MASTER OF SCIENCE
IN
OPERATIONS RESEARCH

APPLYING A FIX-AND-RELAX HEURISTIC TO U.S. NAVY FORCE STRUCTURE PLANNING
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Capital Investment Planning Aid (CIPA) is an optimization-based decision support system created for the U.S. Navy to help plan yearly force structure procurement and retirement. CIPA constraints include yearly industrial and budget limits, as well as mission inventory and force mix requirements. Over a 30-year planning horizon, CIPA helps plan over $1 trillion. Several approaches have been proposed and implemented to solve the CIPA core, a mixed-integer linear program (MILP). Unfortunately, some of these MILPs cannot be solved in a reasonable amount of time using general-purpose commercially available optimization software. This thesis presents a new MILP-based heuristic technique, fix-and-relax, that yields good quality solutions and reduces the computational solution time for the set of realistic test cases.

KEYWORDS: Operations Research, Capital Investment Planning Aid, CIPA, Heuristic, Optimization, Integer Linear Programming

BARRIER PATROL AND AIR DEFENSE SYSTEM: DEVELOPING AND INTEGRATING FLIGHT PROFILES
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In order to support the Brazilian Air Defense System, principally, in the Amazon region, the Brazilian Air Force has recently acquired the R-99, Airborne Warning and Control System (AWACS). This aircraft and the types of missions it can support are innovative in the Brazilian Air Force. The R-99 will be used for patrolling the Brazilian borders and interception control of illicit air traffic in the Amazon region. This thesis develops a planning tool, called the Campaign Decision Aid, to optimize the utilization of the R-99 in its search and detection mission. Basic principles of Radar Theory and simple Search and Detection models are used to support the analytical evaluation and optimal selection of the R-99 patrolling flight profiles. Also, stochastic modeling theory is used to develop measures of effectiveness to evaluate the integrated effort of detaining the illegal traffic using interceptors, which are flown from pre-determined Air Bases in the Amazon Region. Utilization of this Campaign Decision Aid will contribute to the control and integrity of Brazilian territory.

KEYWORDS: Air Defense, Patrolling Optimization, Measures of Effectiveness, AWACS, Air Surveillance

OPTIMIZATION MODELS FOR ALLOCATION OF AIR STRIKE ASSETS WITH PERSISTENCE

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The explosion of information available to decision-makers at all levels on the battlefield has led to tremendous strides in the ability to process, decide and act. At the same time, there is increasing demand for faster and better decisions. This thesis addresses one type of critical decision that must be made quickly and effectively, namely how to assign strike aircraft to targets once the targets have been identified. More specifically, the primary questions that this research attempts to answer are:

"How do we optimally employ available aircraft and weapons on the current set of targets?"

"How can we modify a previously optimized assignment list to face changes in the tactical situation, in a manner that balances the desire to obtain a new optimal solution with the desire to minimize disruption of existing plans based on the previous solution?"

The general air strike planning problem is divided into five areas: target selection, weapon allocation, mission formation and assignment, mission routing and scheduling, and contingency planning. This thesis addresses weapon allocation, and mission allocation and assignment, for the aircraft of an air strike package (the "package" will typically contain other aircraft with non-strike roles such as suppression of enemy air defense; these aircraft are not directly considered in this thesis).

Contributions to the strike-planning problem include: (1) a static allocation model in which each aircraft makes at most one sortie during the planning time horizon, (2) a dynamic model in which each aircraft may make more than one sortie during that horizon, and (3) extensions of these models with "persistence incentives," which discourage major changes in the results when partial but important changes in the tactical situation necessitate reoptimization. All of these models are mixed-integer programs.

These models are demonstrated in realistic scenarios. For instance, these models can allocate 156 air assets from seven bases to 100 targets in just few seconds on a personal computer. This particular problem has three types of aircraft and two possible weapons configurations for each aircraft. There are three types of weapons and 20 different packages can be formed from the aircraft available.

The persistence paradigm plays an important role in this thesis. It is shown that a new optimal plan can differ drastically from a previous plan after only small changes in the tactical situation. To handle these unexpected changes more conveniently, the persistent model adds a term to the original objective function that penalizes deviations from the original plan. The new plan is nearly optimal in the standard sense, and unit-level planners and pilots have fewer plan changes to handle.

This research is performed under the sponsorship and guidance of SPAWAR (Space and Naval Warfare Center). The result of this work is to be used inside REDS (Real-Time Execution Decision Support), a decision-support tool currently being developed at SPAWAR under sponsorship of the Office of Naval Research. The optimization modeling developed in this thesis will support SPAWAR's goal of having REDS provide the best solution for allocation of strike assets in a dynamic tactical environment.

KEYWORDS: Air Tasking Orders, ATO, Weapon Allocation, Strike Package, Persistence, Mixed-Integer Program, MIP, Optimization, Operations Research

A BRANCH-AND-BOUND ALGORITHM FOR THE NETWORK DIVERSION PROBLEM

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In the network diversion problem (NDP), a minimum-weight set of edges in a directed graph $G = (V, E)$ whose deletion forces all *s-t* communication to pass through one or more diversion edges in a diversion set E_D must be found. A specialized branch-and-bound algorithm for this NP-complete problem was developed and tested. The algorithm is based on partitioning the solution space with respect to edges in certain *s-t* cuts and yields a non-standard, non-binary enumeration tree. The algorithm is coded in Java version 1.4 and run on a 1.5 MHz Pentium IV computer with 384 megabytes of RAM. An instance of NDP on a grid graph with 2502 vertices, 9900 edges and one diversion edge is solved in 5.66 seconds; the same problem with 10 diversion edges is solved in only 0.84 seconds.

KEYWORDS: Networks, Cuts, Network Diversion, Simple Path, Enumeration, Branch-and-bound

THE EFFECT OF SENSOR PERFORMANCE ON SAFE MINEFIELD TRANSIT

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Mines are relatively cheap weapons that can be employed in significant quantity by any country with even a modest military budget, and can be very effective at severely damaging or sinking ships or denying maritime access to an area. In this thesis, simulation and analytical models are formulated and studied to investigate the benefits and risks of mine avoidance, without object classification capability, under circumstances that include imperfect sensors and false targets. Two models of mine avoidance maneuvering are formulated, with increasing complexity in both their analytical and simulation implementations. With both formulations, results are obtained and analyzed to produce tables showing the probability of successful minefield transit as a function of sensor probability of detection vs. density of mine and non-mine, mine-like bottom objects, and the false alarm rate. The tables show the range of those parameter values for which mine avoidance maneuvering improves the probability of safe transit, and the values for which mine avoidance maneuvering reduces the probability of safe transit. The decrease is attributable to the fact that mine avoidance maneuvering increases the distance traveled in the minefield and the consequent risk of damage or destruction by an undetected mine. Quantitative results for the increased distance traveled in the minefield are also presented. Finally, a comparison of the two models of mine avoidance maneuvering show, not surprisingly, that the results of the simpler model are not good approximations of the results obtained with the more complex model, suggesting that even greater complexity in maneuver modeling may be desirable for some purposes.

KEYWORDS: Mine, Minefield, NOMBO, Simulation, Stochastic Model, ROC Curve Model, Simkit, JAVA