I. Introduction

Background

For years, America's nuclear war plans have been modeled using a preemptive goal programming model called the Arsenal Exchange Model (AEM). The algorithms in this model were designed under the restrictions of 1970's computer technology, which required the model to sacrifice exactness to reduce its computational complexity. One particular area in which AEM falls short is in the application of Multiple Independently Targetable Reentry Vehicle (MIRV) footprint constraints.

To address this and other shortcomings, the United States Strategic Command (USSTRATCOM) is developing a new linear programming model, the Weapons Assignment Model (WAM).

General Description of WAM

This section gives a general description of WAM, including differences between AEM and WAM, the required user inputs to WAM, and footprint constraints.

Improvements in WAM. The proposed model will differ from AEM in several respects. AEM allocates weapon types to target classes, whereas WAM will assign specific weapons to individual targets (9). This approach has several advantages. First, damage calculations will be more accurate because they can be made using the actual hardness of the individual targets, whereas AEM uses an average hardness for each target in a target class. Second, better control of the allocation is afforded the user. This occurs since assigning weapons to individual targets facilitates greater segregation between attack options. Also, the user can apply weapon range limitations and known probabilities of arrival when specific targets are known (4).

WAM will also incorporate Designated Ground Zero (DGZ) selection into the optimization process. A DGZ is formed when more than one installation is to be attacked with the same warhead (5). WAM will create DGZs as it assigns weapons. Currently, DGZ construction and selection for AEM is done with a preprocessor prior to AEM execution (4). Thus, DGZ selection in AEM is not done as a part of the optimization process.

Finally, WAM will incorporate MIRV footprint constraints into the allocation process. AEM does not include the footprint constraints in its allocation process. Instead, AEM uses a heuristic after the allocation is complete that swaps weapons assignments to ensure footprint requirements are met. The subject of MIRV footprints is covered in more detail later. The development of MIRV footprint constraints that can be incorporated into the weapon allocation process is the thrust of this research.

Inputs. The inputs to WAM can be divided into two main categories - resources and goals. Resource inputs describe available weapons and potential targets. Available weapons include types of weapons, such as Peacekeeper warheads, B-1B gravity bombs, or Trident missile warheads. The input data includes weapon parameters such as yield, reliability and number of MIRVs carried. Goals are objectives that the decision maker wants to be met. An example of a goal would be to achieve 90% damage expectancy (DE) against a particular class of targets, where DE reflects the probability of arrival of a weapon and the destructiveness of the weapon. Since the goals are assigned a priority which reflects their importance, WAM will use a preemptive goal programming formulation to ensure satisfaction of the different goals. The goals are dictated by force employment policies. The goal inputs are used to ensure the desired force employment is achieved. This is done by establishing a goal hierarchy, whereby the goal that is given highest priority will be met first, followed by satisfaction of the goal with the second highest priority, until all of the available resources are exhausted (4).

Footprint Constraints

Footprint constraints are constraints that account for the fact that MIRVs deployed from the same post boost vehicle (PBV) have certain geographic restrictions placed on their targets. Langley and Billings define a footprint as "a geometric figure whose size, shape, and orientation are dependent on the specific MIRV weapon system and launch site, and which defines an area of feasible coverage by a single MIRV (9:15)." These restrictions are due to the fact that a PBV has a limited amount of energy to use in dispersing its MIRVs. Therefore, the total sum of energy imparted to a set of MIRVs from a single PBV is bounded (9:8). This energy can be distributed in an infinite number of ways. For example, all but one of the MIRVs can be targeted to a tight group of targets or DGZs, while a single MIRV uses most of the PBV energy to strike a distant DGZ. Alternatively, the energy could be distributed evenly to the MIRVs so they strike evenly spaced DGZs. (9:8) These two concepts are illustrated in Figure 1-1.

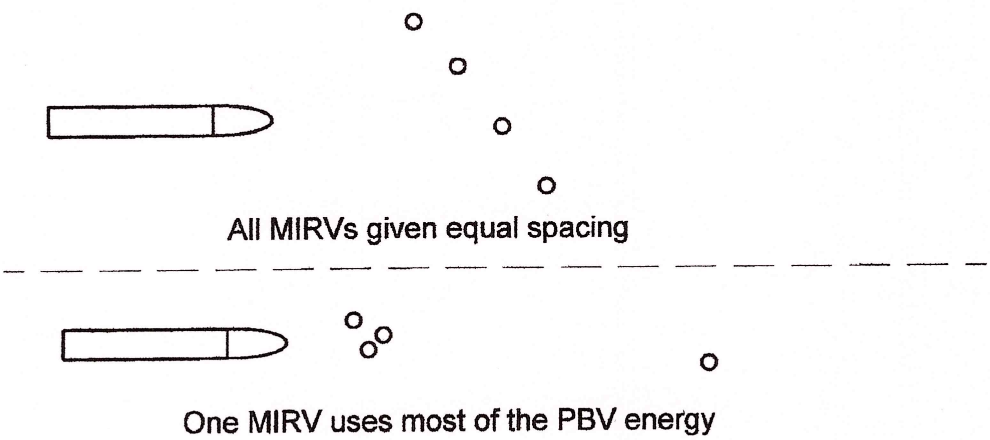

Figure 1-1. MIRV Distribution Options (9:9)

AEM does not include footprint constraints in its optimization process. Instead, it arrives at a solution using preemptive goal programming which allows MIRV targeting to be unrestricted. Once an allocation of all weapons is achieved, a heuristic algorithm is used to swap MIRV/target combinations until all MIRVs have realistic footprints (5). The heuristic uses a rectangular approximation of the MIRV footprint. The rectangle is laid across a set of targets and any DGZ that falls outside the rectangle is considered to be outside the footprint for that PBV. DGZs are then traded between weapon systems until all DGZs fall within the footprint for their respective PBV (6). This heuristic is used to assure feasibility, but it does so without regard to the optimality of the solution. The result is a feasible solution that is no longer optimal.

Problem Definition

The Weapons Assignment Model will include MIRV footprint constraints in its formulation. The problem is to find a way to do this that permits the inclusion of the footprint constraints in a linear program. Thus, the purpose of this research is to develop an acceptable technique to model MIRV footprint constraints for the Weapons Assignment Model. The technique must be compatible with a linear programming formulation.

Scope

This thesis will focus only on the MIRV footprint constraints of WAM. For the purpose of finding a MIRV footprint model, an acceptable technique is defined as one that can replicate the results of a true footprint. The replication of the results does not have to be 100% correct in all cases, but it should be sufficiently accurate so as not to detract from the effectiveness of the solutions generated by the Weapons Assignment Model.

The footprinting methodology developed in this research is applicable only to missiles, and does not apply to the problem of footprinting bomber aircraft.

Format

Chapter II provides a more detailed description of the footprinting problem. The necessary background information to model MIRV footprints is presented.

Chapter III discusses two proposed models for the footprint constraints. These are geometric approximation (GA) and energy space transformation (EST). The methodology of the proposed models, including their formulation into linear constraints, are presented in detail. In Chapter IV, the models are tested against a missile simulation software package called Missile Performance System (MPS). The models are developed and modified as necessary to produce acceptable results. In Chapter V, the models are validated. Chapter VI presents conclusions from the testing and makes recommendations.

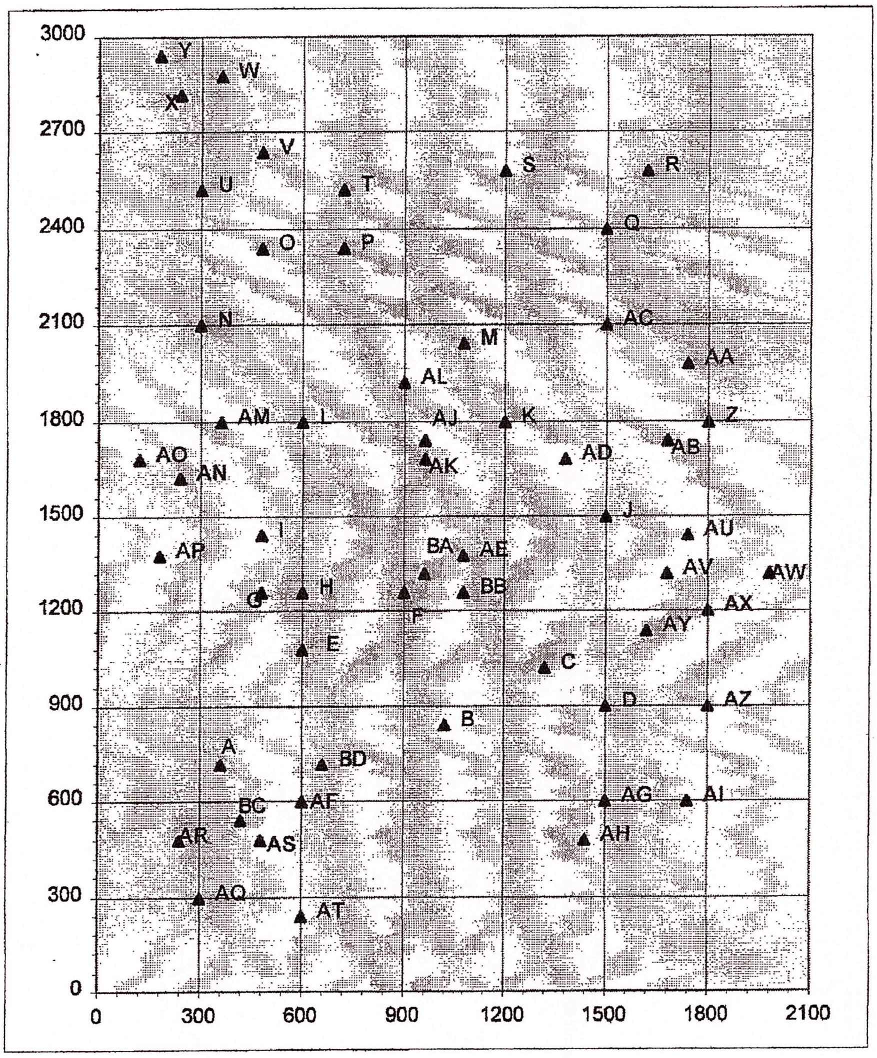

Figure 4-1. Target Area Grid (Units are in Nautical Miles)

Missile Simulation

In order to assess the proposed models, a high fidelity simulation is required to provide data on the true capability of missile systems. The Microcomputer Missile Performance Software System (MPS) was chosen to meet this requirement. MPS is maintained by Kaman Sciences Corporation under the direction of the U. S. Air Force Studies and Analyses Agency (12:iii). It provides a detailed model of every aspect of a ballistic missile's flight. This gives an accurate assessment of the performance of missile systems used in this research. The user defines booster, Post Boost Vehicle (PBV), and Reentry Vehicle (RV) subsystems by providing a series of parameter inputs. A missile system is then defined by a combination of one of each of the above subsystems. MPS can provide a variety of outputs including maximum booster range, PBV down range and cross range stick lengths, and sortie feasibility reports which include the percentage of PBV fuel remaining at each RV deployment.

Missile Systems

The missile systems used in this research are fictitious. In order to provide a more thorough analysis of the models, two different missile systems were used. These missile systems were designed with capabilities that provide a rigorous test of the methodology and models presented.

The first missile system chosen for use is the US-3RV system contained in the MPS sample data file. The system carries three RVs, each weighing 1167 pounds. The RVs are carried on a pusher, nose forward type PBV with a dry weight of 2435 pounds and a usable fuel weight of 1394 pounds. A three stage booster is used to launch the PBV assembly. The maximum booster range of the US-3RV system without using PBV fuel for PBV range extension is 4840 nm.

The second missile system is called the US-4RV system. This missile uses the same booster and RVs as the US-3RV system. The PBV is modified to carry a fourth