

MASTER OF SCIENCE IN OPERATIONS RESEARCH

AN ALGORITHM FOR ENUMERATING THE NEAR-MINIMUM WEIGHT S - T CUTS OF A GRAPH

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An algorithm for enumerating near-minimum weight s - t cuts in directed and undirected graphs, with applications to network interdiction and network reliability is provided. “Near-minimum” means within a factor of $1+\epsilon$ of the minimum for some $\epsilon \geq 0$. The algorithm is based on recursive inclusion and exclusion of edges in locally minimum-weight cuts identified with a maximum flow algorithm. A polynomial-time complexity result when $\epsilon = 0$, and for $\epsilon > 0$ the demonstration of good empirical efficiency is proven. The algorithm is programmed in Java, run on a 733 MHz Pentium III computer with 128 megabytes of memory, and tested on a number of graphs. For example, all 274,550 near-minimum cuts within 10% of the minimum weight can be obtained in 74 seconds for a 627 vertex 2,450 edge unweighted graph. All 20,806 near-minimum cuts within 20% of minimum can be enumerated in 61 seconds on the same graph with weights being uniformly distributed integers in the range $[1,10]$.

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Near-Minimum Cuts, Cut Enumeration, Minimum Cuts, Network Interdiction

OPTIMIZING PROCUREMENT PLANNING OF NAVY SHIPS AND AIRCRAFT

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The United States Navy Chief of Naval Operations Assessment Division (N81) is responsible for planning long-range capital expenditure on ships, submarines and aircraft. This planning is complicated, involves billions of dollars over decades, and determines future Navy capability. Navy force structure analysts have to balance: yearly budgets; requirements, current inventory, and procurement options for ships, submarines, and aircraft; and capacity and workforce levels of shipyards and factories. N81 Navy analysts currently use the Extended Planning Annex/Total Obligated Authority (a spreadsheet that estimates the financial impact of any complete future plan) to assist them with their complex planning. The Capital Investment Planning Aid (CIPA) is a prototypic optimization model, limited in scale, previously developed to demonstrate the benefits of augmenting EPA/TOA with optimization. This thesis introduces Generalizing Procurement Planning for Naval Ships and Aircraft (GENSA), which extends CIPA. GENSA is tested with a 30-year planning horizon with 29 mission areas, 45 ship classes, 39 aircraft types, 13 production facilities, and four categories of money. A current base case and an excursion demonstrate GENSA can be used to address exigent issues optimally.

OPERATIONS RESEARCH

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Integer Linear Programming, Military Capital Budgeting, Optimization, Force Structure

ESTIMATING HULL COATING THICKNESS DISTRIBUTIONS USING THE EM ALGORITHM

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The underwater hull coating system on surface ships is comprised anti-corrosive (AC) and anti-fouling (AF) paint. The AF layers are designed to wear away, continuously leaching cuprous oxide to inhibit marine growth. The thickness of the AF paint layers determines the expected service life of a coating system. Thus, it is important to assess the thickness of the AF layers to determine if the current hull coating system is sufficient. The Naval Ship Technical Manual (NSTM) provides specific guidelines as to how much AF paint should be applied. Unfortunately, the AF layers cannot be measured directly. The distribution of total paint thickness measurements is currently used as a proxy for the distribution of the thickness of the AF paint layers when determining if the existing coating system meets the hull coating requirements. A remedy for this situation is proposed. A non-parametric maximum likelihood estimator for the cumulative distribution function of the AF layers, based on the EM algorithm, has been developed. Monte Carlo simulation is used to study the properties of this statistical approach for estimating the AF thickness. This model can be used to help decide if sufficient AF paint is on the underwater hull of a ship.

DoD KEY TECHNOLOGY AREA: Materials, Processes, and Structures, Ships and Watercraft

KEYWORDS: Deconvolution, EM Algorithm, Anti-Fouling Paint, Underwater Hull Coating System

A PARAMETRIC COST MODEL FOR ESTIMATING OPERATING AND SUPPORT COSTS OF U.S. NAVY AIRCRAFT

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This study provides parametric O&S cost models for future US Navy aircraft acquisition programs based on physical and performance parameters. The proposed parametric cost models provide decisionmakers with a tool for developing rough-order-of-magnitude annual O&S cost estimates for future U.S. Navy aircraft acquisition programs. The historic aircraft cost data was provided by the Naval Center for Cost Analysis (NCCA) in a spreadsheet format and the data were extracted from the Navy Visibility and Maintenance of Operating and Support Cost (VAMOS) data warehouse. After validating the assumption that the average annual O&S cost for any aircraft type/model/series is constant from year to year, cost estimating relationships are developed. The first model developed is based on multivariate regression. In this case, forward stepwise regression was used to find the model with the best fit. Since the multivariate regression model turns out to be impractical, having more than 30 variables in the equation, a tree-based model is presented as an alternative. Additionally, single variable cost estimating relationships are formulated based on the physical and performance parameters *length*, *weight*, and *thrust*.

DoD KEY TECHNOLOGY AREA: Other (Cost Analysis)

KEYWORDS: Cost Estimation, Operating and Support Cost, Aircraft, Regression, Tree Models

OPERATIONS RESEARCH

HETEROGENEOUS SALVO MODEL FOR THE NAVY AFTER NEXT

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The Navy Warfare Development Command has taken the lead in studying needed Capabilities for the Navy After Next. Amongst the ideas they are considering are innovative special purpose littoral warfare platforms as well as alternative relationships between platforms, sensors, weapons, and information. This thesis presents a low-resolution model for analysis of Navy After Next concepts and demonstrates the potential use of the model. Presented is an adaptation of the existing Hughes Salvo Model which had been limited to analysis of engagements between forces composed of identical units, i.e., homogeneous forces. This heterogeneous extension is an analytical device that captures the unique combat characteristics of individual units. The model helps decisionmakers understand salvo warfare of heterogeneous forces by simplifying the complex relationships within and between forces during battle. Using a previous work that tested Hughes' model, the accuracy of this heterogeneous salvo model is examined by comparing results. This thesis further demonstrates the strength of the heterogeneous salvo model through an analysis of a hypothetical campaign scenario and through an examination of alternative tactics.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Surface/Under Surface Vehicles-Ships and Watercraft, Modeling and Simulation

KEYWORDS: Combat Models, Salvo Model, Hughes Salvo Model, Naval Tactics, Campaign Analysis

AN ANALYSIS ON THE SURVIVABILITY OF LAND ATTACK MISSILES (LAM)

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This thesis develops a process to assist military planners in assessing and evaluating the effectiveness of land attack missiles. The aforementioned process contains the means to address the variety of important issues and concerns that are associated with the employment of such land attack missile systems. The Department of the Navy is proposing a new land attack missile that will be employed by the Destroyer of the 21st Century (DD 21) to assist in performing Naval Surface Fire Support missions for Marines and Army troops operating ashore. This research focuses on using the Extended Air Defense Simulation (EADSIM) to estimate the probability of LAM survival for different variants of land attack missiles against various threats. The analysis concludes that the most survivable cruise missile variants have an altitude of at least 4,000 meters, speed of at least 1,610 knots, and stealthy enough to limit the enemy air defense site detection range to 1% of its maximum range. Survivable ballistic missile variants have a lofted trajectory, speed in the 2,577 knot range, and stealthy enough to limit the enemy air defense site detection range to 10% of its maximum range. The data in this thesis is from unclassified sources, but the process can be applied with classified numerical parameters.

DoD KEY TECHNOLOGY AREA: Air Vehicles, Battlespace Environments, Conventional Weapons, Sensors, Modeling and Simulation

KEYWORDS: Land Attack Missile, Advanced Land Attack Missile, Cruise Missiles, Ballistic Missiles, Missile Survivability

OPERATIONS RESEARCH

OPTIMIZING POSITIONING OF NAVY WHOLESALE INVENTORY

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Naval Inventory Control Point (NAVICP) currently manages more than 210,000 line items to supply 957 customers worldwide. NAVICP positions these items within a distribution network of 22 Defense Depots operated by the Defense Logistics Agency (DLA). NAVICP plans to reduce supply system distribution cost by optimizing their use of this distribution network. This thesis develops a heuristic algorithm that optimally positions line items to serve historical requisitions by Naval units over an 18-month period. Repositioning minimizes distribution costs subject to constraints on customer wait time and depot capacities. This model suggests a distribution scheme for 32,521 unique wholesale items from 22 depots to 126 aggregated customer regions worldwide. The Navy can reduce distribution cost by better strategic positioning of Navy wholesale inventory within the existing distribution network. The Navy can also achieve savings by positioning stocks at just a few locations, rather than at many, and by positioning items together in aggregate product groups, a policy that is widely admired in logistics.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Inventory Positioning, Location Problem, Optimization, Logistics

COST-ATTRIBUTE ANALYSIS OF RESTRUCTURING H-60R/S FLEET REPLACEMENT SQUADRONS

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The U.S. Navy helicopter community will soon experience an unprecedented transformation; one that will see a massive shift in the identity of the community and in its fleet operations. In accordance with the Helicopter Master Plan (HMP), two new airframes, the SH-60R and CH-60S, will replace the existing helicopter inventory. This thesis develops the optimal way to structure the Fleet Replacement Squadrons (FRSs), specifying the location of the various FRSs and other training necessities. Four organizational options for restructuring the FRSs are considered: two separate airframe specific FRSs per coast, one combined FRS per coast, one FRS per airframe, and one single site combined FRS. Two different training plans are considered with each option. These training plans will consider whether or not to consolidate those portions of the syllabus common to both airframes. Training, maintenance, and support cost data are determined through the use of VAMOS data and historical annual training requirements. A thorough attribute analysis of the different alternatives is performed. Using standard economic analysis techniques, multi-attribute decision theory is applied to enable a commander to choose the best option for FRS restructuring. When cost attributes are varied, the best alternative is to have two separate FRSs in NAS North Island, and two separate FRSs in NAS Jacksonville/Mayport.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Manpower, Personnel, and Training

KEYWORDS: Helicopter Master Plan, CH-60S, SH-60R, Cost-Benefit Analysis, Flight Training, Additive Weighting and Scaling Model

OPERATIONS RESEARCH

AN ANALYSIS OF THE INFLUENCE OF SIGNALS INTELLIGENCE THROUGH WARGAMING

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Signals intelligence (SIGINT), information derived from the monitoring, interception, decryption and evaluation of an adversary's electronic communications, has long been viewed as a significant factor in modern warfare. However, relatively little research has been conducted to quantify the influence of SIGINT in war. The purpose of this thesis is to investigate and quantify the influence of SIGINT in warfare by developing an interactive wargame based on the McCue simulation of the U-boat War in the Atlantic. The research comprises two phases. Phase one consists of constructing an interactive wargame version of McCue's simulation. In the wargame, a human player directs convoys across a chessboard representation of the North Atlantic while the computer controls the movement of the U-boats and tabulates the number of U-boat attack-days. Phase one tests how well the wargame models reality using historical data. The second phase of research consists of experimenting within the wargame to explore the effects of varying levels of SIGINT. Each iteration of the wargame, reflecting one of four possible SIGINT conditions, is repeated to derive statistics about the influence of signals intelligence. The results show about a twenty-five percent net change in the number of attack-days for the side utilizing SIGINT.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Java, Modeling and Simulation, Signals Intelligence (SIGINT), Wargaming

SCHEDULING AND DISTRIBUTING INTRA-THEATRE WARTIME POL REQUIREMENTS

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The Commander-in-Chief, United States Pacific Command (USCINCPAC) Joint Petroleum Office (JPO) oversees the storage and distribution of all petroleum products in the Pacific Theater. JPO planners use the decision support system described in this thesis to help determine if intra-theater wartime petroleum requirements can be satisfied for simulated or operational scenarios. Prior to the work presented in this thesis, JPO performed such analyses manually. The system uses optimization models to produce delivery plans and dispatch schedules for daily shipments of three fuel types via five different transportation modes (pipelines, tankers, barges, railcars, and trucks) amongst fifteen Defense Fuel Support Points (DFSPs). The system uses a spreadsheet interface to import data and to report results, such as fuel inventories and shortages across the distribution network, in tabular and graphical form. Dispatch schedules produced by the system provide detailed schedules for individual transportation assets and test the capacity assumptions employed in the delivery planning model. The USCINCPAC JPO used this system during two recent exercises, simulating wartime operating conditions and environment at the command level; for both exercises the system enabled JPO planners to perform rapid assessments of intra-theater fuel distribution capabilities and quickly validate the feasibility of intra-theater fuel distribution alternatives.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Petroleum Distribution Planning, Linear Programming, Integer Programming, Optimization

OPERATIONS RESEARCH

FUNDING SITE CLEANUP AT CLOSING ARMY INSTALLATIONS: AN INTEGER LINEAR PROGRAMMING APPROACH

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Since 1988, the United States Army has closed 112 and has completed or will soon complete realignment of another 27 of its domestic installations. The Army estimates the total cost (between 1988 and 2001) of these closures and realignments to be \$5.3 billion, of which about \$2.3 billion (43%) is associated with environmental cleanup. Beyond 2001, the Army expects to spend an additional \$1.09 billion to complete cleanup and continue restoration. The Army Base Realignment and Closure Office (BRACO) is currently funding environmental cleanup at 649 sites on 39 current and former Army installations. BRACO's environmental restoration budget from 2001 to 2007 to support cleanup at these installations (totaling over \$620 million) is not sufficient to support each installation's requirement for those years. Considering environmental policies and yearly funding requests from 2001 to 2015 for each site, this thesis develops optimization models and a spreadsheet interface to help BRACO allocate its budget. Model results prescribe either funding each site as requested or delaying cleanup by one to five years. Extensive model use helped BRACO analyze alternate yearly budgets, suggest alternate site funding, and determine site funding for 2001 to 2007.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Integer Linear Program, Optimization, Environmental Cleanup, Budget Allocation, BRAC

THE BOOST PROGRAM AND ITS EFFECT ON RETENTION AND PERFORMANCE

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This thesis is an analysis to determine if fleet input (Track I) compared with civilian input (Track II) personnel into the Broadened Opportunity for Officer Selection and Training (BOOST) program is related to the retention and performance of a Navy commissioned officer. The data focuses on BOOST classes, 1981-1992, to measure fleet performance and retention. Prior-enlisted officer (Track I) BOOST graduates obtain a subspecialty, receive graduate education, and enter the Lieutenant Commander promotion board at statistically significant higher rates than their civilian (Track II) counterparts. It is hypothesized that candidates with a "prior service" background have more knowledge, commitment and overall understanding of the military that will help them succeed as officers.

DoD KEY TECHNOLOGY AREA: Manpower, Personnel and Training

KEYWORDS: BOOST, Officer Programs, Prior Service, Retention

OPERATIONS RESEARCH

FINDING THE IMPORTANT FACTORS IN BATTLE OUTCOMES: A STATISTICAL EXPLORATION OF DATA FROM MAJOR BATTLES

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This study explores important factors in battle outcomes through a statistical analysis of data from major historical battles. The data set of CDB90FT has been made available and documented by the Center for Army Analysis (CAA). The quality of the historical data is good. There are 660 battles listed in the data set containing over 140 numerical features for each battle. The earliest battle in the data set is the Netherlands' War of Independence in 1600, while the last one is from the Israel-Lebanon War in 1982. The data set contains many interesting facts on the battles including the initial strengths, the total strengths, the number of casualties, the lengths of the front lines, terrain features, command capability of leaders, weather conditions, etc. The approach is to use the data set as the basis for an objective and scientific comprehensive analysis, seeking patterns, trends, and relationships in combat. After making campaign-wise grouping and analysis, it is found that the Force Ratio is a valid estimator of the battle outcome. In addition, the Casualty Rate has declined steadily over the past four centuries while Dispersion has increased.

DoD KEY TECHNOLOGY AREA: Other (History)

KEYWORDS: Dispersion, Daily Casualty Rate, Force Ratio

