

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	55.2	16.4	7.6	8.0	7.7	4.4	17.1
Q.5	30	12	6.5	4	6	3.5	7
MODE	14	1	1	1	6	1	2
S	53.6	24.1	6.3	7.2	7.1	3.3	24.7
Q.25	14	3	2	2	2	1	2
Q.75	80	22	11	15	9.5	6	24
MIN	4	1	1	1	1	1	1
MAX	226	189	23	25	31	11	151

TIME (MINUTES)

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	135	69.2	45.4	43.3	44.3	29.6	61.4
Q.5	114	45	34	28.5	31	23	33.5
MODE	90	20	20	10	15	2	10
S	82.2	80	43	40.8	38.8	20.8	76.8
Q.25	68	20	18	10	15	10	14
Q.75	204	87	57	72	60	45	80.3
MIN	12	2	2	1	2	2	1
MAX	357	400	200	124	176	70	400

RATE (LIFTS/HOUR)

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	22.8	17.2	13.7	15.1	13.1	14.4	20.4
Q.5	22	13.1	10.4	12.3	11.6	8.6	15
MODE	20	3	30	30	4	30	30
S	12.4	12.7	10.4	11.9	8.9	13.6	14.8
Q.25	12.5	7.8	5.4	8.2	6.2	4.8	8
Q.75	29.5	24	20	18	18	18	30
MIN	2.8	2	2	3	2.6	2	2
MAX	55.2	51.4	40	60	48.3	54	60
SSZ	83	71	57	26	64	22	80

G. VERTREP STORES TRANSFERS GREATER THAN 2000 YARDS

LIFTS

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	34.7	5.6	5.8	3	4.7	3.9	9.4
Q.5	22	2	3	2	2	3	4
MODE	8	1	1	2	1	1	1
S	38	8.9	6.7	3.4	5.7	3.5	16.6
Q.25	10	1	1.5	1	1	1	2
Q.75	41	5	6.5	3	26	5	11
MIN	1	1	1	1	1	1	1
MAX	158	53	25	20	6	132	131

TIME (MINUTES)

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	127	33.7	45.0	33.1	33.1	52.4	48.3
Q.5	85	22	32.5	20	20	38	25
MODE	70	20	10	20	20	10	15
S	112.5	33.0	48.7	47.2	29.5	62.8	71.6
Q.25	46	15	135	15	15	18	15
Q.75	190	37	49.5	30	33	66	59
MIN	3	3	5	2	3	5	5
MAX	486	232	252	315	141	305	570

RATES (LIFTS/HOUR)

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	18.7	9.0	9.1	8.0	9.9	6.0	12.6
Q.5	13.3	6	6	6	6	4.3	9.2
MODE	18	6	2.4	6	6	2.6	4
S	3.4	9.5	7.4	8.4	8.4	3.5	11.1
Q.25	9.2	3	4	3.3	4	3.4	4
Q.75	25.5	11.5	12	9	12.5	8.6	17.1
MIN	3.6	2	2.4	2	2	2	2
MAX	63.5	60	31.9	60	44	13.3	60
SSZ	55	130	36	53	107	22	111

APPENDIX C. TOTAL TIME UNREP STATISTICS

A. TOTAL TIME REFUELING STATISTICS

Amount of Fuel Transferred (Mbbl) per UNREP

STAT	AXB	CV	AXL	CG	DD	DDG	FF	FFG
AVG	27.7	12.7	3.2	2.5	2.2	1.7	1.3	1.1
Q.5	25.3	11.3	2.9	2.4	1.9	1.6	1.2	1.1
MODE	14.8	10.3	3.1	2.4	1.0	1.7	1.1	1.1
S	15.5	5.8	1.9	1.2	1.2	0.7	0.6	0.5
MIN	3.7	2.3	0.1	0.3	0.1	0.2	0.1	0.1
MAX	64.3	29.8	9.8	7.7	5.9	3.9	3.9	3.6
Q.25	16.8	8.4	1.8	1.6	1.3	1.2	0.9	0.8
Q.75	38.5	16.2	4.3	3.1	2.8	2.1	1.7	1.4

Total Time for Refueling UNREPs in Minutes

AVG	228	140	112	67	71	59	59	61
Q.5	224	131	98	60	63	53	53	56
MODE	130	114	94	49	55	46	38	57
S	102	48	52	33	33	23	25	27
MIN	83	43	40	29	15	25	15	11
MAX	776	285	297	173	173	176	170	156
Q.25	162	110	84	49	53	43	43	44
Q.75	257	167	126	76	81	65	67	69

Summary Percentages of Controlling Variables

DANT	.83	.54	.81	.78	.72	.69	.73	.66
MULT	.19	.63	.35	.36	.45	.51	.46	.44
STAT	.07	.15	.18	.11	.11	.23	.16	.09

Average Number of Transfer Stations Used Per UNREP

STA	2.5	2.6	1.4	1.8	1.6	1.7	1.2	1.1

Percentage of UNREPs with simultaneous Fueling and CONREP

F&C	--	.24	--	.15	.20	.14	.08	.12

Average Rig/Unrig Time and Standard Deviation in Minutes

MEAN	18	23	18	12	11	13	11	13
ST DEV	7	13	8	5	5	6	5	6

Sample Size for Analysis

SSZ	67	227	156	349	460	322	635	293

B. TOTAL TIME CONREP STATISTICS

Total Number of Lifts per UNREP

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	84	14	14	14	11	9	34
Q.5	60	7	9	10	7	6	17
MODE	29	5	3	3	2	3	12
S	68	16	13	11	11	11	44
MIN	1	1	1	1	1	2	1
MAX	341	85	67	58	52	61	260
Q.25	36	5	4	5	4	3	8
Q.75	106	21	21	19	14	11	41

Total Time for CONREP in Minutes

STAT	CV	CG	DD	DDG	FF	FFG	CLF
AVG	193	97	98	91	93	85	128
Q.5	181	83	85	77	80	76	115
MODE	186	67	55	57	47	80	75
S	77	48	52	47	43	46	72
MIN	70	28	25	27	20	32	42
MAX	429	288	284	300	246	239	497
Q.25	137	67	59	59	59	48	84
Q.75	231	109	124	115	120	102	144

Summary Percentages of Controlling Factors

DANT	.54	.72	.80	.82	.77	.83	.86
MULT	.43	.26	.40	.54	.46	.53	.28
STAT	.15	.03	.05	.27	.13	.24	.22
AMO	.27	.21	.16	.14	.16	.05	.14

Average Number of Stations Used Per UNREP

STA	1.6	1.1	1.0	1.0	1.0	1.0	1.25

Sample Sizes for Analysis

SSZ	169	124	121	113	102	58	149

Summary Statistics for CONREP Ammunition Rig/Unrig Times

AVG	23	19	24	24	19	24	23
ST DEV	11	9	10	12	9	4	12
SSZ	34	27	19	16	17	3	28

Summary Statistics for CONREP Stores Rig/Unrig Time

AVG	23	22	15	19	19	18	19
ST DEV	13	11	7	10	10	8	12
SSZ	135	95	102	97	85	55	172

APPENDIX D. REGRESSION MODEL COEFFICIENTS

The several regression models computed have been combined into a smaller set of models. The following tables represent the observed coefficient values, and qualitative statistics of each receiving ship class model. The combined model coefficients fall within the 95% confidence intervals of the regressions coefficients listed for each seaparate ship class model.

UL is the upper confidence bound LL is the lower confidence bound, EST is the mean value, and T-VAL is the calculated t statistic of the regression coefficient. R2 is the R^2 value of the full model. SE is the computed standard error of the model. In the single station models standard error is in minutes and in the total time models the standard error must be considered in terms of the log log transformation of the observed data. SSZ is the sample size of the model.

A. SINGLE STATION SIMPLE LINEAR REGRESSION COEFFICIENTS

SINGLE STATION SIMPLE LINEAR REGRESSION

REFUELING MODEL COEFFICIENTS

		BETA 0			BETA 1				
RCVR	LL	EST	UL	LL	EST	UL	R2	SE	SSZ
CV	7.73	13.03	18.33	15.89	17.16	18.42	.63	20.30	411
CG	7.29	9.84	12.38	16.05	17.80	19.54	.41	13.23	582
DD	8.80	11.40	13.98	15.08	16.75	18.41	.39	14.04	717
DDG	3.29	5.55	7.82	16.08	18.21	20.33	.47	11.01	567
FF	6.37	8.40	10.43	13.81	15.41	17.02	.37	10.20	662
FFG	7.03	9.50	11.98	15.88	17.82	19.76	.33	13.80	322
CVJP5	16.99	22.48	27.96	13.60	14.74	15.88	.69	20.23	297
AXBJP5	30.00	55.12	78.21	8.03	10.52	13.00	.43	51.11	91
SMLJP5	9.96	12.16	14.35	0.07	0.09	0.11	.27	11.09	305

SINGLE STATION SIMPLE LINEAR REGRESSION

CONREP AMMUNITION COEFFICIENTS

	BETA 0			BETA 1					
RCVR	LL	EST	UL	LL	EST	UL	R2	SE	SSZ
CV	26	59	92	1.2	1.7	2.2	.60	62	34
CG	17	42.1	66	1.4	3.7	6.6	.19	43	27
DD	5.7	15.7	25.7	.7	1.8	3.0	.36	13	19
DDG	8.5	15.3	22.2	1.6	2.0	2.4	.62	39	16
FF	11.5	35.2	58.9	-2.5	.3	3.2	0.0	28	17
FFG									0
CLF	22.9	35.2	47.6	0.7	1.2	1.7	.56	17	24

SINGLE STATION SIMPLE LINEAR REGRESSION

CONREP STORES COEFFICIENTS

	BETA 0			BETA 1					
RCVR	LL	EST	UL	LL	EST	UL	R2	SE	SSZ
CV	28	41	54	1.5	1.7	2.0	.58	48	135
CG	12.2	17.0	21.6	1.8	2.1	2.3	.75	15	95
DD	12.1	16.8	21.6	1.9	2.1	2.4	.71	17	102
DDG	8.5	15.3	22.2	1.6	2.0	2.4	.51	22	97
FF	11.4	16.4	21.4	1.9	2.2	2.5	.70	16	85
FFG	2.7	10.0	17.3	2.3	2.8	3.3	.71	20	55
CLF	23.7	29.3	35.9	1.4	1.6	1.7	.66	29	172

B. TOTAL TIME REFUELING COEFFICIENTS AND CONFIDENCE INTERVALS

MULTIPLE REGRESSION COEFFICIENT TABLE FOR TOTAL UNREP REFUELING MODELS
THE RECOMMENDED MODELS IN THE TEXT ARE WITHIN THE 95% CONFIDENCE INTERVALS OF THE TABLE

		BETA 0	AO	AOE	AOR	DANT	MULT	STAT	CONREP	JP5	FSTA2	FSTA4	DORJ	FUEL	R2	SE	SSZ
	UL	3.76			-.12						.23	.06	0	.61			
CV	EST	3.55			-.25						.14	-.21	-.09	.53	.49	.23	191
	LL	3.35			-.37						.07	-.35	-.18	.44			
	T VAL	34.1			-3.8						2.8	-2.8	-1.8	13.0			
	UL	4.10	.44	-.08		-.03	.11	.19	.25		-.03			.42			
CG	EST	3.99	.30	-.17		-.11	.05	.09	.15		-.13			.35	.35	.27	293
	LL	3.87	.16	-.26		-.18	-.02	0	.05		-.22			.22			
	T VAL	65.7	4.3	-3.7		-2.8	1.4	1.9	2.9		-2.7			9.2			
	UL	4.13			.16	-.05			.23		-.05			.38			
DD	EST	4.07			.08	-.11			.15		-.11			.31	.26	.27	352
	LL	3.99			.01	-.17			.07		-.18			.25			
	T VAL	99.0			2.3	-3.6			3.7		-3.5			9.1			
	UL	4.02		-.16				.17	.39		-.10			.44			
DDG	EST	3.94		-.30				.09	.27		-.19			.36	.24	.31	308
	LL	3.86		-.44				0	.16		-.27			.27			
	T VAL	115.0		-4.3				2.1	4.5		-4.4			8.1			
	UL	3.95	.19			-.03		.11	.38		-.13			.48			
FF	EST	3.91	.10			-.03		.05	.31		-.19			.43	.43	.24	543
	LL	3.86	.01			-.12		0	.23		-.24			.38			
	T VAL	175	2.2			-3.3		1.8	8.0		-6.7			16			
	UL	3.92		.18					.59					.51			
FFG	EST	3.89		.08					.47					.43	.47	.25	232
	LL	3.85		0					.35					.36			
	T VAL	207		1.9					7.6					11.3			
												FSTA1					
	UL	3.92										.34		.65			
AX8	EST	3.50										.16		.57	.78	.18	68
	LL	3.23										-.02		.49			
	T VAL	25.9										1.8		14.3			
	UL	4.38		.36							-.14			.46			
AXL	EST	4.29		.18							-.24			.38	.43	.26	144
	LL	4.20		0							-.33			.30			
	T VAL	96.0		1.9							-4.9			9.6			

C. TOTAL TIME CONREP COEFFICIENTS AND CONFIDENCE INTERVALS

MULTIPLE REGRESSION COEFFICIENT TABLE FOR TOTAL UNREP CONVENTIONAL REPLENISHMENT MODELS
THE RECOMMENDED MODELS IN THE TEXT ARE WITHIN THE 95% CONFIDENCE INTERVALS OF THE TABLE

		BETA 0	AE	AO	AOE	AOR	TAO	DANT	MULT	STAT	FUEL	AMO	CSTA2	LIFT	R2	SE	SSZ
	UL	4.41								.12				.29			
CV	EST	4.09								.06				.22	.23	.31	99
	LL	3.78								0				.16			
	T VAL	26.0								2.1				6.6			
	UL	3.97			.04							.67		.37			
CG	EST	3.77			-.23							.48		.30	.46	.35	94
	LL	3.57			-.49							.30		.22			
	T VAL				-1.7							5.2		7.9			
	UL	4.38			-.21	-.03	-.05	-.02			.54			.36			
DD	EST	4.02			-.45	-.25	-.28	-.22			.34			.27	.51	.36	92
	LL	3.67			-.68	-.53	-.52	-.42			.14			.18			
	T VAL	22.7			-3.8	-1.7	-2.4	-2.2			3.3			6.0			
	UL	3.72	.40		-.44		0				.54			.44			
DDG	EST	3.51	.24		-.64		-.21				.38			.36	.60	.31	112
	LL	3.31	.07		-.84		-.44				.21			.29			
	T VAL	34.2	2.8		-6.3		-1.9				4.5			10.0			
	UL	4.18			-.11		-.03				.24			.37			
FF	EST	3.96			-.27		-.19				.11			.31	.58	.30	96
	LL	3.74			-.43		-.34				-.02			.24			
	T VAL	36.0			-3.4		-2.5				1.7			9.4			
	UL	3.83									.58			.45			
FFG	EST	3.52									.36			.32			
	LL	3.20									.15			.18			
	T VAL	22.4									3.4			4.7			
	UL	4.36								.49	.36	.56		.23			
AXL	EST	4.11								.25	.18	.32		.16	.32	.36	71
	LL	3.86								.02	0	.09		.09			
	T VAL	32.6								2.1	1.9	2.8		4.7			
	UL	4.25						.56						.28			
AXB	EST	3.94						.29						.19	.29	.40	71
	LL	3.62						.03						.11			
	T VAL	24.8						2.2						4.4			

APPENDIX E. RECOMMENDED UNREP TOTAL TIME MODELS

A. TRANSFER TO AIRCRAFT CARRIERS

1. When DFM or JP5 is the controlling factor.

$$\hat{TTIME} = e^{(3.55+.137FSTA2-.206FSTA4-.089JP5+.530(\ln(\max(DFM,JP5))))}$$

2. When CONREP ammunition or stores is the controlling factor.

$$\hat{TTIME} = e^{(4.09+.22(\ln LIFT))}$$

B. TRANSFER TO CG'S AND SPRUANCE CLASS DD'S

1. When DFM is the controlling factor.

$$\hat{TTIME} = e^{(4.0-.10DANT+.10STAT-.12FSTA2+.15CONREP+.34(\ln DFM))}$$

2. When CONREP ammunition or stores is the controlling factor.

$$\hat{TTIME} = e^{(3.95-.15DANT+.30FAS+.30(\ln LIFT))}$$

C. TRANSFERS TO DDG, FF OR FFG

1. When DFM is the controlling factor.

$$\hat{TTIME} = e^{(3.90-.07DANT+.10STAT-.20FSTA2+.35CONREP+.43(\ln DFM))}$$

2. When CONREP ammunition or stores is the controlling factor.

$$TTIME = e^{(3.70-.15DANT+.20FAS+.35(\ln LIFT))}$$

D. TRANSFERS TO CLF SHIPS

1. AO, AOE, AOR or TAO consol refueling

$$\hat{TTIME} = e^{(4.29-.23FSTA2+.38(\ln(\max(DFM,JP5))))}$$

2. **AE, AFS when DFM is the controlling factor.**

$$\hat{TTIME} = e^{(3.50+.57(\ln(DFM)))}$$

3. **Any CLF when CONREP ammunition or stores is the controlling factor.**

$$\hat{TTIME} = e^{(4.05+.18FUEL+.32AMO+.17(\ln LIFT))}$$

E. TRANSFERS FROM AE/AFS TO SMALL COMBATANTS (CONTROLLED BY DFM).

$$\hat{TTIME} = e^{(4.32+.23AFS+.41AMO+.312(\ln DFM))}$$

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