CURRENT DEPLOYMENT ADVISORS AND POTENTIAL FUTURE DEVELOPMENTS

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1 INTRODUCTION

New more capable sonar designs such as the Swedish Visby Sonar ASW/MCM Suite with hull mounted, variable depth and ROV sonars, or the UK RN's new Sonar 2087[1] for ASW and Sonar 2193 for MCM, provide a larger suite of configuration and deployment options. The deployment considerations include physical elements (depths, tracks), processing elements (active/passive, pulse types, processing methods), environmental aspects (minimising the energy in the water to reduce impact) and the target's characteristics (stealthier, more aware). This increasing capability and complexity leads an exponentially greater difficulty of choosing the correct deployment option in any given situation.

With the current emphasis on minimising environmental impact, a trial and error approach is no longer acceptable and prior modelling to advise the most likely optimum configuration is essential. Starting with the correct configuration at the widest track spacing that configuration provides for the level of coverage required will minimise any potential impact whilst providing the best detection probabilities.

This paper will review current operational deployment advisors and look at the aspects of the decision that they can currently model, for example, the Visby MCM Advisors and the Sonar 2087 Environmental Prediction System. It will also consider how future systems can cater for the compromise between maximising detection whilst managing environmental impact, particularly in peace-time operations.

2 SONAR DESIGN ADVANCES

With the change of focus in naval strategy from blue water to littoral environments and quiet, smaller, submarine targets and more stealthy mine designs, there is again a greater focus on active sonar design and optimisation. The design and operational aim is always to maintain a tactical advantage over the threat by detecting them at longer ranges than the threat can effectively launch a weapon (be that a submarine launched torpedo or a capable mine). Hence designs strive to gain longer range detections, with the best localisation capability, in a wide range of oceanographic environments which are less well known and less well surveyed than the historically significant regions.

New sonars being designed and deployed generally employ a range of possible techniques to optimise their performance including:

- Lower frequencies to reduce propagation losses and potentially reduce the effectiveness of any stealth coatings.
- Wide frequency bandwidths to gain more signal to noise ratio.

- More exotic signal forms to maximise signal detection against reverberation or to be less exploitable by the target.
- Variable depth operations – such as towed VDS sonars and ROVs.
- Bi-static operations which separate the transmitter and receiver arrays, either due to size/deployment considerations or to gain the benefits that separation can provide to surveillance modes, such as in the UK RN's Sonar 2087.
- Multiple sonar operations where several of the same sonar or several different sonars are deployed in the same region. Examples may include the combination of frigate ASW and helicopter dipping sonars, or multiple active sonobuoy patterns, or combinations of hull-mounted MCM and ROV sonars.

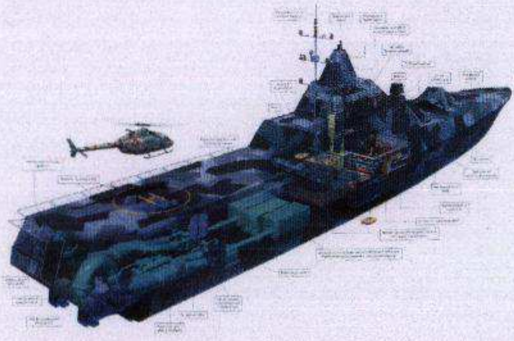


Figure 1: The Swedish Visby Corvette can be deployed with complex sonar suite including hull mounted sonars, VDS sonar, and ROV sonars.

3 DEPLOYMENT CHALLENGES

For the operators of such modern complex sonar suites and in joint operations, new challenges exist in optimising the deployment.

- Active, Passive or Both – which mode of operation will be best in the current environmental conditions and against the current perceived threat? If focussing on either active or passive then the deployment can be optimised more easily. If wishing to gain good performance on both active and passive then which should be optimised first – setting the receive array to the correct depth for passive operations then checking the active performance, or setting the best active deployment and checking the resulting passive performance?
- Deployment Combinations – for a bi-static active sonar the combination of possible deployments comprise – transmitter depth, receiver depth, pulse power, pulse length, pulse type, and pulse combination. The possible envelope of operation may have hundreds of possible combinations, leading to large numbers of modelling runs to model a 3D environment to provide predictions of performance. This modelling should also be affected by the changes in the deployment as the depth of arrays is varied (e.g. the towed array will be further from interference by the ownship the deeper it is deployed) (see Figure 2).

- For complex pulse types and combinations of pulses, what features of the environmental or tactical situation drive the optimum selection? The detection thresholds against noise and reverberation are well published for standard CW and FM signals but less clear for complex signal types as the results are likely to depend on the coherence of the other noise in the environment. Noise and reverberation models used in operational situations do not normally provide this level of information to help differentiate between different complex types.

- With combinations of hull mounted and ROV sonars in MCM scenarios, what are the optimum tracks to follow to ensure a region is suitably cleansed? How can the effects of the seabed, particularly its shape, be considered and the operator shown the effects of the ROV depth on its ability to gain full coverage?

- The increase in environmental awareness has also introduced limitations on what might be achievable in peacetime operations. It is no longer acceptable to use trial and error in choosing the best active pulse types as the amount of sound energy emitted should be minimised, also the source levels should be minimised wherever possible[2].

- Although the consideration of the environmental impact has arisen from the new lower frequency active sonars it is not just the low frequency sonars that must be considered in this respect. Published papers show that use of very high frequency sonars in coastal situation could inhibit certain breeds of fish from passing through the region[3].

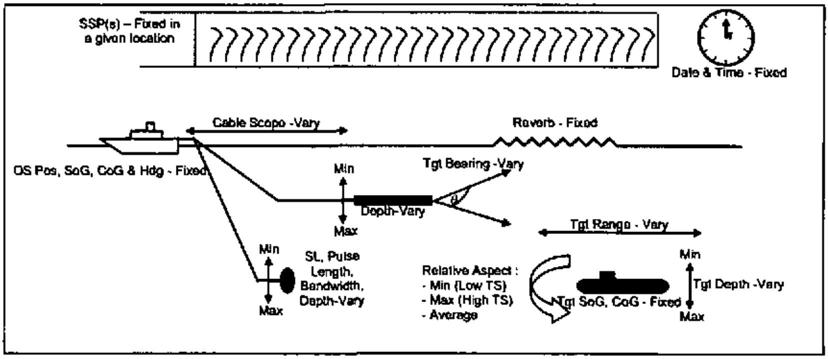


Figure 2: A typical set of considerations in optimising an active sonar deployment situation leads to hundreds of possible combinations that may need to be assessed.

4 POSSIBLE SOLUTIONS

In our private venture and contracted development work the following solutions have been considered, refined and implemented within operationally deployed systems to counter this increasing complexity, whilst keeping the systems practical for use by the ship's command and sonar operators.

4.1 Detection Thresholds and Modelling

The basic concepts are utilised in modelling system that cover a wide range of sonars:

- A consistent modelling approach across the whole frequency band such that certain sonar modes are not favoured just because the data or models change. Typical examples are where at low frequencies there is a preference to switch to PE derivative models, however at the switch over point there is highly likely to be a step change in the results being obtained. Hence it is highly desirable to utilise the same model when comparing passive and active sonars, otherwise one will be unnecessarily favoured over the other.

- A suite of Detection Threshold equations is required to cover all modes of operations of sonars. These must be consistently defined.

- Supplementary additional constraints to differentiate between sonar modes that effectively generate the same detection thresholds. Typical examples of this are considerations of the basic geometries of the time the target will be within the beam versus the integration periods utilised.

4.2 Constraint Modelling

When considering large problem solution envelopes one may consider:

- Brute force algorithms that try all possible combinations. The obvious disadvantage being the run times involved in running hundreds of model scenarios.

- Analytical solutions that recommend a solution from previous data. These provide a fast solution but there will always some uncertainty over the applicability to the current environment and scenario, hence there always has to be a check run of the modelling to verify that the analytic result is reasonable in the locality.

4.3 Interference Models

With multiple sonars in an environment there are several important impacts that can be modelled to varying levels of complexity. Anecdotal evidence suggests that three or more similar sonars in shallow water regions is highly detrimental to the detection performance of each sonar.

- The most obvious is the ping sequence and distance between sonars. In such cases it is likely that the sonar hydrophone pre-amplifiers are overloaded by the direct signals received from other nearby sonars; leading to blind rings in range.

- The general increase in the reverberation background level due to the additional energy in the water.

- The increases Sound Exposure Levels to which the local animal population may be subjected.

4.4 Training Simulations

Whilst operational systems have always tried to model the predicted performance of the sonar to the best ability, conversely training systems have often made very simple performance approximations in both the environment and the detection abilities of the sonars in the training scenario. Improving these simulations can lead to more realistic training scenarios.

5 DEPLOYED SYSTEM EXAMPLES

5.1 Underwater Environmental Modelling System (UwEM)

UwEM provides the sonar modelling capability for the Royal Swedish Navies Visby Corvette sonar suite and covers sonars from low frequency passive to ROV MCM sonars (i.e. typically 25Hz to 250kHz). To cover these sonars, a range of Detection Threshold equations linked to a range of Probability of Detection (PoD) formulae such that the best model is used for each type of sonar (broadband, narrowband, active CW, active FM, intercept and MCM bottom detection). An example of these is the MCM bottom detection algorithm which combines both target reflection detection as well as shadow detection.

In this case the signal excess (SE) can be thought of as either the maximum of the signal-to-reverb (for echo detection) or reverb-to-noise (for shadow detection). Combining these detection methods leads to an equation representing the total signal to noise as follows:

$$SE = MAX\,(SL + TS - 2.PL - (RL \,\&\, NL) - DT,\quad (RL \,\&\, NL) - NL - DT)$$

or

$$SE = ((SL + TS - 2.PL) \,\&\, RL \,\&\, NL) - NL - DT$$

Where SL = Source Level, TS = Target Strength, PL = Propagation Loss,
RL = Reverberation Level, NL = Noise Level and DT = Detection Threshold.
The symbol '&' is used to represent a power sum (i.e. $10 * \log(10^{(x/10)} + 10^{(y/10)})$)

Similarly, in the shallow water of the Baltic, several Visby vessels may be searching in the same locality. Hence an interference model is included to allow them to collaborate on the ping cycle, frequencies and bandwidths to minimise interference levels (**Figure 3**).

Figure 3: Example of reduced detection due to interference from other local sonars. The potential detection has several missing rings and patterns due to the other sonars.

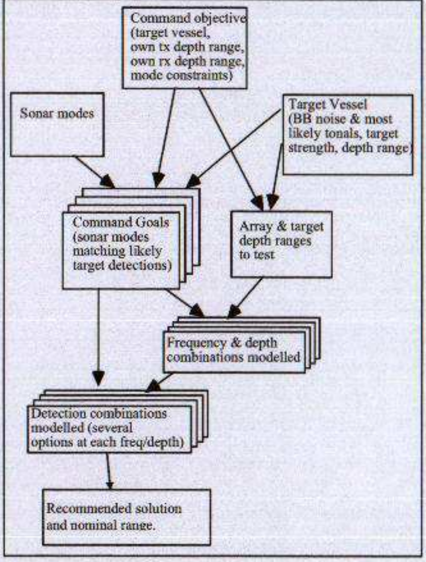
- *OS – Ownship*
- *S1, S2, S3, S4 – are other sonars operating in the region.*
- *Red areas are regions of good detection from ownship's sonar.*
- *Grey areas are regions of possible detection from ownship's sonar.*
- *Blue is the chart background (no detection)*

5.2 Sonar 2087 Environmental Prediction System (EPS) - Constraint Modelling

The Environmental Prediction System (EPS) is provided as the embedded performance prediction tool within Sonar 2087. This tool acts as a third-party software component within the Thales architecture and, based upon the command constraints entered, provides an undirected search process for recommending the best deployment options. A six stage modelling process is implemented as shown in Figure 4.

Figure 4: The constraint modelling within EPS uses a filtered search technique to model all likely combinations.

1. Based on the command constraints supplied, build up a list of all applicable combinations of depths, array positions and sonar modes of operation.
2. Filter the list to reject those combinations which do not satisfy additional geometric considerations or where no target data are known.
3. Sort the list to the optimum order to minimise the processing time used in the modelling stage.
4. Run an underwater propagation model for each unique combination of frequency and depth.
5. Run a suite of Probability of Detection algorithms for all possible combinations.
6. Chose the 'best' results from the possible combinations.



With each scenario providing a full Nx2D modelling solution and many combinations to compare, the method of rating the 'best' solution from such a large quantity of data required a cost function to be defined. After testing a number of options, this was resolved by determining the 'detection volume' and resolving this back to an 'effective range' value for each mode of operation. The cost function algorithm is based on the PoD values, pD(r,z), weighted by the range using the following:

Detection Volume, V_D is a measure of the total volume of water in which a target can be detected, based on the Probability of Detection at each range and depth, $p_D(r,z)$ (from 0 to maximum range and 0 to maximum depth).

$$V_D = \iint p_D(r,z).2\pi r.dr.dz$$

To this EPS applies a further weighting based on the probability of the target, $p_T(z)$, being between depths Z_{Tmin} & Z_{Tmax}.

$$V_{DT} = \iint p_T(z).p_D(r,z).2\pi r.dr.dz$$

where $\int_{ZT\min}^{ZT\max} p_T(z).dz = 1$ (box function)

and $p_T(z) = 0$ at all other depths.

Finally, EPS reconverts to an Effective Range (R_e).

$$R_e = \sqrt{(V_{DT} / (\pi.(Z_{T\max} - Z_{T\min})))}$$

The best combination is therefore taken as being the mode with the largest effective range.

Though this method ensures that all possible combinations have been modelled, the disadvantage is the length of time that can be taken to perform all the modelling runs for the combinations considered. This is mitigated by providing two level of modelling fidelity using comparable range-independent and range-dependent models. Using a fast range-independent model can provide a quick-look analysis to quick check of the current situation. Using a slower range-dependent solution can be run prior to deployment or even during the deployment process, which itself takes a significant amount of time.

5.3 Environmental Risk Management Capability (Sonar) - Batch Processing using GAMs

The Environmental Risk Management Capability (Sonar) has been developed to support UK RN sonar operations around the world by modelling the potential risk of sonar operations to marine mammals and recreational divers[4]. Essentially, ERMC(S) computes Sound Exposure Levels received in water due to the use of one or more sonars over an extended scenario.

The problem here is essentially similar to that of EPS; the system can predict the risk due to a specific scenario, but if that solution is considered unacceptable, how does the operator know what best to change about the scenario to achieve an operationally and environmentally acceptable solution? Again very long run times may ensue.

To resolve the problem with long run times for large combinations of sonar modes and locations, the development of the ERMC(S) plans to use a parametric solution[3]. During the development phase, thousands of scenarios will be run with varying operational parameters and environmental characteristics and the distributions of the resulting Sound Exposure Levels received by the simulated animals will be recorded. Variants of Generalized Additive Models (GAMs)[5] will be fitted to the data, permitting flexible spline-based models that have few a priori restrictions on the functional form. These models provide multi-dimensional best-fit solution surfaces for risk with respect to operational parameters, given in a single equation. This equation then forms a predictive model into which the combination of operational parameters can be entered. The calculation of risk can then be made using simple linear algebra, ensuring a quick analysis of the reduction in risk produced by each permutation of parameters. Further, because of the mathematical tractability of the spline basis of the GAMs used, searches of the surface for optima are amenable to rapid analysis.

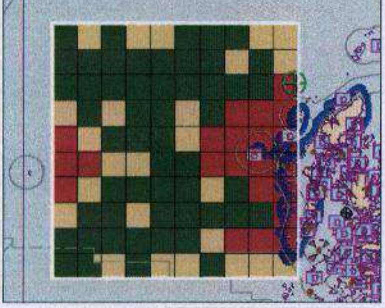


Figure 5: The GAMs utilised in ERMC(S) should be able to indicate the best regions in which to operate the specified scenario. In the diagram, colour is used to represent the best location for the sonar deployment. The green, yellow and red colours represent an arbitrary scale of goodness rather than a specific rule.

5.4 Maritime Training Simulations

As providers of the Royal Navies new Maritime Training suites, we are including the same operational modelling capabilities into the simulation environment that are included in the operational systems. As provider of both sets of functionality, it is now easier to provide the real operational modelling than try to provide a simpler simulation. Open software interfaces allow exchange of data between these system more readily and more cost-effectively than writing a separate simulation model.

6 FUTURE DEVELOPMENT

The next logical development in the process for sonar system operational modelling is the combination of the sonar performance and impact assessment into a single optimisation. At present the two optimisations are considered separately:

What sonar deployment gives me the best operational performance?

What sonar deployment gives me a sustainable environmental solution?

These will almost inevitably give different results as the optimisation will tend to pull in opposite directions. Working on a combined optimisation is an operationally relevant run-time with intelligible and explanatory results is perhaps the next step. The work on GAMs may help to promote a realistic solution to this problem.

7 REFERENCES

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