ANNEX A. TO PROPAGATION STUDIES FROM THE USERS POINT OF VIEW.
DETECTION THRESHOLDS

1. INTRODUCTION

1.1 Figure 1 illustrates in diagrammatic form the components of a sonar system that lie between the hydrophone array and the decision "target present" or "target absent". These components consist of:

1.1.1 A Receiver
This is designed to process the signal appearing across its input terminal A-B in the most advantageous manner.

1.1.2 A Visual or Aural Display
Displays of present and past signals backgrounds.

1.1.3 A Human Observer
The observer, based on the display, makes the required decision.

2. DEFINITION

2.1 Detection threshold is defined as the minimum signal-to-noise ratio consistent with a 50% probability of detection and a specified probability of false alarms (eg: 0/01%). For broadband sonars, assuming a square law detector and non-fluctuating mean noise power (Gaussian in nature), it can be shown that:

$DT = 5\log d - 5\log BT + |5\log T/t| + p$ (all logs to base 10) where

d = Detection index for a 50% probability of false alarms of 0.01%
T = Integration time
t = Signal duration
p = Processing losses due to non-ideal electronics etc.
B = Receiver Bandwidth

Now if we assume $t \geq T$ then:

$DT = 5\log d - 5\log BT + p$

2.2 For Gaussian noise and probability of false alarm of 0.01% and when the product of the pre-detection filter bandwidth and the post detection integration time is large, d = 16, and this expression becomes for broadband signals:

$DT = 6 - 5\log dBT + 4$ (assuming p = 4 dB) $= 10 - 5\log BT$

Note that the foregoing implies an ideal integrator and refers to actual integration time - not to the number of integrations performed by digital electronics multiplied by the update rate.

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Note also that fluctuations in mean noise power in a beam and the details of processing used to establish a threshold detection level in each beam are but two contributing factors towards the Operational Degradation Factor used in the sonar equations. If the analysis bandwidth (B) is less than 1 Hz, the S/N ratio normally improves over a given frequency interval due to the presence of narrowband signal components. This can improve DT by a factor of -10log(1/B) (because background noise is quoted at spectrum level in the sonar equation). Hence for the large bandwidth-time products and narrowband signals:

$$\begin{aligned} DT &= 10 - 5\log BT - 10\log(1/B) \\ &= 10 - 5\log BT - 5\log(1/B)^2 \\ &= 10 - 5\log(BT/B^2) \\ &= 10 - 5\log(T/B)\ \text{dB} \end{aligned}$$

If digital techniques are used:

$$DT = 5\log d - 10\log(1/B) + p - 5\log n$$

where n+ the number of integrations (The "integration factor") and each of these integrations involves independent time samples. n x update rate must be $\geq$ 1/Bandwidth, for the time samples to be independent.

2.3 Some signal processing equipments allow an overlap in the time samples used for integration purposes. These samples are therefore no longer independent and the 1.5 dB improvement per doubling of integration factor inherent in the term 5 log n will not be achieved. Too much overlapping of time samples also results in a "smearing" of the display.

2.4 If in addition a history display provides visual integration, a further improvement of nearly 5logn dB may be achieved, where N is the number of lines displayed. Research has shown that the visual integration gain versus number of lines displayed is included at Figure 2. The following formula can therefore be applied for initial detection on a VDU:

$$DT = 5\log d + p - 10\log(1/B) - 5\log n - VIG$$

where VIG = Visual integration gain obtained from the graph.

2.5 Visual integration is usually more efficient using a paper recorder, and in cases where a paper recorder lofargram is used for initial detection, up to 30 minutes of history may contribute towards this process. In practice d turns out to be a function of the number of integrations (See Table 1).

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When variations in d are taken into account in this manner the appropriate value of p to use is +4 dB (i.a.w. SPWG Pub 4 Vol 1).

TABLE 1 - DETECTION INDEX FOR BANDWIDTH-TIME PRODUCTS

BT	d	$5 \log_{10} d$
1	42.7	8.2
2	30.2	7.4
4	24.0	6.9
8	19.5	6.5
16	17.8	6.3
32	17.0	6.2
64	16.2	6.1
128	15.1	6.0

2.6 For an active sonar using a square law detector assuming a large bandwidth - time product (50% probability of detection and a 0.01% probability of false alarm):

DT - 5logd - 5log(t/B) dB

where t = Pulselength and B = Pre-detection bandwidth

The value of d used depends on the processing employed and whether the sonar is noise or reverberation limited.

Automation of Underwater Acoustic Prediction

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The prediction of the acoustic propagation through the ocean has been used to help in the understand the underwater environment and predict the performance and effectiveness of sonar systems. In the past, the means of running the models has been manually intensive and the outputs of the models have not been easily visualised. However computer hardware and software systems are now available to allow this process to be automated. HAIS (the Hydroacoustic Information System) is one of the most recent examples of this type of system using advanced workstation hardware, WIMP interface, relational database data storage and full graphical data output. This paper discusses the requirements of such a system and shows how they may be satisfied.

The History

The prediction of the acoustic propagation through the ocean has been used to help the understanding of the underwater environment and predict the performance and effectiveness of sonar systems. Several propagation loss models have been developed and discussed at length in IOA proceedings etc. These are usually split into two camps, the ray tracing approach for deep-water/high frequencies and the wave equation approach for shallow water/low frequencies. Models in both these camps can also be segmented as to whether they allow range dependence of the environment.

The Problem

Ultimately, all the models are limited by the knowledge of the environmental data entered to run the model. The environmental data for a range dependent model can become cumbersome and take a significant amount of the analysts time to compile. The data required usually includes:

a) Water depth variation with range.

b) Sound speed variation with both depth and range (often calculated from the salinity and temperature variation of the water).

c) Sediment depth, type and characteristics.

d) Source depth and frequency.

e) Attenuation data and surface loss and bottom loss data.

This data is used to model the behaviour of sound in the water including the effects of reflection, refraction, scattering and absorption. The output of the models is some form of propagation loss curve or data; either as a function of range, or as function of range and depth.

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The propagation loss (PL) data may be processed further using the Sonar Equation to predict the performance of a sonar system. The medium used to perform this analysis is usually the Figure of Merit (FOM) of the sonar, which allows the Probability of Detection (P(D)) to be determined. The FOM is either a nominally fixed value for given system, or it may be calculated on-the-run from the basic sonar configuration and specification.

P(D) = 50% equates to a Signal Excess (SE) of 0dB

where, for an Active Sonar:

SE = FOM - 2.PL
FOM = SL + TS - [(NL - DI) or RL] - DT

or, for a Passive Sonar:

SE = FOM - PL
FOM = SL - (NL - DI) - DT

(SL = source level of radiated noise, TS = target strength of reflecting object, NL = noise level to which the receiver is subjected, DI = directivity index of the receiver, and DT = detection threshold of the receiver including the benefits of the signal processing method)

In practice, the means of supplying the data to all the different models and methods of displaying the results are all different. The are also few automated systems capable of taking the PL results and predicting PoD.

The Requirement

In creating a user-friendly system for operational use, the drudgery of running various models and analysing the results must be removed. This involves satisfying a number of basic requirements:

a) Provision of a database of environmental data for the area of the oceans concerned.

b) A capability to handle both historic modal data and surveyed measurements of particular parameters.

c) Provision of a chart like presentation ('tactical picture') of the area.

d) Provision of a means to select and view the environmental data easily.

e) Automated data compilation for the range dependent propagation loss models.

f) 'Black-box' implementation of the the PL models (whichever are thought to be most suitable for the particular purpose) such that the interface to the model is transparent to the user.

g) Automated storage of the model results.

h) Provision of a means to view the outputs of the models - displays of the ray paths, eigenrays between two specified points, or propagation loss incurred.

i) Provision of a database of platform and sonar specifications to allow the FOM to be derived automatically.

j) Automated conversion from PL to P(D) based on either single values of FOM or sonar specifications.

k) Capability to simulate both active and passive sonar systems.

l) Capability to connect to measurement probes for trials or operational use (XBT - expendable bathythermograph, CTD - conductivity, temperature, depth probes, etc).

m) Capability to display and interpret satellite images.

The Solution

Such a system has been developed by SEMA Scientific (under sub-contract to Dowty-Sema) for the Swedish Defence Materiels Administration. The system was developed for the shallow water Baltic Sea environment where changes in salinity levels and temperature levels have a significant effect on the sound speed in the water column. The system has, however, since been modified to work equally well in deep water; making it effectively independent of the operational area.

The system is called HAIS (the Hydroacoustic Information System).

HAIS is the result of 10 man-years of structured software development and Ada language code running on the DEC VAXstation family of desk-top and mini-computer workstations. The user interface and displays use WIMP technology (windows, icons, mouse and pull-down menus) to make the system simple to learn, fast to use and create high quality colour or 'grey-scale' output. A video copier may be attached to obtain hardcopies of almost equal quality.

The functionality provided by HAIS satisfies, or has the capability to satisfy, all the requirements of an automated acoustic prediction system, including:

a) Storage of environmental and tactical data in a relational database:
   - gridded water/sediment depths (1.5 million points),
   - gridded climatological salinity & temperature profiles (~5000),
   - gridded noise parameters (wind, ice cover etc),
   - tabular PL and P(D) data (attenuation, losses, scattering etc),
   - survey data entry (salinity, temperature, sound speed, noise levels and water depths).

b) 1D, 2D and 3D displays of the environmental data.

c) User input and data displays overlaid on a chart of the area concerned; chart able to be viewed at various zoom levels.

d) Automated data extraction for displays based on user entered chart locations.

e) Automated data extraction for the PL models based on user entered chart locations.

f) Black box models - currently:
   - Ada Ray Trace model for ray tracing, eigenrays and PL data,
   - Fortran Wave Equation model (IFD) for PL data,
   - Fortran Salinity and Temperature profile forecast model (MERMAID - under licence from ARE, Portland).

g) Automated storage of the model results into the relational database for future use.

h) Automatic generation of graphical displays of the ray paths, eigenrays between two specified points, or propagation loss incurred (in cross-section or plan views).

i) Provision of a database of platform and sonar specifications to allow the FOM to be derived automatically.

j) Automatic conversion from PL to P(D) based on either single values of FOM or the platform and sonar specifications (in cross-section or plan views).

k) P(D) calculated for active FM and CW sonars, passive narrowband and broadband sonars, and in either towed array, variable depth or hull mounted formats.

l) Capability to connect to measurement probes for trials or operational use (XBT - expendable bathythermograph, CTD - conductivity, temperature, depth probes, etc).

m) Capability to display and interpret satellite images.

This package allows the detection performance of sonar systems to be analysed in a quick and easily visualisable method with the minimum of user intervention. Some examples of the types of displays available are shown in figures 1 to 5, covering water depth in plan and 3D, ray tracing, and probability of detection in cross-section and plan.

Such a system has uses in research, as a naval tactical aid or as a trials/exercise analysis and evaluation system.

The Future

The future of systems like HAIS is governed by the developments in three fields:

a) Improved hardware - increasing the speed of model run times, allowing improved visualisation of the results and user-friendly interfaces to the system.

b) Standardisation of models and faster models (such as INSIGHT as discussed earlier in the programme).

c) Increased integration into systems allowing direct environmental data input.

Summary

To summarise, the need for automated systems to hold the underwater environmental data, run acoustic propagation loss models and provide comprehensive display facilities of the environment, the PL and the P(D) has been demonstrated. The requirements for such a system have been stated. One advanced solution to the problem has been given; namely HAIS, and finally, the future of these types has been suggested.

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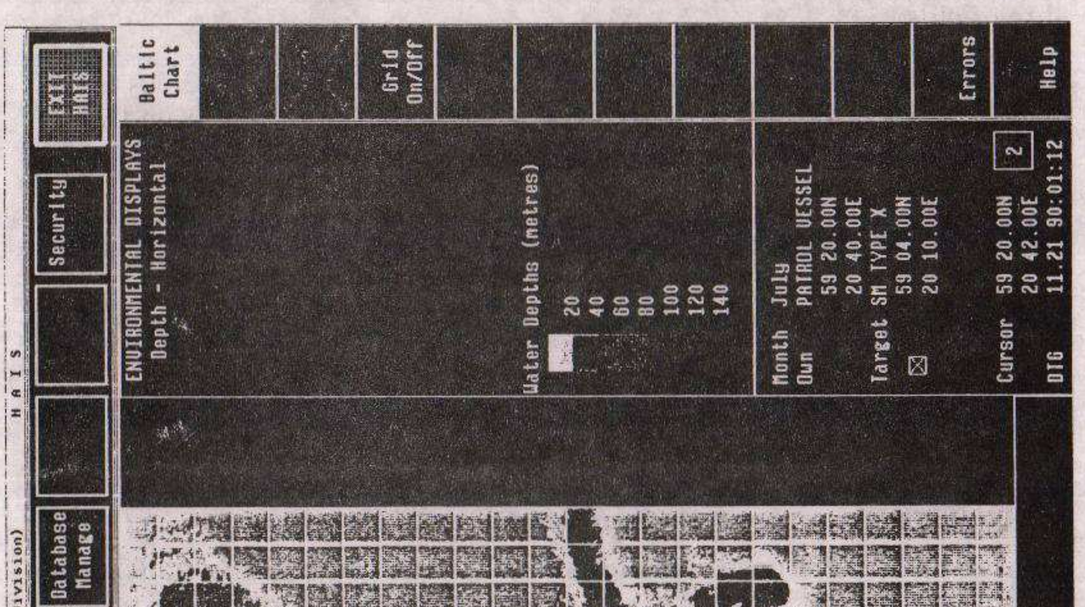
Figure 1: HAIS - Chart of Baltic Water Depths



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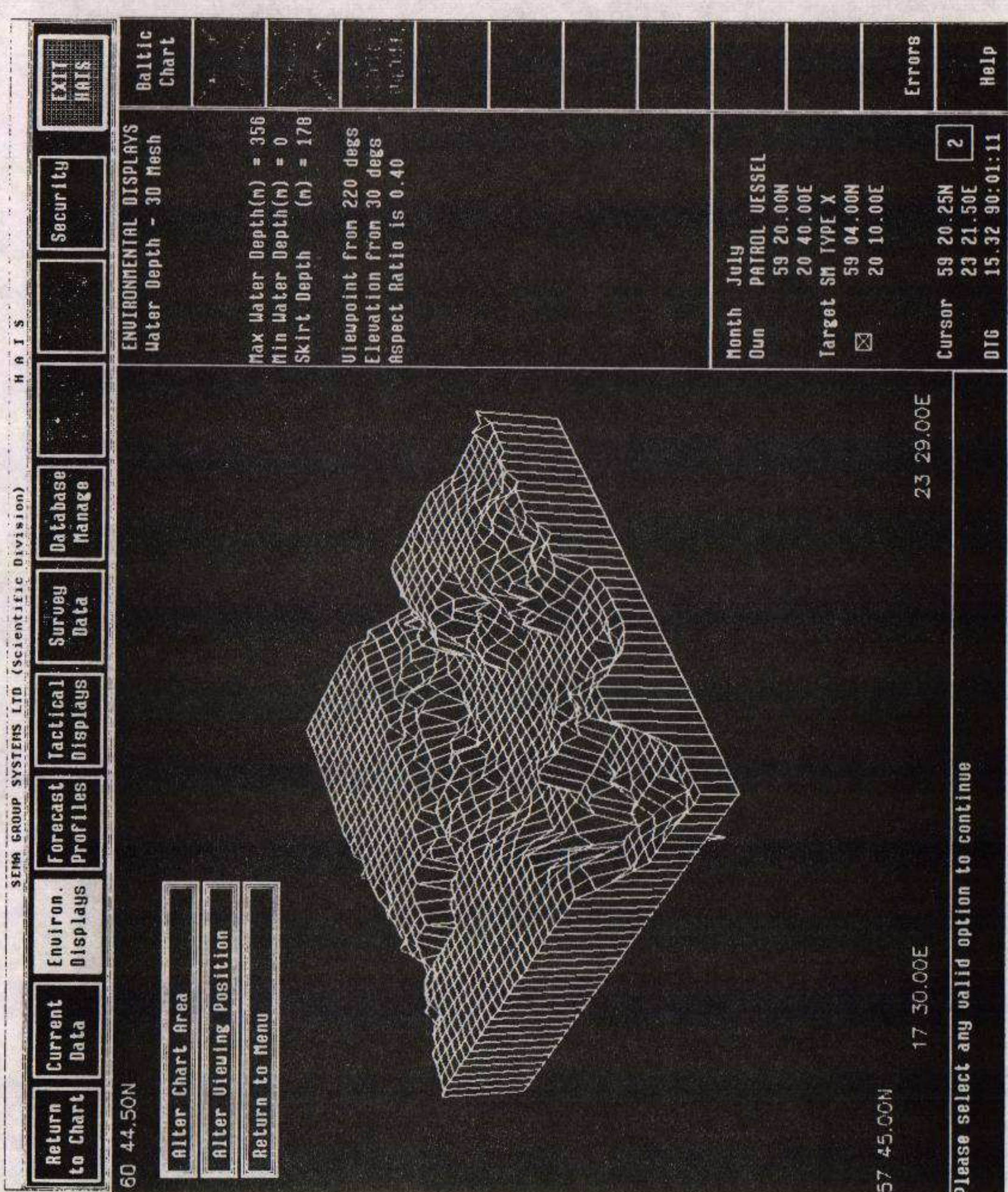
<u>Figure 2:</u> HAIS - 3-D view of Water Depth off Stockholm



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<u>Figure 3:</u> HAIS - Typical Display of Ray Paths

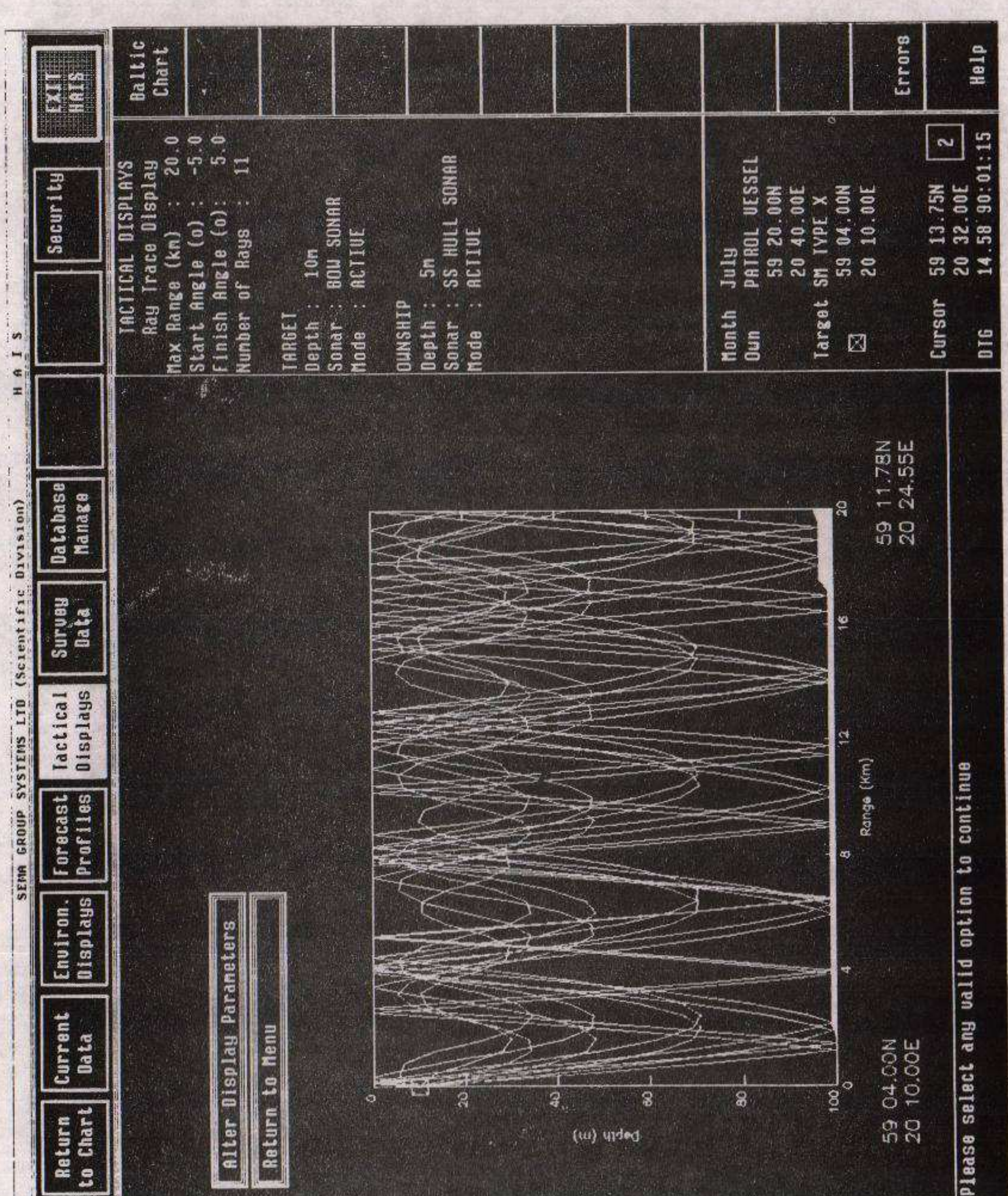

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Figure 4: HAIS - Typical Probability of Detection Display (Plan View)

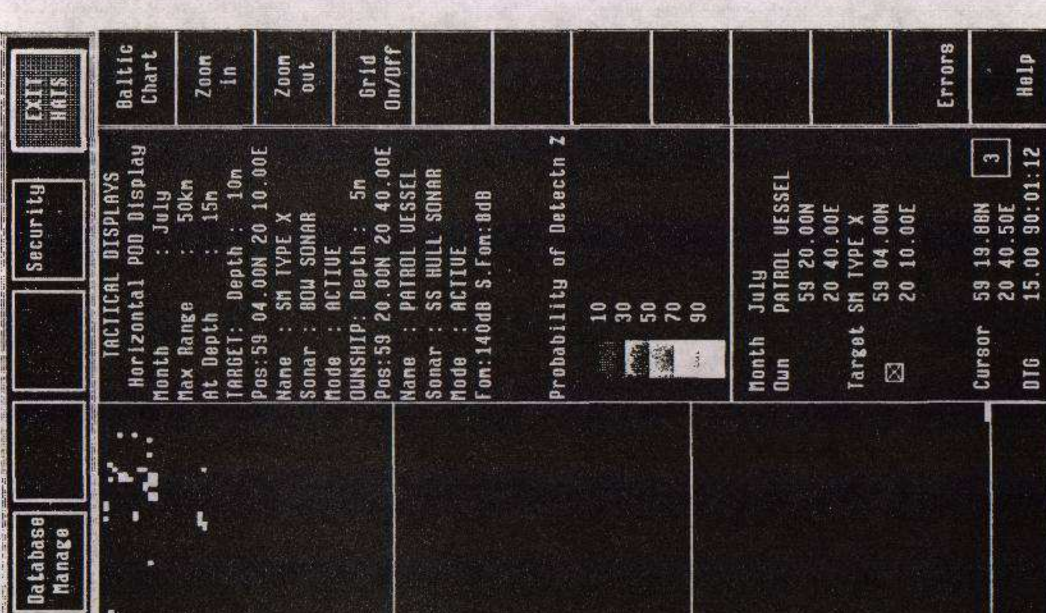

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Figure 5: HAIS - Typical Probability of Detection Display (X-section)