

THE USE OF PREPROCESSED CRUISE MISSILE DATA FOR STRATEGIC PLANNING

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Abstract

This paper presents the results of a cruise missile preprocessing study accomplished by the USSTRATCOM Strategic Plans Division at Offutt AFB, NE to evaluate the use of preprocessed cruise missile sorties to accelerate cruise missile planning and explore alternative methods for assigning weapons to targets. Historically, the weapon allocation process provided the cruise missile planners with a group of targets to strike with cruise missiles. Cruise missile planners grouped the targets into weapon loads, selected launch areas, and planned routes from the launch areas to targets using the Automated Routing and Maintenance System (ARMS). Preprocessing is the process of performing detailed flight modeling of cruise missile routes from all potential launch points to all targets prior to target assignment in order to select the best subset of the preprocessed routes to maximize total target damage. Individual sortie effectiveness against specific targets was generated using ARMS. An integer programming model was used to generate an optimal assignment of cruise missiles to targets. The assignment problem was solved using SAS/OR, a commercial off-the-shelf software package. Cruise missile planners accomplished final refinement of the SAS/OR solution. Preprocessing improved the overall target damage and reduced the time required to plan the cruise missiles.

Background

In the past, the weapon allocation process employed the Hungarian algorithm and other algorithms to provide USSTRATCOM cruise missile planners with a group of targets to strike with cruise missiles. Cruise missile planners used their experience and heuristic methods to evaluate the targets and determine suitable launch areas. The launch areas had to be close enough to range the targets and geographically positioned to avoid high threat areas prior to launch and permit effective route planning from the launch area to the target. In a sparse target environment, ranging sufficient numbers of targets from each launch area to support the standard weapon loads becomes more of a problem. After launch areas and target tie-ups are determined, several weeks were spent planning the individual routes using the Automated Routing and Maintenance System (ARMS).

USSTRATCOM/J525 initiated a study to evaluate the feasibility of using an integer programming model and preprocessing cruise missile missions to accelerate the cruise missile application process. Five critical factors were examined: the time required to preprocess the cruise missile missions, the usefulness of the mission data generated by existing planning tools in solving the cruise missile assignment problem, the validity of the proposed integer programming model, the capability of commercial off-the-shelf software to solve the integer programming problem, and the acceptability of the ARMS planned cruise missile routes selected in the optimal solution.

This paper focuses on the technical aspects of the problem and does not address operational use in detail. There are several possible strategies, and operational implementation should be based on careful analysis of the benefits and costs of the alternative approaches. Factors that must be considered include: total time required to develop a solution, solution quality, data storage requirements, software development costs, maintenance costs, planner workload impact, and compatibility with other planning systems (including those outside USSTRATCOM). At this point in concept development, it is impossible to quantify most of these factors, but the proven technical feasibility of cruise missile preprocessing warrants continued development of a concept of operation.

The study began by retrieving targets and launch areas that had been used in recent plans and exhaustively planning cruise missile routes from several launch points to all selected targets. Cruise missile sortie data were developed using ARMS to determine missile capability, probability of arrival (PA) and probability of damage (PD) of individual sorties against specific targets. An integer programming model was used to generate an assignment of cruise missiles to targets that optimized target damage. The assignment problem was solved using SAS/OR, a commercial software package developed by SAS Institute.

Model

Optimizing the allocation of weapons can be expressed as a problem of dividing m weapons among n targets. For each target i , there is a value a_{ij} associated with the assignment of weapon j to target i . The value of a_{ij} is most commonly related to

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the level of damage a weapon would inflict on a target. When weapon j is assigned to target i , $f_{ij} = 1$, otherwise, $f_{ij} = 0$. As a first step, consider the case of no more than one weapon assigned to each target. We want to find an allocation of weapons to targets that maximizes

$$\sum_{i=1}^n \sum_{j=1}^m a_{ij} f_{ij}$$

subject to

$$\sum_{j=1}^m f_{ij} \leq 1, \quad \forall i, \quad (1)$$

$$\sum_{i=1}^n f_{ij} = 1, \quad \forall j, \quad (2)$$

$$f_{ij} \in \{0, 1\}, \quad \forall i, \quad \forall j. \quad (3)$$

Inequality (1) ensures that no more than one weapon is assigned to a target, and equation (2) ensures that each weapon is assigned to exactly one target. Since each weapon can be assigned to only a single target, the model describes a simple assignment problem. Each individual cruise missile would be modeled separately, although missiles launched from the same geographical area would have nearly identical capability. The similarity of some weapons allows them to be grouped together, an approach similar to the one currently used, in which all weapons of a similar type have the same or similar a_{ij} values, with no distinction due to launch area or routing. The current model specifies a type of weapon to assign to each target and the application planners determine launch area and routing. Since this approach fails to consider the sensitivity of a weapon system's capability to geographic factors, assignments might be made that are difficult for the planners to apply.

If we consider the geographic factors and distinguish between the capabilities of two different weapons of the same type (e.g. launched from different locations), the solution will tend to avoid assigning weapons to targets against which they have little capability (e.g. out of range). The current allocation process employs heuristic methods to compensate for many of these conditions (e.g. range arcs). The heuristic methods are necessarily approximations and will introduce some inaccuracy that could be eliminated by using detailed modeling results to provide better a_{ij} values.

To reduce the computer work load, weapons from closely located launch areas can be grouped together. Grouping weapons of similar capability transforms the assignment problem into a

transportation problem; the launch areas are sources and the targets are destinations.

Grouping the weapons means that weapon j no longer represents a single weapon, but rather a weapon from group j . Since we no longer identify individual weapons (and limit them to one), constraints must be introduced to limit the number of weapons assigned. We will specify a weapon class k , and a set of weapon groups $A(k)$, such that all weapon groups $j \in A(k)$ share a common characteristic that limits the number of those weapons that can be part of the solution (e.g. a specific type of cruise missile). The limit will be denoted as M_k and is an upper bound for the number of weapons assigned from class k (the source limit in the transportation problem). So, in general, we can develop a new constraint for a class of weapons k that replaces equation (2):

$$\sum_{i=1}^n \sum_{j \in A(k)} f_{ij} \leq M_k, \quad \forall k. \quad (2a)$$

Some weapon systems are further constrained by loading characteristics that are unique to that weapon system. Cruise missile loads are restricted to a few standard loads. Since a load constraint is appropriate for only a particular group of weapons, we must establish a weapon group, j , for the weapon type of interest. For example, all cruise missiles of a specific type launched from a single launch area would be a weapon group to which common load restrictions would apply. The set $C(j)$ is defined as the set of weapon loads, l , applicable to weapon group j ; weapon load l is suitable for weapon group j if and only if $l \in C(j)$. For example, if standard weapon loads for cruise missiles are six or ten missiles, $C(j) = \{6, 10\}$. The numbers of six and ten missile loads launched from area j are denoted L_{j6} and L_{j10} , respectively. So, the total number of missiles launched from an area must equal the sum of the number of missiles in the individual loads and the cruise missile assignment problem then is to maximize:

$$\sum_{i=1}^n \sum_{j=1}^m a_{ij} f_{ij}$$

subject to

$$\sum_{j=1}^m f_{ij} \leq 1, \quad \forall i, \quad (1)$$

$$\sum_{i=1}^n \sum_{j \in A(k)} f_{ij} \leq M_k, \quad \forall k, \quad (2a)$$

$$f_{ij} \in \{0, 1\}, \quad \forall i, \quad \forall j, \quad (3)$$

$$\sum_{i=1}^n f_{ij} - 6L_{j6} - 10L_{j10} = 0, \forall j \in A(cm), \quad (4)$$

$$L_{ji} \text{ integer}, \quad \forall j, \forall i. \quad (5)$$

The structure of the problem will cause f_{ij} to assume only integer values which leaves only L_{ji} to be specified as integer. The reason for this is that if introducing a fraction of another sortie to the solution would improve the value of the objective function, introducing the whole sortie would improve it more. Not specifying f_{ij} as binary will substantially reduce the time required to solve the problem.

To solve the problem, values for a_{ij} must be determined that reflect a contribution to effectiveness. Target value and the amount of damage inflicted are the most obvious components of a_{ij} . Additional analysis needs to be done to determine the most effective target values.

Procedures

Recently planned cruise missile routes were evaluated to determine targets and launch areas because they were readily available and provided a realistic scenario for the problem. Tie-ups were constructed to identify the launch point and the cruise missile target, with only enough other data to allow the tie-up to be migrated to ARMS. ARMS was utilized to make an initial range determination. Those ranges were used as an input to a small COBOL program that built several ARMS input files. Launch point to target combinations that exceeded a maximum expected standoff distance were excluded from further consideration; the remaining launch point-target combinations were processed in ARMS to develop a route for each combination. ARMS generated the probability of damage and probability of arrival data necessary to build the input data for the integer programming model.

ARMS routing jobs ran over a five week period on an IBM mainframe. Jobs were submitted using edited JCL rather than the ARMS user interface. This technique substantially reduced the amount of time required to prepare the jobs for submission. The current work station interface does not lend itself to preparing the routing jobs because of the large amount of time required to construct a job and the large number of jobs involved.

The integer programming problem was solved on an IBM 9000 mainframe using SAS/OR, a commercial off-the-shelf software package. SAS/OR input files were constructed from target and damage data extracted from an ARMS sortie report. The problem was partitioned as much as possible to accel-

erate processing. SAS/OR solves the integer programming problem by first solving a linear programming relaxation (LPR) and then using branch and bound to find the optimal integer solution.

Six typical sorties and solution statistics were provided to the strike team planners for their evaluation.

Results/Analysis

The initial cruise missile ARMS runs were completed in five weeks. Processing was done primarily at night and on weekends, and some improvement could be expected in a production environment if daytime processing was allowed. Route development in ARMS is the longest task in the process.

After the initial route planning, frequent automated maintenance of the route pool would be accomplished rather than developing the routes from scratch. Once the initial route pool was developed, most target base changes could be accommodated overnight, and even very large changes could be completed in a few days. It is important that the maintenance process be sufficiently automated that little planner attention be required until the routes were ready to be evaluated. ARMS currently flags sorties that are affected by data base changes. It would be a simple change to automatically process routes in ARMS for all of the affected routes and new targets. Further, the new route pool could be processed to recommend tie-up changes to modify existing plans in response to small target base changes. Depending on the quality of the ARMS routes, the process could proceed to this point before requiring planner evaluation of the routes.

SAS/OR was executed against a problem with a known solution to verify the operation of the model and the software. The problem was formed by altering a moderately large partition of an operational plan. A feasible solution was constructed manually and damage values for the solution sorties were set high enough to make that solution optimal. The SAS/OR solution exactly duplicated the known solution.

The SAS/OR software satisfactorily solved several problems constructed from the original problem. The data extracted from existing plans were partitioned to form several problems with a wide range of size and complexity. Generally, an integer solution within a few tenths of one percent of the optimal LPR solution could be found in less than ten minutes, while completing the branch and bound procedure to evaluate all possible solutions takes several hours. The suboptimal solution would be satisfactory for planning purposes and provides a significant advantage in

speed. Small cases will require special handling when large weapon loads are planned. As the problems become smaller, the problem of tying up large loads becomes more difficult because of the smaller number of alternative routes from each launch point. SAS/OR can be run to identify launch areas and/or targets that will prevent a feasible solution from being found. Planners would have to manually plan some routes so that there was a sufficient number of routes to select from to ensure that a feasible solution could be found.

This task is analogous to the one the planners face today when planning small attacks; preprocessing would identify the difficult areas and targets and allow planners to concentrate their effort to achieve a solution more rapidly.

Jobs consisting of several different combinations of sorties and targets were run to evaluate the capability of SAS/OR to solve the problem. Larger jobs achieved a solution that was within a fraction of a percent of the linear programming relaxation solution in less than ten minutes, completing a few thousand iterations of the branch and bound search. Five hundred thousand iterations of the branch and bound search ran for over twenty hours and improved the solution by only 0.1 percent. The smallest jobs ran in less than a minute, but the integer solution was not as close to the relaxed solution. This is expected, since the smaller problems present fewer alternative solutions.

Solution results indicate that the branch and bound algorithm will converge fairly rapidly on a good solution and exhaustive evaluation of the branch and bound tree increases the run time substantially without providing a significantly better solution. Solutions were successfully verified for feasibility and checked for reasonableness.

Acceptability of ARMS routes is a critical factor in the success of this approach. The missions were generally acceptable and the number of routes that would require additional planner work appears to be small enough that the overall workload would be reduced. To keep the workload small, it is imperative that the routes developed by ARMS continue to improve in quality and the maintenance process be automated sufficiently.

Six representative cruise missile missions were provided to the cruise missile planners for their evaluation. Two sorties were among the routes with the best objective function value, two were near the middle, and two were among the worst missions. One of the routes was judged to be acceptable as planned and two required minor changes that could be accomplished in a few minutes.

The timing of the planners' evaluation and modification of the ARMS sorties will significantly affect the planner workload. If the planners must evaluate and modify all of the route pool sorties prior to selection, workload would increase dramatically, but the selection process would proceed rapidly to a satisfactory solution that would require little, if any, manipulation. Alternatively, if the planners evaluate only the selected routes, many routes may need to be modified, and there may not even be a feasible solution, requiring additional routes to be constructed. A hybrid approach would appear to be most effective. Targets with only low value routes would be evaluated before selection to determine if the routes could be improved. Further, launch areas and targets that are likely to cause problems in the selection process are easy to identify and additional routes could be constructed to ensure a feasible solution exists. The total number of routes the planners must modify or construct needs to be kept well below the number planned today if preprocessing is to provide much benefit. The key to keeping the number small is ensuring that a high percentage of ARMS routes are acceptable without planner modification.

During the course of the study, several conditions were identified that require planner evaluation.

For preprocessing to be effective, the requirement for planner evaluation needs to be kept to a minimum or the workload becomes overwhelming because of the large number of sorties in the route pool. The conditions that required planner evaluation resulted in data base or software changes to improve the quality of the sorties developed by ARMS. Other items will probably surface as preprocessing is explored more, but experience has shown that these problems provide opportunities to improve the sortie development software.

The mainframe interface and the capability to bypass ARMS job preparation completely with JCL was essential to the timely completion of the study. In the planned transition to processing solely on work stations rather than the mainframe, it is imperative that some similar capability be retained. Future analysis should evaluate the impact of work station and mainframe processing and job preparation.

Conclusions

Study results verify the feasibility of preprocessing cruise missiles to support mission planning if ARMS routes are acceptable.

- The route preprocessing can be accomplished in a reasonable amount of time. Since routes for stationary targets can be rolled over from year to year, the need to preprocess large numbers of sor-

ties is reduced. Frequent overnight runs would keep the route pool current.

- ARMS generates sufficient data to solve the cruise missile application problem.
- The proposed integer programming model will provide a valid assignment of cruise missile routes to targets.
- The integer programming problem can be solved by inexpensive commercial off-the-shelf software similar to SAS/OR.
- The weak point in the solutions provided in the study is a lack of consensus on the amount of planner manipulation required to make an ARMS sortie acceptable.

Preprocessing has been used effectively since the study was completed. Further study and analysis of the applicability of similar methods to the allocation process and ballistic missile planning is warranted. Although the use of existing planning tools reduced the cost of the study, many inefficiencies exist that suggest modifications to ARMS to make it more compatible with the preprocessing concept. These modifications fall into two categories:

- a. processing and data base changes to support a more automated approach to cruise missile preprocessing.
- b. ARMS routing characteristics that require planner manipulation of ARMS routes

The first category should affect only the higher level modules that control the routing processes and generally would not alter the more complex routing and simulation modules. The second category would involve changes to the more complex modules, but would be beneficial whether or not preprocessing is used.



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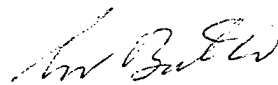
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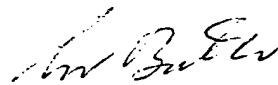
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