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A SAMPLE MEASURE OF EFFECTIVENESS FOR AN ANV IN BARRIER OPERATIONS

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SCIENCE APPLICATIONS, INC.
1651 Old Meadow Road, McLean, Virginia 22101
(703)790-5900

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This paper calculates one potential measure of effectiveness for an ANV in maintaining an ASW Barrier and demonstrates the feasibility of calculating such measures.

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Section 1

INTRODUCTION

In considering a measure of military worth suitable for conducting an assessment of military worth of candidate advanced Navy vehicle concepts two schemes are prevalent. One scheme requires a weighted sum of individual operation (or task) measures of effectiveness. The other relies on task-by-task comparisons of individual operation measures. Whether or not it proves feasible to find an acceptable set of task weights, it is hoped that additional insight into the problems of conducting a military worth assessment might be gained by a typical attempt at developing an individual measure of effectiveness for one of these tasks with a postulated vehicle.

This paper calculates one potential measure of effectiveness for an advanced Navy vehicle (ANV) in maintaining an ASW barrier and demonstrates the feasibility of calculating such measures. This paper is meant to be representative of the type of thought processes used in the calculation of a measure of effectiveness of a particular ANV. It is not a sample of a general methodology that encompasses all conceivable tasks and vehicles or a final analysis prior to point design selection.

The need for subcalculations or model runs, where pointed out, may provide some indication of the additional manpower and computational resources required to provide a more refined and flexible assessment incorporating many tasks and alternate vehicle point designs. This simple analysis makes assumptions and approximations in order to accomplish the analysis. The results, then, can be no more accurate than these assumptions. It can, however, be a departure point for both refining the point design selection and the analyses that are the essential inputs to an assessment of military worth.

A

Section 2

A SAMPLE APPROACH TO DEVELOPMENT OF A MEASURE OF EFFECTIVENESS IN BARRIER OPERATIONS

For a sample development of a measure of effectiveness, an ASW barrier in the GIUK Gap is selected. The rough sizing estimates of the 8K SES are chosen and the measure, "Total Soviet Submarine Patrol Days Eliminated", is investigated[1].

In developing a calculational procedure for this measure, the analyst would typically go through the following steps, bearing in mind that what is wanted is a technique for comparison of various ANVs in the ASW barrier operation:

First, the operation (task) is broken into more readily analyzable parts. For an ASW barrier, this would include:

- Transit to the barrier and operations prior to achieving a steady state of barrier patrol;
- Detection of transitors;
- Localization of transitors;
- Transitor kill;

~~1/~~ The 8K SES was chosen to provide numbers for the calculations. The methodology is useful in understanding any vehicle that performs the task using the range of tactics considered.

- ANV replenishment operations;
- Self defense.

Next, particular aspects that appear to be vehicle-dependent are identified:

- Transit Portion of Operations:

  Here, the effective speed of the vehicle to get on station, together with its after-transit endurance, appears important in distinguishing vehicle capabilities. It is noted that if resupply is already available in the barrier, the latter aspect may not have a strong influence on the overall measure of effectiveness.

- Detection/Classification

  While the capability to devote payload capacity to detection or classification sensors may effect the outcome of an effective barrier in the case of some vehicles, typically the choice of vehicles will moderate the range of sensor possibilities through limitations imposed by vehicle profile capabilities; in addition, effective sweep rate is likely to be a driving parameter in the detection of transitors.

- Localization of Transitors

  Again, localization sensor payload may impact the vehicles' capability in this subtask. Probably more relevant, however, will be time late to the detected datum since the area of uncertainty in the absence of additional information grows rapidly.

- Kill

  The available vehicle profiles or the payload capacity may effect the size and type of weapons that are utilized in the kill phase. This, in turn, may drive the overall performance effectiveness of a vehicle. In addition, after localization, factors effecting the timeliness of weapon delivery could severely increase requirements on the localization capability of the weapon system.

- Replenishment

  In modeling this effect into an ANV barrier capabilities measure, the main impact will be a cost one. That is, how much does it cost to keep x-vehicles operating in the barrier. For the constant cost approach that we would like to take here, this is transformed into how many are operating in the barrier if we buy y-ANVs?

- Defense

  Expected attrition is the main concern in self-defense. To a large extent, this will be handled in the vulnerability analysis. Again, can the defense suite be handled within the payload constraints? What is the probability of hit, given defense failure (e.g., perhaps the vehicle cannot be hit due to ANV profile, signature or avoidance capability)? Given a hit, what is the vehicle's vulnerability?

Section 3

THE SCENARIO BACKGROUND

Here, we are interested in an ASW barrier 2,300 nm from an availalbe U.S. port for the vehicle. The barrier is about 700 nm in length, and the estimated attempted transits from day 1 through day 90 are:

Day 1 - Day 2	**10 subs/day**
Day 3 - Day 10	**6 subs/day**
Day 11 - Day 50	**2 subs/day**
Day 51 - Day 90	**1 sub/day**

Figure 1 shows the war-patrol days crossing the barrier as a function of time. It is noted that a premium is placed upon early arrival at the barrier to the extent that neither near-term nor long-term effectiveness in the barrier is effected.

The numbers shown, therefore, represent a situation in which no prior deployment through the barrier has been achieved. However, a number of enemy submarines have already started for, and in fact, some begin to enter the barrier at the very start of the barrier operation. Such a situation might arise, for example, if this unusual level of transitors were sufficient for the U.S. to take action even, if only to detect and pass off to a platform that would trail the transitor.

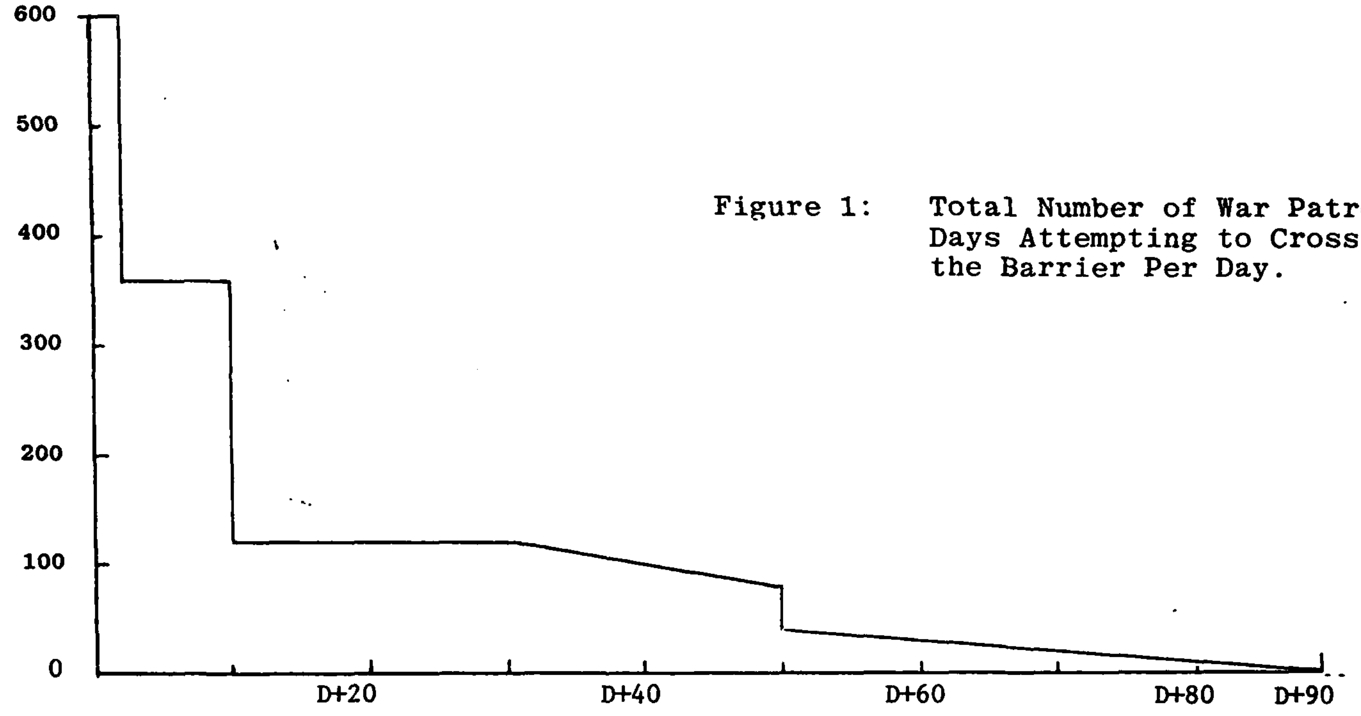

Figure 1: Total Number of War Patrol Days Attempting to Cross the Barrier Per Day.

(NOTE: For 60 Day Patrols, the Total War-Patrol Days Attempting to Cross the Barrier is: 9,280.)

The operational concepts to be considered are examined by the appropriate subtask area:

TRANSIT PHASE -

- On Day 1, sprint at 50 knots to the barrier; utilize one of the detection/prosecution options below until replenishment ship arrives.
- On Day 1, sprint at 70 knots to the barrier; utilize one of the detection/prosecution options below until replenisment ship arrives.

END TRANSIT PHASE -

- Replenishment ship arrives 105 hours from the start of hostilities. ANV goes into steady state operations.

STEADY STATE OPERATIONS -

- Detection:
    - Transitor detection is accomplished by utilizing the sprint-drift tactic with a sprint speed of:
        - 50 knots, or
        - 70 knots.
    - Transitor detection is accomplished from a station-keeping mode.

- Localization:
  - (For the sprint-drift tactic) localization is accomplished utilizing a sprint to datum tactic* at:
    - 50 knots, or
    - 70 knots.
  - (For the station-keeping ANV) localization is accomplished by helicopters stationed on the ANV.
  - Localization is accomplished if the localizer to transitor range is within 10 nm.
- Kill:
  - When localization is accomplished, kill is assured.
- Replenishment: (Steady State)
  - Replenishment requirements are provided by the replenishment vehicle which is appropriately replaced as needed (it is not considered in this analysis any further, though a more detailed analysis should). The required replenishment interval and duration are vehicle-dependent.

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* See Appendix D to Working Papers, "PURSUIT", Sante Fe Corporation, dated 27 April 1976.

Section 4

VEHICLE CHARACTERISTICS

The various operational concept profiles will be considered for an ANV with the following characteristics:

ENDURANCE (Hours)	SPEED (Knots)
125	0
100	50
53.6	70

SENSOR RANGE: 75 nm

TIME to deploy, look, and recover sensor: 1 hour.

REPLENISHMENT TIME: 12 hours.

(Note: Some other replenishment times, not presented here, have also been examined. The turn-around time does not appear to strongly drive the choice of profile although overall effectivenes is enhanced by a lower replenishment time.)

Section 5

ANALYTIC RESULTS

The Appendices describe a technique for determining the expected kill of enemy submarines by the barrier. Utilizing this technique, the following "War Patrol" days eliminated may be calculated for the rate of barrier crossings shown in Figure 1 and the vehicle parameters of Section 4.

From Table 1, it is seen that despite the added advantage of arriving at the barrier in time to destroy a large fraction of the high transitor rate during the first two days of conflict, this advantage is diminished when one considers the longer term effect of persistence on station for the scenario examined. It is worth pointing out, however, that an ability to refuel in the barrier upon arrival (a situation not unreasonable for the GIUK Gap with Allied bases readily available) would alter the outcome.

An additional interesting point is that the fixed sensor with helicopter prosecutors is within 12% of the best of the cases examined. The success of this profile, however, should be moderated by the cost and additional requirements imposed by the helicopter. For the scenario examined, it is further noted that the station keeping profile, in the transit phase, might prove slightly better than shown if a modest reduction in fuel consumption (over that presented) were obtained in the station keeping mode.

Table 1

Transit Phase: Patrol Days Eliminated by 2 Barrier ANVs

Transit Profile	First 2 Days	Next 8 Days	Transit Phase Total
Sprint @ 70 knots to barrier; Prosecute and search* @ 70 knots.	218.6	53.5	271.7
Sprint @ 70 knots to barrier; Prosecute and search @ 50 knots.	143.2	163.4	306.6
Sprint @ 50 knots to barrier; Prosecute and search @ 70 knots.	28.8	256.9	285.7
Sprint @ 50 knots to barrier; Prosecute and search @ 50 knots.	18.9	361.4	380.3
Sprint @ 70 knots to barrier; Helicopter prosecution and fixed sensor search.	148.5	193.6	342.1

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* For simplicity, in the transit phase, Search and Prosecution are only considered at the same speed. No adjustment has been made for the added endurance due to drift cycles. The speed in the search mode refers to the Sprint portion of the search.

The steady state phase of the barrier operations is presented in Table 2 with a number of profiles examined. Whereas in the transit phase, there appears to be a slight advantage to slower transit and search operations, due to the grave impact of endurance until the steady state conduct of the barrier, the higher sweep rates and shorter prosecutions times obtained by the higher speed profile more than compensate for the reduced endurance of the craft at high speed (N.B. Station-keeping profile).

Table 2

Steady State Phase: Patrol Days Eliminated by 2 Barrier ANVs

Profile	Patrol Days Eliminated
Search* @ 50 knots; Prosecute @ 50 knots.	3,999
Search @ 50 knots; Prosecute @ 70 knots.	4,441
Search @ 70 knots; Prosecute @ 50 knots.	4,457
Search @ 70 knots; Prosecute @ 70 knots.	5,009
Search from station-keeping platform; Prosecute by helicopter	2,828

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* The speed of the search refers to the sprint portion of the Sprint/Drift cycle. The added endurance from the drift cycle has been accounted for.

Section 6

CONCLUSION

Since the estimates of vehicle parametrics are probably not firm at this point, the choice of profile that is apparent from this simple analysis (i.e., that profile yielding the highest total number of war patrol days eliminated:

Transit at 50 knots;
Search, until tanker arrives, at 50 knots;
Then, search and prosecute at 70 knots,
Yielding 5,390 patrol days eliminated)

should bear this point in mind. With the exception of the station-keeping profile for the steady state operations, there is only about a 20% variance in the outcome for the profiles examined.

As more accurate estimates of vehicle parametrics and more sophisticated models are developed, a more definitive stand may be taken on both the choice of vehicle profiles and the selection of point designs.

Appendix A

SPRINT/DRIFT IN A BARRIER[*]

A vehicle is assumed to be in a sprint-drift mode operating in a barrier. (In the sprint-drift mode, a vehicle at some time, t_o begins a drift cycle, during which it deploys a sensor with a cookie cutter circular range, R, turns on the sensor, effective momentarily, and recovers the sensor. It then, starting at time $t_o + T_L$, sprints a distance Δx at speed V_B, thereupon resuming the drift cycle, etc.).

There are some number of vehicles in the barrier characterized by the constant equal separation between vehicles, S , and barrier length, L.

Given that a transit is attempted, this Appendix shows a technique for calculating the probability of detecting the transitor. Specifically, the probability of detection is written as:

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[*] This is a revision of the probability of detection presented in Reference 1, Appendix C. It incorporates the later developments in the analysis of this tactic presented in Appendix A of Reference 1.

$P_D = P_{D/E}P_E$ * where

$P_{D/E}$ is the probability of a detection, given an encounter. An encounter is defined as a situation in which the transitor has an effective closest point of approach with the detector range of the sensor. This is effectively calculated in Appendix A of Reference 1. And, P_E is the probability of an encounter. Appendix B of Reference 1 calculates the latter quantity.

Considering, once again, perpendicular crossings of the barrier,

$$P_D = \min \left\{ \frac{R}{S} \sqrt{1 + K^2},\ \tfrac{1}{2} \right\} \cdot \alpha$$

$$\text{where } K = \left(\frac{\Delta x}{V_B T_L + \Delta x} \right) \frac{V_B}{V_t} \quad \text{and}$$

$$\alpha = \begin{cases} \sqrt{1 - \lambda^2} + \dfrac{\sin \lambda}{\lambda} & \text{for } \lambda \leq 1 \\ \pi/2\,\lambda & \text{for } \lambda \geq 1 \end{cases}$$

$$\lambda = \frac{V_t}{2R} \sqrt{1 + K^2} \left(T_L + \frac{\Delta x}{V_B} \right) .$$

The operator, of course, once again may choose Δx so as to maximize the overall P_D .

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* The actual probability, in the case where multiple encounters are possible would involve a calculation of the probabilities of multiple encounters and detection by one or more of the vehicles in the multiple encounter situation. As long as the single encounter P_E is strictly less than 1, however, multiple encounters cannot occur for the geometry considered. Thus, caution should be exercised in applying these equations to close spacings between ANVs.

APPENDIX B

CONSIDERATION OF BARRIER PROFILES

Using the technique of Appendix A, it is possible for a fixed number of vehicles in the barrier, utilizing the sprint-drift technique, to determine the probability of detecting a transitor. Unfortunately, a particular ANV, in the applications to be considered, will not spend all of its time in a search mode. Some time will be spent in replenishment and some time may be devoted to investigating and prosecuting contacts of search operations.

Another aspect of a potential profile that applies to the variety of tasks to be performed is that they may occur at speeds other (and hopefully better for that subtask) than the sprint speed used for barrier patrol. In fact, a question that has not been addressed is the endurance of the vehicle in the sprint-drift patrol (i.e., the drift cycle may consume fuel more slowly than the sprint cycle).

While an integral approach, that appropriately adjusts the weight in consideration of already spent fuel may be the most elegant (and accurate) approach. The current status of vehicle designs neither warrant nor lend themselves to such an approach. Rather, a simple characterization of the submarine at a specific speed will be considered sufficient for this level of analysis.

Thus:

Letting the subscript D refer to the drift cycle, S refer to the sprint cycle and, P refer to the prosecution phase, the following relations can be obtained:

Fraction of time drifting

$$f_D = \left(\frac{T_L}{T_L + \frac{\Delta x}{V_B}} \right) \left(1 - f_P \right)$$

Fraction of time prosecuting

$$f_P = \frac{C_P R}{1 + C_P R}$$

where C_P is the time spent prosecuting each contact; R is the rate at which an individual barrier ship (in the search mode) generates contacts for prosecution, and T_L, Δx, and V_B are the time in the drift cycle, the sprint distance and sprint speed, respectively.

The endurance for this profile, therefore, is:

$$E = \left[f_D/E(V_D) + (1-f_D-f_P)/E(V_S) + f_P/E(V_P) \right]^{-1}$$

$E(V_i)$ is the endurance of the vehicle at a constant speed, V_i. The base loss factor for the vehicles in the search mode in the barrier (i.e., the number of vehicles in replenishment, prosecution and search required to maintain one vehicle in search) is, therefore, for a replenishment time, TA,

$$BLF = \frac{E + TA}{(1-f_P)\,E}$$

$$= 1 + C_P R + TA \left\{ \frac{f_D}{(1-f_P)E(V_D)} + \frac{1-f_D-f_P}{(1-f_P)E(V_S)} + \frac{C_P R}{E(V_P)} \right\} .$$

The value of R may be calculated from Appendix A. C_P can be calculated from either an engagement model or, as was done in this paper, by an assumed prosecution technique*.

Thus, in order to determine the effectiveness of a given total number of vehicles in the barrier, an interative process is utilized in which a number of vehicles in the search mode is assumed and the total barrier requirements are calculated utilizing the technique in this Appendix. Δx is adjusted to give the greatest probability of detection by the barrier forces. The assumed number in the search mode is again adjusted until the desired total number is achieved.

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* The technique used here is described in a preliminary working paper, "PURSUIT", by Sante Fe Corporation provided under work sponsored by OP-96V.

REFERENCE

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"(DRAFT)" Working Paper on Measures of Effectiveness for Naval Vehicles (U)", SAI/McLean, April 1976.