Sufficiency Analysis in Surface Combatant Force Structure Studies

Michael S. Morris

The Surface Warfare Division of Chief of Naval Operations has conducted a series of major studies to determine the required surface combatant force structure. Interdisciplinary teams drawn from a variety of organizations used several analysis tools to perform the studies. This approach resulted in a blending of diverse analysis tools including wargaming, computer modeling, and simple analytical models. This article focuses on the methodology developed and used in these studies, emphasizing, in particular, the analysis performed by APL in support of this effort. (Keywords: Analysis, Force structure, Methodology, Modeling, Surface combatant.)

INTRODUCTION

The Surface Warfare Division of Chief of Naval Operations (OPNAV N86) has conducted a series of major studies aimed at determining the numbers and types of certain classes of combatants (cruisers, destroyers, and frigates) needed in the 2005 to 2025 timeframe. The studies were conducted in a Joint context; however, force levels of other services, allies, and large U.S. Navy combatants were held constant. Although the focus of this article is on APL's contribution to these efforts, the overall methodology of the studies will be discussed to place the Laboratory's role into perspective. The methodology is believed to be an unusual blend of tools, ranging from war games and computer simulation to simple analytical models.

The first of the Navy studies, the Surface Combatant Force Level Study (SCFLS), was conducted in 1993–1994. The SCFLS addressed the number of surface combatants that would be required to fight a major regional conflict (MRC) set in the year 2005. The types of surface combatants considered included Aegis guided missile cruisers (CG 47 and up), Aegis guided missile destroyers (DDG 51 and up), destroyers of the DD 963 class, and missile frigates of the FFG 7 class.

The major impetus for the SCFLS was the demise of the Soviet Union at the end of the 1980s. The existing analytical basis for surface combatant force structure was the Surface Combatant Force Requirements Study, which used a scenario involving a global, conventional war with the Soviet Union. New analyses of required force levels were therefore needed. The studies also had to be based on DoD-approved scenarios from Defense Planning Guidance. These scenarios postulated the occurrence of two nearly simultaneous MRCs. Several issues were to be addressed. Did the Navy still need the numbers of DDG 51s planned at the time of the study? Were these the right kind of ships for future Desert Storm–like conflicts, and if so, how many of these very capable ships would be needed? Could less capable ships (e.g., FFG 7s and/ or DD 963s) do the job, given a non-Soviet threat? The issue, therefore, was not only how many ships were needed, but also of what mix of ship classes.

The SCFLS concluded that a fraction of the surface combatant force could be versatile but low-capability frigates, and a fraction could be DD 963s, a class highly capable in one or two missions. But overall surface combatant force size could be minimized when a preponderance of the force consisted of Aegis cruisers and destroyers.

Shortly after the SCFLS had concluded, the Navy began a Force Architecture Study. The key assumption for this study was that many DD 963s and FFG 7s would be retired in the 2010–2020 timeframe, and the key issue was to determine the capabilities of any new class or classes of surface combatants that might be introduced in this timeframe. The study needed to account for a number of other changes in conditions such as technological advances in both friendly and adversary systems. Also, starting with the Force Architecture Study, it was recognized that the surface combatant force is constantly engaged in missions around the globe, even in peacetime. This imposes an additional requirement, i.e., the force must be able to perform these peacetime missions efficiently but also be able to transition quickly to wartime missions when needed. The methodology developed in the SCFLS was refined and applied successfully in the Force Architecture Study.

The Surface Combatant 21 (SC 21) Cost and Operational Effectiveness Analysis (COEA) followed hard on the heels of the Force Architecture Study. The COEA continued to examine the problem of the required capabilities of new classes of surface combatants. A primary outcome was the definition of a new class of destroyer, the DD 21.

In the most recent study by the Navy, the surface combatant force structure problem has been revisited to assess the impact of new ship classes and capabilities (DD 21, planned Aegis cruiser/destroyer modernization), new concepts of operation (network-centric warfare), and new and expanded missions (land attack and Theater Ballistic Missile Defense). Once again, the SCFLS methodology has been refined and reused to solve the problem.

EVOLUTION OF THE SCFLS METHODOLOGY

The first phase of the SCFLS actually comprised two parallel efforts, one based on using analytical models and simulations and the other on the use of war games. An analysis team consisting of Navy officers and APL analysts initially sought to update the method used to size forces in the Cold War era. During that period, the methodology had been reduced to counting the major building blocks of naval force structure (CV battle groups, amphibious groups, convoys, etc.) and multiplying by the number of surface combatants needed per building block. With the advantage of decades of analysis, the building blocks had become standardized and the number of surface combatants needed per block was well established for a conventional global war scenario. The perceived needs of the post–Cold War period were to define a new set of building blocks (Joint in nature, i.e., not entirely naval), determine how many such blocks would be required to fight the wars, and determine the number of surface combatants in each block.

The purpose of the war game effort was to gain insight into the manner in which naval forces, and surface combatants in particular, would be employed in future conflicts. The game was played from a Joint perspective, with due regard to the capabilities and limitations of non–surface combatant assets available to the players (senior retired officers from the Air Force, Army, and Navy). A series of games was held, but owing to the cost and time required to play a credible game, it was not feasible to directly compare alternative surface combatant force structures by this means. The games produced detailed records of the missions and movements of surface forces over the campaign. The analysis team studied these data as they became available. Using the methodology of the Cold War era as a model, the team postulated Joint task groups and assessed the ability of these new forms of building blocks to perform the tasks that had been assigned to surface combatants in the war game.

The bottom line of the assessment was that the initial premise was incorrect. The war game effort showed that naval forces could and probably would need to be tailored to assigned tasks. Warfighting entirely in large Cold War–style battle groups would be inefficient because standardized groups generally would have either too little or too much capability.

The problem for the analysis team was therefore reframed. Based on the assumption that naval forces would be tailored to the job required by the Joint force, the problem of determining surface combatant force structure now was seen to have three main parts: (1) determining what tasks needed to be performed, (2) calculating the numbers/mix needed to perform each task, and (3) from the numbers needed for individual tasks, determining the force structure required to achieve all tasks over the course of a two MRC scenario. In the studies following the SCFLS, a fourth component was added to the problem: determining the numbers and types of surface combatants needed to support operations other than warfighting.

Within the overall SCFLS work breakdown, APL was the lead on part 2 above. The process developed and used by Laboratory analysts came to be referred to as "sufficiency analysis."

Early in the SCFLS, using a campaign-level Monte Carlo simulation to determine force structure requirements was considered. In principle, the most direct and convincing means to determine such requirements would be to vary the numbers of surface combatants and observe the impacts on the land-battle outcome. However, to perform this task, the model had to be both very broad in scope and capable of high fidelity. APL made a substantial effort to modify an existing Army model called TACWAR. On the basis of the modifications, land-battle outcomes appeared to adequately reflect the contributions of surface combatants in land-attack missions, where they performed functions similar to those for which the model had been designed. However, even with the modifications, the land-campaign outcomes seemed incorrect with respect to surface combatants assigned to protection tasks. Lacking a better model, the campaign model approach was dropped for the SCFLS.

DETERMINING THE TASKS

Since a war game of the type played in the first SCFLS was costly and time-consuming, the later Navy studies used a different approach to defining sets of tasks for surface combatants. The problem of determining a set of tasks to be performed was solved by means of an open campaign seminar conducted in the APL Warfare Analysis Laboratory (WAL). The seminar developed a comprehensive list of tasks (now called missions) that could be performed by surface combatants over the course of a scenario, and then sorted the missions by their criticality to the success of the Joint force.

A task is a set of targets to be attacked or a set of assets to be defended. For example, surface combatant tasks/missions will certainly include the protection of naval forces (e.g., carriers), the defense of ports, and strikes against fixed strategic targets. In the early days of a campaign, another likely task will be to support ground forces with gunfire and land-attack missiles against advancing hostile troops. Over the next few weeks, force protection tasks may increase owing to an influx of carriers and amphibious ships. Still later, as Army ballistic missile defenses flow into the theater, some of the port protection tasks/missions will be given to the Army. But the number of ships carrying military equipment into the theater will have increased, so some surface combatants will be reassigned to convoy protection. Relatively late in the campaign, as the number of convoys to be escorted decreases (owing to attrition of the submarine threat by anti-submarine warfare [ASW] forces), surface combatants will once again be reassigned, this time to support an amphibious assault.

Two key aspects of task identification are (1) the determination of the location of the task, that is, the location of the asset being defended or the target to be attacked, and (2) the reach of the weapon available to the surface combatant. These factors establish the operating area of any surface combatant assigned to the task. Large operating areas may enable a single surface combatant to contribute to multiple tasks, which tends to reduce the numbers of ships needed to perform the whole set of tasks. For example, strategic land-attack missions could be performed with Tomahawk missiles from almost any ship in the theater, but for all other tasks the assigned ships would have to be near the asset being defended or attacked.

The existing analytical basis for surface combatant force structure . . . used a scenario involving a global, conventional war with the Soviet Union. . . .Could less capable ships . . . do the job, given a non-Soviet threat? The problem . . . was not only how many ships were needed, but also of what mix of ship classes.

SUFFICIENCY ANALYSIS

As noted earlier, APL developed a methodology known as sufficiency analysis in support of the Navy studies that was used to determine the numbers and types of surface combatants needed to perform a task. The process decomposes a complex multiwarfare area problem into a set of simpler single warfare area problems, solves the simpler problems, and then integrates the results to obtain the desired multiwarfare solution. The sufficiency analysis of every task follows the same pattern:

- Threat assessment
- Determination of success criteria
- Single warfare area calculations of force mixes that would satisfy the success criteria
- Integration of the single warfare area results

Threat Assessment

Given a task, analysts assessed the threats faced by the surface combatant assigned to it. The assessment considered enemy orders of battle, expected capabilities, and concepts of operation. The output of the assessment was estimates of the relative likelihood of attack by various types of threats, with respect to both the surface combatants and any assets they were assigned to protect.

Even if the assignment were to attack the enemy, surface combatants would face various types of threats since the operating area for attack would be within the reach of the enemy. In nearly all cases, the threat assessment showed that the task would be a multiwarfare problem, i.e., a potential existed for attacks by a number of different kinds of threat, either on the surface combatants or the asset they were to protect. Usually, however, one threat dominated. For example, in the case of a convoy protection task, the dominant threat generally would be a submarine, but the possibility of air attacks would also have to be considered. For port protection, the primary threat to the port itself was usually a theater ballistic missile, but mines (laid by many different types of platforms) could also pose a significant problem.

Success Criteria

Success criteria provide the basis for determining whether a given set of surface combatants assigned to a task will be able to perform that task at an acceptable level of risk. The criteria must be quantifiable measures of effectiveness (MOEs), together with threshold values for each MOE. In general, for any task there must be a MOE as well as a threshold for every significant threat indicated by the threat assessment. For most tasks, multiple threats, and therefore multiple success criteria, existed. The MOEs selected as success criteria were tactical in nature, quantifiable by well-known operational analysis techniques and tools. Risk was deemed acceptable if and only if all MOEs exceeded the thresholds.

For example, given the task of protecting a convoy facing submarine and air attacks, success for a convoy escort is that no ship in the convoy is lost to either threat. There must be criteria for success against both the submarine and the air threat in this example. With respect to the former, detecting a submarine in time for the convoy to avoid it could be viewed as a success. Alternatively, putting a weapon on the submarine before the submarine fires at the convoy would be considered a success, assuming that a submarine would break contact if it came under attack by the escort. An appropriate MOE, therefore, is the probability of detecting the threat in time for either event to occur. A typical threshold used in the SCFLS was a probability of 0.9. With respect to the air threat, success would be achieved if either the launch platform is killed or the weapon it fires is defeated. An appropriate MOE is the likelihood of either event occurring. Again, the threshold frequently set for this MOE was 0.9.

One way to set a threshold is to look for a point of diminishing return, i.e., find a "knee" on the curve of effectiveness versus number of ships dedicated to the task. This technique can be carried out by analysts and requires little judgment. However, setting thresholds by this means alone was not entirely satisfactory during the SCFLS. It ignored the fact that the consequences (in terms of the outcomes of the war) of failure in performing a task can vary. Furthermore, the likelihoods of attack by various threats are different. Consequently, the Navy officers assigned to the analysis team also used professional judgment to determine the amount of risk considered acceptable.

Single Warfare Area Analysis

The analysis team included experts in a variety of warfare areas, and each one selected tools and techniques for evaluating the MOEs in his or her warfare area. To enable the integration of the single warfare area analyses, this approach had to be parametric in nature, that is, MOEs were calculated for a range of force sizes/compositions/ship positions. It would not have been sufficient for the warfare area experts to simply find a solution to their particular problem alone.

The amount of work that the parametric approach demanded was minimized in the SCFLS by frequent communication among the team members. Each analyst was aware of how a change in force composition/positioning of ships would impact the other warfare areas. This information enabled participants to intelligently search for solutions that might be reasonable compromises among conflicting demands. For example, high-fidelity Monte Carlo simulations were run for combinations of ship sonars, threat submarines, and acoustic environments. The runs served to characterize each combination in terms of a sweep width. Given sweep widths, simple analytical models could be applied to determine the ASW MOEs for many combinations of numbers and types of surface combatants. Among these combinations were some that would be optimal for ASW alone and some that tended to accommodate the other warfare areas.

Integration of Single Warfare Area Results

The process of integrating different warfare areas varies in the details but follows a similar pattern for all tasks. The MOE thresholds for all warfare areas must be satisfied simultaneously, that is, by a single force laydown/disposition. In general, many possible laydowns can satisfy all the success criteria for a given task. Applying three rules eliminates all but one of the solutions. The rules, in order of priority, are as follows:

1. The ships used must be able to defend themselves.
2. The number of ships used must be minimized.
3. The capability of the ships used must be minimized.

In the convoy example, if ASW were the only problem, FFGs would not be allowed by rule 1, since they may not be able to adequately defend themselves against the submarine threat in poor sonar environments. However, the anti-submarine MOE threshold can be exceeded with any combination of three (or more) DD 963/DDG/CGs in an outer screen (say, roughly, 15 mni from convoy center). Rule 2 would eliminate all of the solutions of more than three. Now rule 3 would say that the answer is three DD 963s since the DD 963 is less capable than the DDG or CG.

But there is an air threat too, and the DD 963 cannot defend the convoy against such threats. The analysis of the air defense part of the convoy protection task shows that the air defense criterion is satisfied by one (or more) FFG/DDG/CG near the center of the convoy. The number of ships needed increases as the ships are moved away from center. An anti-air warfare (AAW)–only solution is a single FFG, based on the three rules.

To solve both the ASW and AAW problems, one possible answer is four ships: an ASW screen of three DDs plus one FFG inside the screen for air defense. Another possible solution is to replace the DD with a DDG in the ASW screen. If the air defense criteria can be satisfied with no more than three DDG 51s in the ASW screen, then the DD + FFG combination can be eliminated by rule 2, and the SCFLS answer will be that three ships are needed for the task (if they are DDGs).

FORCE CALCULUS

The sufficiency analysis described here yields the numbers of various classes of surface combatants that must be performing individual tasks on station. The problem remaining is to determine the force structure needed to perform all of the assigned tasks over the entire campaign. The procedures used to do so in the SCFLS were called the "force calculus," which is intended to account for a number of factors and is only briefly described here.

The calculus first considers the fact that more capable ships usually can be substituted for less capable ships, but not vice versa. That is, a cruiser can be used where a destroyer would be adequate, but a destroyer cannot be substituted for a cruiser. Second, the calculus accounts for the fact that, at any given time in the campaign, a certain percentage of the ships in a theater will need refueling or replenishment. Also, at any given time, some ships will be in overhaul or undergoing repairs, thereby preventing their use in either of the two MRCs. These factors increase the number of ships needed in the force structure by about 15%. Allied navies are expected to play a role in future MRCs. Consequently, the number of U.S. Navy ships can be reduced by assuming that some Allied combatants will be in theater.

COMMENTS

The methodology developed in the SCFLS and refined in later studies takes a very complex problem and breaks it into digestible pieces. The process is highly transparent, that is, it is easily understood and open to inspection. The force structure implications of adding or subtracting either tasks or surface combatant capabilities can be examined easily. These features lend credibility to analysis conclusions, which is vital in any discussion concerning the nation's expenditure on very expensive ships.

A disadvantage of the methodology is that one cannot determine the consequences of performing or not performing a task in terms of campaign-level MOEs, e.g., ground lost/gained, Red and Blue force losses, duration of the conflict. To make this determination, one must either resort to war games or a large Monte Carlo simulation. However, as noted earlier, these alternatives have their own problems. In the case of Monte Carlo simulations, model fidelity is likely to be an issue, since fidelity, size, and lack of transparency tend to be correlated. Consequently, the SCFLS methodology may be a viable option in surface combatant force structure studies for the foreseeable future.

THE AUTHOR

MICHAEL S. MORRIS received a B.A. in physics with honors from the University of Virginia in 1960 and an M.S. in physics from Yale University in 1962. He joined APL in 1967 and is presently a physicist on the Principal Professional Staff in the Joint Warfare Analysis Department. In his 33 years at the Laboratory, he has participated in numerous studies for the Navy involving operations analysis and weapon system modeling. Mr. Morris is a member of Phi Beta Kappa. His e-mail address is michael.morris@jhuapl.edu.