

UTILITY OF ANALYTICAL METHODS IN THEATER MISSILE DEFENSE ANALYSIS

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ABSTRACT

The analysis of a weapon system must employ a variety of methods to reduce errors, assure completeness and identify critical conditions that stress the system. Such analyses are conducted at various levels of the system as shown as well as the phase of system development. The application in this paper is theater missile defense acquisition support. Two levels of primary concern are battle (many-on-many) and engagement analysis (few-on-few or one-on-one). A central point for both of these levels of analysis is to ascertain the objective of the analysis. The objectives range from comparisons to requirements with commensurate increases in the range of conditions examined. One incentive for using analytical methods is in establishing the driving parameters. The ability to do so with the simpler methods is because single engagements for TMD do reflect a significant result of what can occur at the battle level. Examples analytical methods for TMD analysis will be drawn from three such methods, JEM (Joint Effectiveness Model), MONGO (not an acronym) and TABS (Technique for Analysis of the Battle Space), which span varying ranges of detail in the models and focus in terms of the emphasis of the system operation.

INTRODUCTION

The use of large scale simulations of Theater Missile Defense (TMD) systems has become the foremost method for analysis of the effectiveness of these systems especially where the situations involve both many different system elements, e.g., weapons, sensor, communications, and many components of each of these elements, e.g. missiles, radars as well as multiple threats. These effectiveness analyses support the acquisition and force employment processes¹ which involve determining key factors such as systems requirements and cost and operational effectiveness analyses (acquisition) / concept planning and force composition (force employment).

Although these large scale simulation methods are critical to system development a complete analysis

approach involves using multiple perspectives 1) to reduce the possibility of errors, 2) to insure completeness, and 3) to identify critical conditions that stress a system. This latter point is emphasized by Hillestad, Bennett, & Moore² in their paper in terms of "cause and effect" which are difficult to derive from the large scale simulations.

Checking for errors in complex simulations is difficult but can be supported by outcomes from simpler analyses that can be duplicated in the large scale simulations. These are the equivalent of the "back of the envelope" calculations which can either bound or predict for a set of simple condition what the "answer" should be.

Completeness is a crucial issue for TMD because of the possible wide range of deployments. A listing of some of the postulated scenarios shown below is indicative of this potential:

- North East Asia (Korea/Japan)
- South West Asia (Iraq/Saudi Arabia)
- NATO / North Africa
- NATO / CIS

Clearly even these scenarios are hardly exhaustive hence more general methods are required to assure no surprises occur because of a set of missed conditions from a limited set of scenarios that may stress the defense system.

This latter point is another key factor which analysis should establish to reduce the possibility of an "Achille's Heel" by determining what conditions stress the defense system. This ability will provide guidance in selecting the scenarios for the large scale simulations hence create greater confidence that the system is robust to all possible variants of deployment and threats.

This paper will discuss specific examples from TMD to indicate how analysis from multiple perspectives should be used to not only support the three factors but also to gain insights into the system effectiveness.

MONGO

MONGO is a fast running C++ program with a PowerPoint-like graphical analyst interface (GUI) that addresses area specific theater defense rather than scenario-specific theater defense. For example, potential TBM launch points can be specified through the drag-and-drop GUI. Then the analyst specifies impact areas of interest and the fineness of the impact grid points within those areas. In addition the analyst can specify and lay down radars and interceptor launch locations, set fire control and endgame constraints, and run the program to determine the protection from each TBM launch location and protection from all the TBM launch locations. MONGO has the capability to plot contours of 11 parameters, including crossing angle, intercept altitude, time-of-flight, etc., for the first intercept opportunity that meets all constraints across the footprints. The analyst can also click on any point in the footprint to generate a file that documents all the inputs and all the parameters calculated internally as a function of target flight time to determine why the intercept was, or was not, successful.

The analyst can import or generate cruise missile trajectories and MONGO will display where they can be intercepted along their flight paths and where they cannot. The calculation uses Digital Terrain Elevation Data (DTED) to determine intervisibility, and includes clutter and multipath effects. Alternately, the analyst can draw shapes, define fineness of grid points within the shapes, and define target parameters such as altitude, RCS (or cruise missile type), and velocity azimuth. MONGO will then show the analyst where the target is detectable and where it is not within the defined areas.

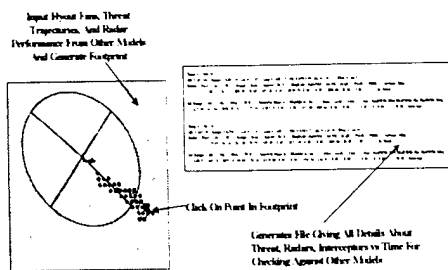


Figure 7 - Model Comparison

MONGO addresses all levels of the analysis objectives mentioned in Figure 2. In the area of Model

Comparison, MONGO has been used to validate calculations made by other models.

As shown in Figure 7, a laydown is set up and a footprint is generated. Then a detailed output file is generated for one point in the footprint. This detailed file is compared to the output from the other program to determine how well the codes match up on radar detection range, interceptor flyout time, intercept altitude, etc. All interceptor flyouts (including shaped) and target trajectories in MONGO are table lookups to eliminate potential differences between codes in trajectory generation methods.

Since MONGO is quick running and has a GUI, it is very easy to make changes to the systems and/or the laydown to observe sensitivities of measures of effectiveness and to set requirements. The following figures give some examples. They are single radar/launcher cases to keep things simple for this paper.

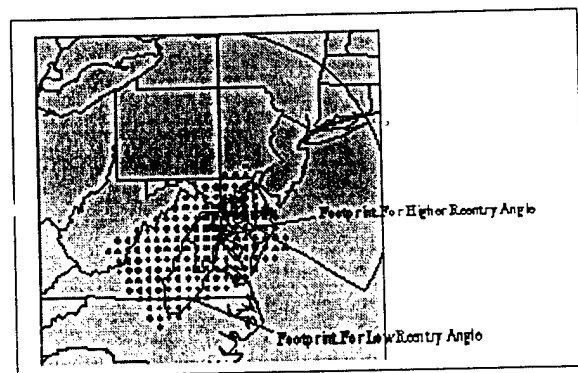


Figure 8 - Sensitivity to Threat Reentry Angle

Figure 8 shows sensitivity of footprint size to threat reentry angle. This example shows clearly how the footprint size decreases drastically as the threat reentry angle is increased.

By selecting objects on the screen and hitting the right mouse button, the analyst gets access to a menu specific to the object type. For example, from the footprint menu, the analyst can determine the area and equivalent radius of the footprint, generate an outline around the footprint for comparison purposes, change the fineness of the grid, etc.

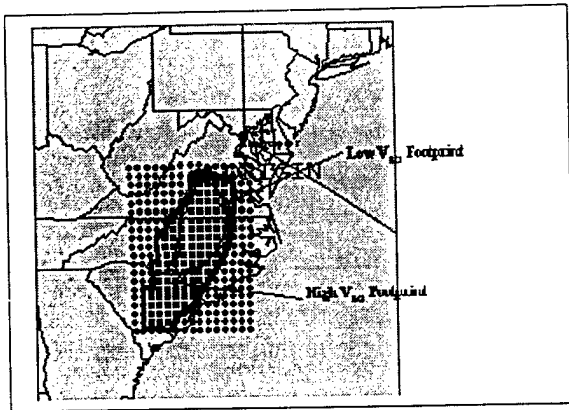


Figure 9 - Burnout Velocity Requirement

Figure 9 shows how MONGO can be used to decide between various burnout velocity requirements. The analyst selects the interceptor type from the menu, reads in a new flyout file for a different booster, and quickly reruns the calculation where all interceptors of that type on the map will now use the new flyout fan. This allows the analyst to quickly determine the performance differences for various booster options in various situations.

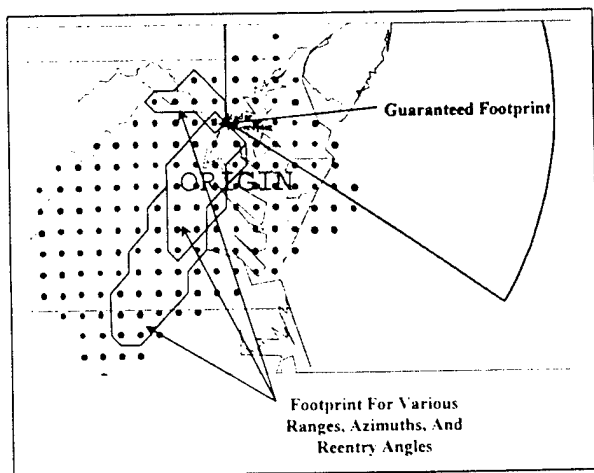


Figure 10 - Guaranteed Footprint

Figure 10 shows how MONGO can be used to determine if a guaranteed defended footprint requirement is met. It is often useful to evaluate performance Vs all possible threats from all possible azimuths and reentry angles, rather than for particular threats from a specific scenario, to determine if the defense is adequate to protect critical assets. MONGO generates footprints for each threat, the composite footprint, and indicates which threat launchers produced leakers. This example shows how the composite

footprint (the intersection of all the individual footprints) can be much smaller than the individual footprints.

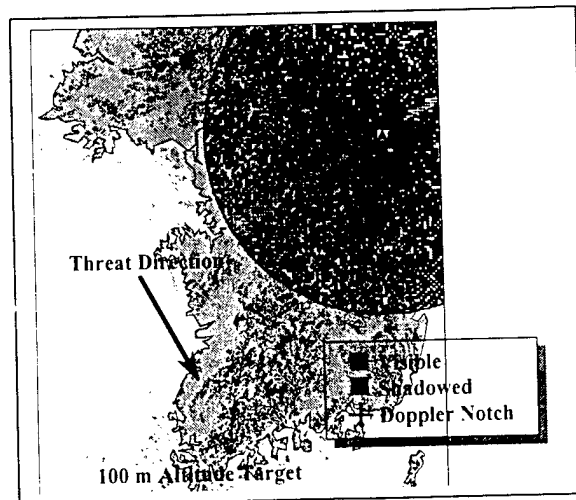


Figure 11 - Airborne Radar Coverage

Finally, MONGO can be used as a preprocessor for many-on-many codes. The analyst can try various laydowns to determine which one best defends critical assets from the most likely threat launch areas. One can also determine where to place radars and their associated search volumes to optimize coverage. Figure 11 shows a case where an airborne radar is attempting to detect targets 100 meters above the terrain in Korea. MONGO indicates areas where the target is detectable, areas where it is not detectable (given desired signal-to-noise ratio), and areas where the target is in the Doppler notch of the radar. This allows the analyst to determine the best placement of the aircraft. It saves a lot of time to perform this intermediate step with MONGO rather than moving directly to placing forces, running the many-on-many codes, and then trying to interpret the results to determine if the laydown is appropriate.

TABS (Technique for Analysis of the Battle Space)

Technique for Analysis of the Battle Space (TABS)³ is a more abstract method that is not scenario specific but provides a rapid means of analyzing systems especially in conceptual development stages.

TABS is structured on the basis of an adjoint method wherein the first step is to use the interceptor and threat trajectories to establish the kinematic battle space on an intercept by intercept altitude basis. This constitutes all of the intercepts that are kinematically accessible by the interceptor. After this is established various system constraints are applied such as the sensor acquisition range, gimbal limits on the interceptor, track time, etc.

which then determines the possible coverage by the defense system.

Once this is determined a large set of engagement parameters is available to provide insights into the variation over the entire possible battle space. A principal outcome of this approach is the ability to determine the range of the various parameters. This provides a completeness check on what the defense system may have to deal with in terms of a nonspecific scenario dependency.

Figure 12 indicates one such example where the end conditions for lethality are shown for three intercept altitudes for an upper tier-like system. In this case the closing velocity and hit-to-kill strike angle variations indicate that the spread is larger at the lower altitudes and narrows as the intercept altitude increases. This also indicates the range that lethality testing and modeling would have to cover to assure completeness in terms of the end conditions.

The ability to look over such a large set of engagements provides the analyst the insights to assure the conditions under which the system is to operate have been identified. This can also be used to determine what part of these conditions the results of the large scale simulations exercise the system.

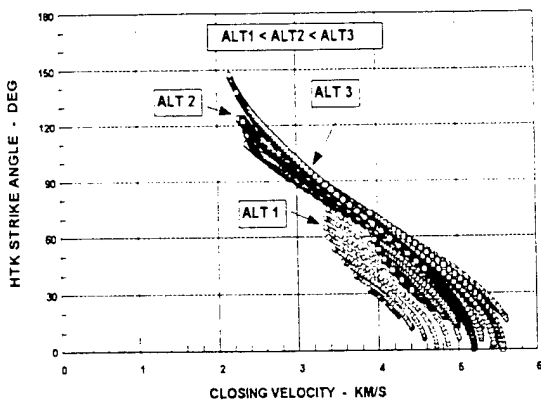


Figure 12 - End Conditions

One of the key features of TABS are the data representations that provide quantitative measures against what appears to be similar to the classic "footprint," i.e., defended area coverage. In Figure 13 this footprint, termed coverage map with TABS, is shown with isocontours of the acquisition range of the ground sensor in this case collocated with the launch site. (Note the ground sensor can be located at any

position with respect to the launch site including elevated positions, e.g. aerostats)

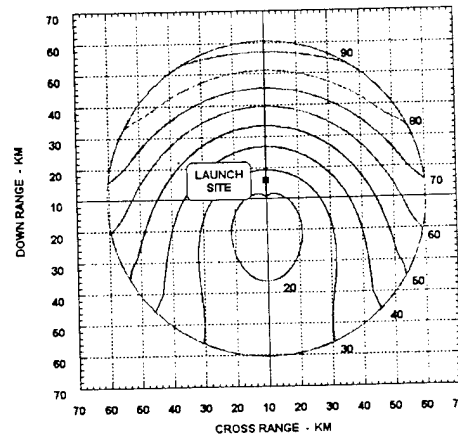


Figure 13 - Coverage Map

For example, a range of 20 km is required to defend the closed area in the middle of the map. In order to defend the launch site an acquisition range of 30 km is required. Some what over 90 km is required to engage targets at the edge of the footprint. Although for this example the defended area is shown as circular, application of various system constraints will change the defended area.

The next figure (Figure 14) shows the integral of these contours as a function of the acquisition range. In this example 90 per cent of the defended area is covered by a sensor range of 86 kilometers whereas the last 10 per cent requires an increase in the acquisition range of 16 kilometers. For the approximately range to the fourth power dependency this nearly doubles the power to cover the last 10 per cent. The cause of this is the slow down of the interceptor as it reaches out hence longer time required and longer acquisition range.

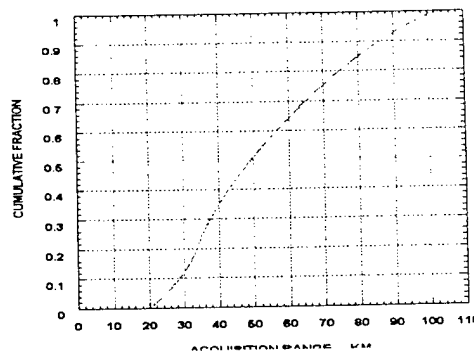


Figure 14 - Integral of Coverage Map

Similar examples of other parameters have shown that such sensitivities provide the "cause and effect" insights at the top level. Analyses such as these allow rapid assessments of the worth of increased performance requirements.

Figure 15 shows another example of TABS in establishing battle space sensitivities. In this case an ascent phase intercept concept was analyzed to determine the area that intercepts could be performed for intercept altitudes from 80 to 200 km.

Clearly only a very small region of possible launch sites can be covered when intercepts at 80 km are attempted. Obviously this is a kinematic limit, i.e., the velocity limit of the interceptor. The area of possible launch sites that can be conducted grows with higher intercept altitude. The outer ring at 200 km is due to allowing a rather low radar acquisition elevation angle that allowed those in that region to just barely exceed the limit. These would likely disappear with a more realistic limit. This particular example provides a case of how certain results can be analyzed with analytical methods.

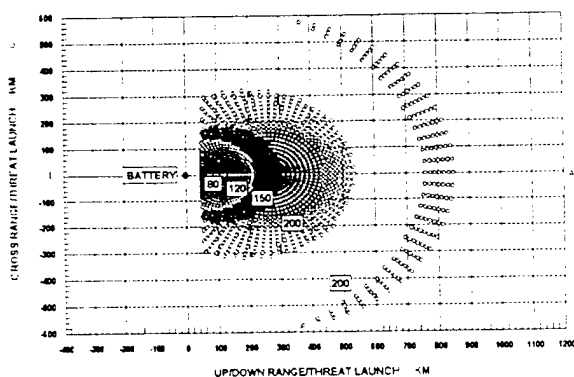


Figure 15 – Ascent Phase Battle Space

The number of dots on these footprints is indicative of the number of engagements that can be analyzed with TABS and in this case numbers in the thousands.

As stated TABS is the most abstract of these methods and because of the simpler methods applied is very rapid in setting up. In one such case an analysis was conducted in a matter of 4 days from the basic description of the problem.

SUMMARY

These examples are only a fraction of the possible analyses that can be conducted with analytical methods.

The utility of these methods they provide a system context for concepts in early development, can establish interactions between system elements, and determine sensitivities of key parameters.

They can support requirements development in determining the range of potential employment conditions and in identifying critical/stress conditions.

Large scale simulation development is supported by comparing subset results for analytical methods against subsets of identical conditions of the large scale simulations. Support for scenario development of the large scale simulations is provided by determining the range of conditions over defended areas and comparing the simulation results against the total span for completeness.

Checks of scenarios can be performed to determine sensitivity of specific/limited conditions in scenario to plausible changes and to identify range of conditions exercised in scenario.

Although somewhat simplified relative to the large scale simulations used for analysis of the complex interactions during a many-on-many battle analytical methods find significant application for TMD. Used in conjunction with large scale simulations they provide an efficient and effective means of unraveling the TMD operational puzzle.

- 1 Davis, P.K., 1995. "Distributed Interactive Simulation in the Evolution of DoD Warfare Modeling and Simulation." *Proceedings of the IEEE, Special Issue on Distributed Interactive Simulation*, Vol. 83, No. 8 (Aug): 1135 - 1155.
- 2 Hillestad, R.J., Bennett, B., & Moore L., "Modeling for Campaign Analysis, Lessons for the Next Generation of Models, Executive Summary", Prepared for the United States Air Force. ISBN: 8330-2438-8, 1996. Although focus in on the campaign level the authors note that their conclusions are generally applicable to all levels of modeling and simulation.
- 3 Sugiuchi, H., Margopoulos, W.B., Baran, M., and Pipes, J., "Technique for Analysis of the Battle Space (TABS)," *Proceedings of the 1996 South Eastern Simulation Conference, SESC'96*, Science Applications International Corporation, Huntsville, AL, October 7 & 8 1996 (U)

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