# Operational Experiences for Maritime Homeland Security Operations

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***Abstract* - As global communities learn to operate within a world of tensions, there is an increased need to redefine security measures and develop more advanced methods of defense. Increasing measures are being taken to ensure underwater soft targets are controlled and secure to eliminate limitless destruction. Terrorist organizations now have the ability to develop, procure and deploy mines and/or underwater, improvised explosive devices. Technology such as unmanned underwater systems, situational awareness and sensor fusion software, and diver-held search systems are enabling change detection operations and diver detection; while ship hull inspection systems have been operationally demonstrated to mitigate against attacks on soft targets.**

## I. INTRODUCTION

In 2003, Coalition Forces embarked on an ambitious program to open the Iraqi Port of Umm Qsar for humanitarian aid shipments. Based upon the difficult Coalition Clearance Diving lessons learned, a beta version of the Common Operator Interface Navy – EOD (COIN) was delivered to US Navy Fleet operators in 2004. It was utilized during numerous operations and exercises over the next four years. The COIN engine, SeeTrack Military, is the de facto standard smart software that delivers tactical situational awareness to international navies for unmanned systems and operators by providing a worldview of the battlespace. In its history, COIN has achieved a successful Full-Fleet Certification after 2008 Exercise Rim of the Pacific. Involving the Royal Netherlands Navy, Royal Australian Navy, Royal Navy, U.S. Navy and Canadian Clearance Diving Task Group, this exercise successfully executed surveys and Rapid Environmental Assessment (REA) for very shallow water mine clearance, in support of forcible entry and humanitarian amphibious operations in the Hawaiian Operations Area. The four year development period exploited numerous international, coalition, humanitarian and civilian scientific and municipal authority operational opportunities to solicit operator feedback directly to the developer and program manager.

Figure 1: Examples of Soft Targets

Using some of the software tools that are operated in the COIN program (**Figure 2**) and building upon it with additional tools such as change detection, maritime security situational awareness can be provided. Change detection (**Figure 3**) is used to take historic surveys that may have been performed by different sensors and compare this with newly gathered survey data. Sonar performance prediction together with feature-based navigation processing is used to enable rapid and accurate reporting of results of maritime incidents.

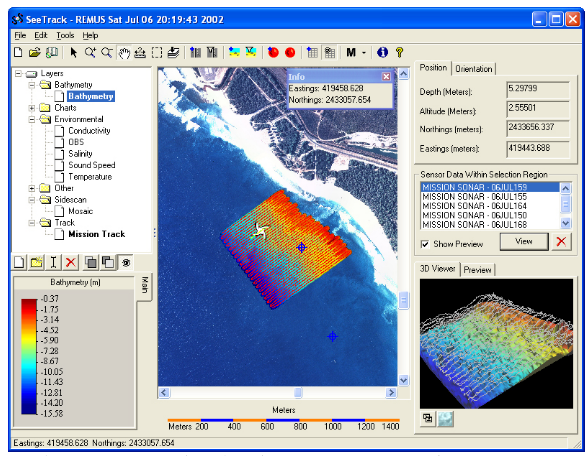


Figure 2: COIN Situational Awareness Screen from RIMPAC

This paper will present the cutting-edge systems and software that combine to present a single, relevant picture of the world, which allows for agile and rapid response for homeland security operators (first responders). Examples of information gathered from operations will be presented.

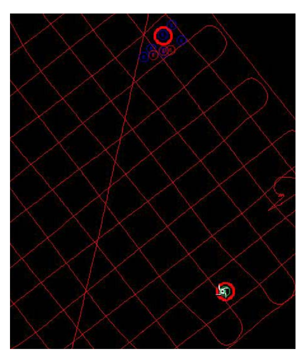

Figure 3: Two changes highlighted in red using automated change detection

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## II. COIN BACKGROUND

With the diversity of systems used operationally, data products were historically visualized in their own, discrete software packages. Interoperability between these systems was difficult, therefore generating a common picture of the environment that all the users could share for planning and analysis was a key issue that had to be addressed. The Common Operator Interface Navy (COIN) is an application that is intended to support the mine countermeasures (MCM) platforms and other equipment used by US Navy Explosive Ordnance Disposal Mobile Units and Mobile Diving and Salvage Units for MCM and underwater survey and object clearance operations. The purpose of this application is to provide mission planning, execution, analysis, and reporting with a consistent user interface among the EOD supported systems (**Figure 4**).

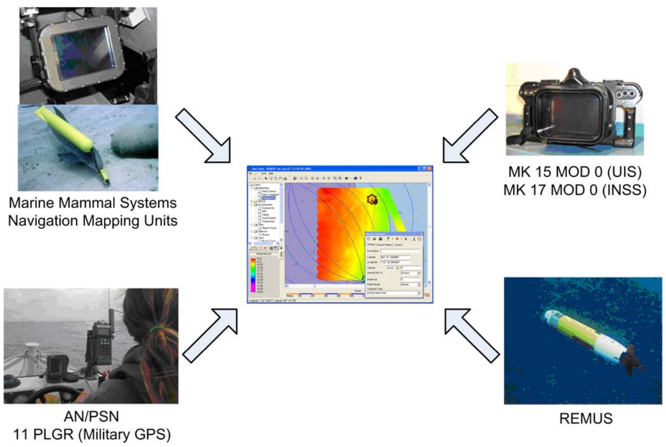


**Figure 4: Typical equipment used in COIN**

COIN's central component is the SeeTrack Military [1] system that provides a mission planning, monitoring and post-processing software tool kit for rapid on-site analysis and data fusion of sensor data, including sidescan, imaging sonar, and video from autonomous underwater vehicles (AUV), towed systems, diver hand held systems, and marine mammal systems. The SeeTrack system was developed by SeeByte Ltd and is becoming ubiquitous in the Clearance Diving Community. It is now operationally used by many groups including: Royal New Zealand Navy, Royal Netherlands Navy, NATO Undersea Research Center, Royal Australian Navy, Australian DSTO, Office of Naval Research, US Navy, and Canadian MARPAC Forces, among others. SeeTrack uses open standard throughout and provides navigational and environmental data in comma separated files and industry standard relational databases with metadata retained. Imagery is stored in industry standard geo-referenced formats that are accessible from any standard image viewer.

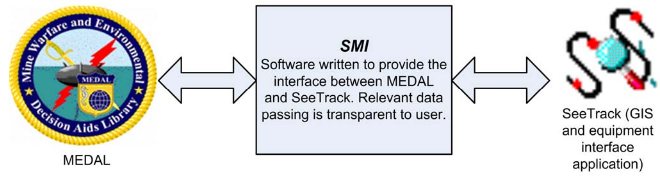


Figure 5: COIN data exchange architecture

COIN also provides a tight integration (Figure 5) with the Mine Warfare and Environmental Decision Aids Library (MEDAL). This is the US Navy's designated overarching mine warfare command, control, and tactical decision aid software system. MEDAL has been fully integrated into GCCS-M. MEDAL is fielded throughout the US Navy within surface, air, and Explosive Ordnance Disposal MCM forces and tactical staffs throughout the naval fleet and mine warfare command structure.

A series of major objectives and capabilities were identified by the US Navy and form the cornerstone of the COIN application:
1) Operator interfaces which are efficient and easy to use
2) Easy to learn (minimize operator training requirements)
3) User-centered system validated by Navy users and field commanders
4) Support for required systems (interoperable and upgradeable)
5) Tactical integration of the Diver, Marine Mammal Systems (MMS), and Unmanned Underwater Vehicle (UUV) operational elements to accomplish the required mission profiles
6) Minimize incidents of operator error

## III. MISSION PLANNING

During the mission planning phase, MEDAL tasking is generated by the MCM Commander. Nautical charts and other geo-rectified imagery, together with environmental information detailing aspects such as water characteristics, seabed types, bathymetry, current flow and direction, may be imported and displayed (Figure 6). Intelligent planning modules use this data to aid in optimal mission planning given the environmental characteristics and operational constraints of the oparea.

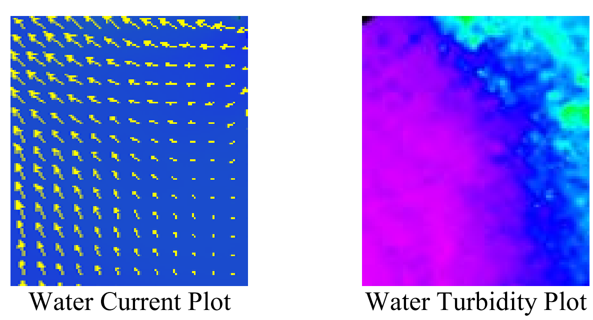


Figure 6: Environmental information

Tactical information from MEDAL can be displayed directly within COIN planning screens (Figure 7).

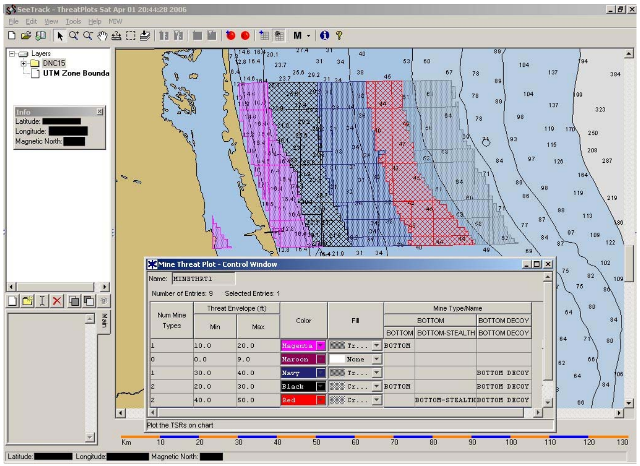

Figure 7: Typical MEDAL information displayed within SeeTrack GIS screen

Mission planning is as easy as moving to the location in the world where one wants to start planning.  Waypoints and standard searching patterns can be dropped into the world by a simple point-and-click with the mouse (Figure 8).

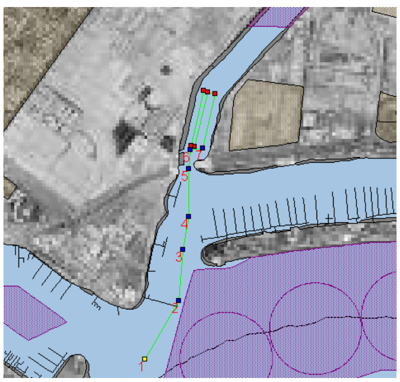
Figure 8: Point and click mission planning

Multiple missions can be planned and loaded, allowing for mission de-confliction and coordination of assets available. Plans can also be exchanged between other tactical systems allowing missions to be aligned with tactical and operational theatre objectives (Figure 9).

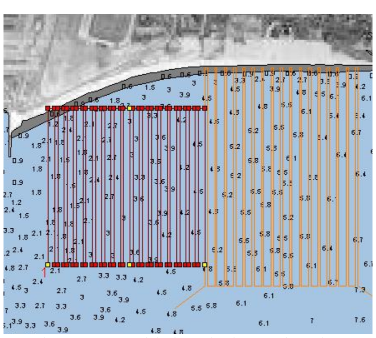
Figure 9: Multiple missions planning

The modular and generic mission planning system can be used to plan for multiple assets. Modules built in can take these mission plans and export them to tactical systems such as Falcon View and Joint Mission Planner. When the operator is satisfied with the mission plan, it can be sent to the platform with a click of a button. The plan is verified as accepted and valid, and executed.  Software development kits are available for 3rd parties to write their own plugins and modules.

The operator may plan missions anywhere in the world using, in the case of COIN, pre-installed world or downloaded tactical imagery. Support for common vector charts and raster imagery enables operators to have geographic imagery rapidly available.

## IV. Mission Monitoring

Multiple assets can be monitored in real time. The tracks are overlayed onto any layers and mission data available (Figure 10).

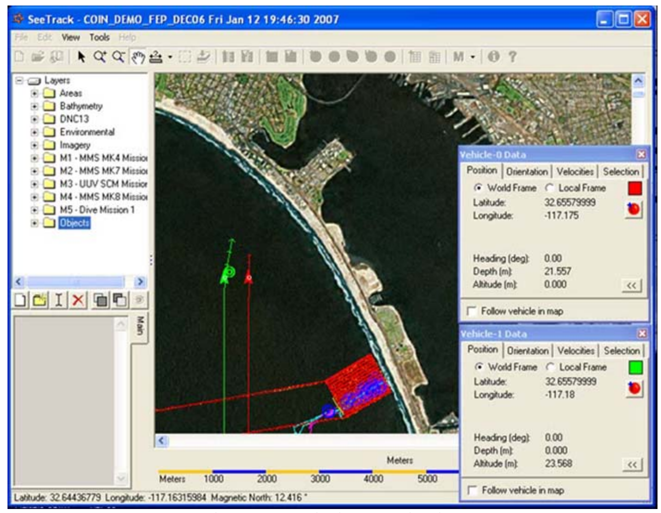

Figure 10: Mission monitoring

Support is provided for mission planning, processing collected data, and making real time actionable decisions with autonomous systems. As the operators require additional experience and needs for more functionality, optional modules can be added as needed.

## V. Post-Mission Analysis

Once the AUV has completed its mission, it can be plugged (or WiFi'd) into the system and data is downloaded using a simple data download wizard. The environmental data such as water temperature and depth profile is displayed. The imaging sonar data will be mosaiced upon direction from the operator, or this can be pre-programmed to automatically occur with an operator-selected resolution.

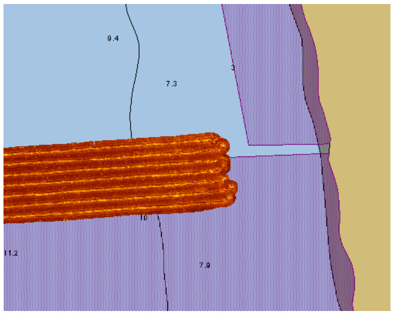

Figure 11: Mosaicing of data on charts and any other available imagery

Either before or after the sonar data is mosaiced (Figure 11), the operator can both manually review and analyze the imaging sonar data or this can be done automatically by the computer with optionally installed processing algorithm modules. The mosaic can be viewed via click and zoom capability, and objects can be correlated by the operator. Objects are automatically correlated between the waterfall display and the mosaic. Contacts that are identified can be marked and assigned a category (Figure 12). An optional module allows for the combat swimmer mission to be planned over gathered image data and charts, and then downloaded to the diver's hand held unit.

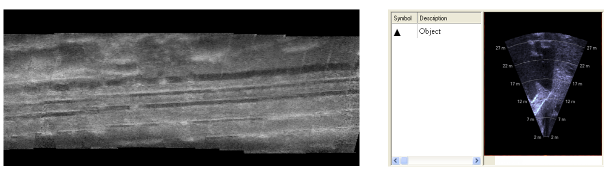


Figure 12: Forward looking imaging sonar mosaic (left) and typical contact viewing screen (right)

The COIN toolset is designed to be portable, operates in a high-end laptop environment, and operators utilize it in the field (Figure 13). A built-in change detection module allows operators in the field to rapidly identify changes without the need for laborious side-by-side image comparison of current data versus historic.

Figure 13: On-site data processing and communications

## VI. Navigation Processing

Navigation processing is available to perform data re-navigation. This correction occurs using features or landmarks (single item position and multiple item pattern orientation) identified in the sensor imagery and has been shown by the US Navy to improve CLA by as much as 100%. Assets using different navigation systems can be adjusted so that comparisons can be made on a consistent baseline.

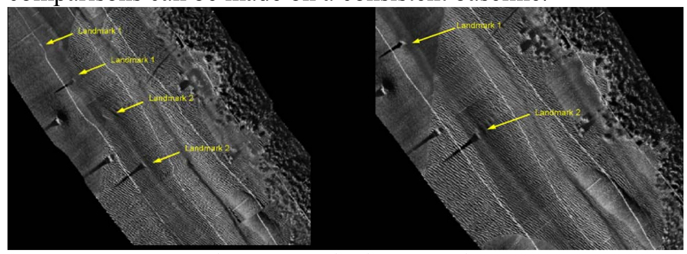


Figure 14: Navigation Processing

In Figure 14 multiple landmarks have been identified on the left image. Due to navigation drift there appears to be four targets, however there are only two. The right image shows the result of a feature based re-navigation.

This use of navigation re-processing is critical when multiple missions are run over the same area as is typical in homeland security operations. A baseline pre-incident survey may exist and post incident a new survey is gathered. This is often, by necessity, by a different asset than was used in the pre-survey; as there might be military involvement post incident whereas before it may have been local authority.

## VII. Change Detection

The Change Detection system utilizes two missions for which contacts have been marked, one historic, the other current. The module compares, at the metadata level, the list of contacts from the two missions and highlights the changes in their positions. The contact list from one mission is read into the other mission. SeeTrack produces a geo-referenced layer that highlights the differences between the 2 object layers. The change detection module assumes that the mission analysis for the 2 missions has already been carried out. This may be done manually by an operator, or automatically by an ATR (computer aided detection/classification) module.

Operationally the change detection process is carried out in three phases.

**In the first, the Pre-incident Survey Phase:** A mission plan would be generated as described in the previous mission planning section. The mission plan would be run on systems such as an AUV or towed sonar. The raw sensor data from the mission is imported directly into SeeTrack. Post mission analysis is preformed on the data including: Contact marking, sensor mosaicing, navigation processing. Where overlap occurs in the sonar data there can be multiple views of the same contact, multiple detections can be automatically grouped together (and QA'd by a human operator) into individual targets (Figure 15). This uses both the detections absolute position and the spatial organization of the detections to ensure a correct grouping. This is vital when the separation of the detections is approximately the vehicle navigation error.

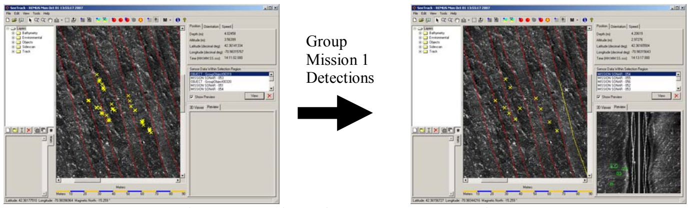


Figure 15: First phase contact grouping

**In the second, Post Incident Phase:** A post-incident mission is run. The change detection approach operates on metadata (the detections) rather than the image data. This means that the approach is very fast; it removes the need to have the system conduct the same trajectory each time. A different platform can also be used as a variety of sidescan sonar systems are supported.

As in the first phase, the user would generate a sortie plan and an exploratory operation would be run using the system of choice. The collected sensor data would be imported directly into SeeTrack. Post mission analysis would be performed on the data including contact grouping (Figure 16).

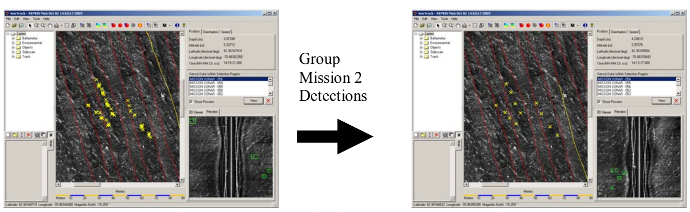


Figure 16: Second phase contact grouping

The missions are then combined together and the operator is cued to the highlighted changes in contacts between the missions (Figure 17).

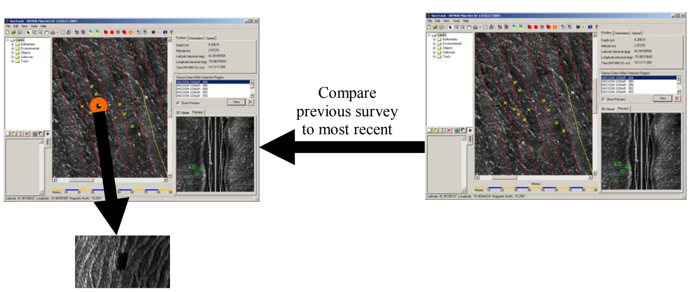


Figure 17: Automated change detection results

**The third phase s the Target Re-acquisition and Confirmation Phase:** Re-Acquisition, identification and neutralization can be planned using the sortie planner and the re-acquisition asset and/or neutralizer can be programmed to the local area of the contact for confirmation and/or destruction.

## VIII. Performance Analysis

Mine warfare operations rely upon gathering a situational awareness of the battle space that they are working in by utilizing multiple sensors and platforms to gather information. This information is placed into a single operating picture to allow tactical decisions to be made. High-resolution side-scan sonar provides much of the information to determine the picture of the seafloor. Operators are becoming increasingly aware of the need to quantitatively assess their Mine Counter Measures (MCM) capabilities. It is critical that they meet the ever-increasing demands of the MCM community for certainty, when utilizing automated Computer-Aided-Detection/Computer-Aided-Classification (CAD/CAC) models and high-resolution sonar (a more general term for CAD/CAC is automated target detection (ATR)).

The Performance Analysis and Training Tool (PATT) module can be used to assess the MCM capabilities of a complete MCM system [2]. The capability of an operator or a CAD/CAC algorithm to effectively clear a survey region is quantitatively measured (e.g. probability of detection, probability of false alarm) by PATT using an Augmented Reality approach. The key to this approach relies on accurately inserting simulated, ground-truth targets into real sensor data. Automated mission planning, risk analysis, and Q-route planning are capabilities which derive the quantitative analysis output from the core PATT module.

MCM capabilities are generally evaluated through expensive sea trials that only use a small number of targets. A statistically robust measure of capability is therefore difficult to obtain. The PATT module deals with this by inserting multiple simulated mine targets into real side-scan sonar data allowing accurate quantitative estimates to be obtained. These targets have had realistic sensor performance qualities imparted to them in the process. The topology of the seafloor is estimated through image segmentation algorithms. Critical sonar parameters, such as the range and resolution, are determined during the process to ensure that the simulated targets are accurately integrated into the imagery. Evaluation results can therefore be obtained against a variety of controlled ground truth parameters such as sonar range, mine type, mine orientation and environmental constraints to the sensor (surface return, shadow, obstruction, noise).

The environment heavily impacts MCM operations' probability of success. The PATT module uses a Seafloor Classification module to provide information on the seabed characteristics within the survey region. A wavelet-based classification system initially classifies each individual sonar image after which a Markov Random Field (MRF)-based fusion system merges these results to provide a large-scale classification mosaic of the region. The impact of the seafloor on MCM system and sensor capabilities can therefore be measured.

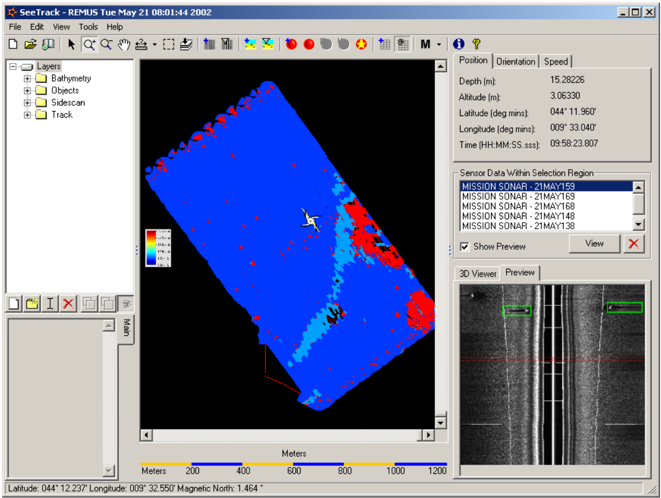

Figure 18: Risk layer display

Illustrated in Figure 18, risk [3] can be visualized as a new layer in COIN. The hot spots (red) are areas that reflect high risk for evaluated sensor performance (difficult area for mine hunting).

The output of the core PATT module is a series of ROC Curves providing a measure of Probability of Detection (PD) versus the Probability of False Alarm (PFA) with respect to the confidence level of the detector for any seafloor type, target type or range of analysis. The statistics can be used to provide a measure of risk of undiscovered mine targets being present in the survey region given the number of targets found using a binomial model. This capability is critical for tactical and operational mission planning. This can later be used for planning the safest routes for shipping through the application of Fast Marching methods.

PATT may also be used for autonomous underwater vehicle (AUV) re-planning to maximize sensor performance in terms of reliable MCM capabilities. Given the MCM capability evaluation provided by PATT, the system uses this information to provide an optimized mission plan for detections and classification. This mission will consider the environment of the survey region being inspected along with the impact this will have on the MCM system to maximize the probability of discovery. Results provided will demonstrate that more sophisticated mission plans are required for complex environments while the typical lawnmower trajectory is sufficient for benign regions.

The results from PATT (principally the probability of detection) may be used to provide an estimate of risk. This work has been taken from the Center for Naval Analysis, which developed a system and terms for presenting risk in laymen and non-MCM professional terms utilized by Clearance Divers explaining remaining risk to Amphibious Force Commanders. The risk can be modeled in two ways. First, the expected number of remaining mines can be estimated based upon a probabilistic model. Second, the performance of a risk reduction measure, such as a second run of high resolution survey around the mines found already in the post mission analysis, can be assessed.

The standard PATT module has a small set of hard to detect, standard mine target shapes that are currently used in the system. These models are represented in the system by a height map where each value in the map represents the elevation of the target. Once the resolution of the height map is known, the object may be inserted into the imagery at any orientation and attitude at the correct size. SeeByte has recently completed a module that allows the operator to input new mine targets into the system. 3-D models of mine targets or Improved Explosive Devices (IED's) may be drawn up in a commercial package such as Google SketchUp and then converted into the required PATT format. This will ensure that PATT may be constantly upgraded to include new targets when evaluating and training new operators and CAD/CAC models, as well as when countering improvised non-standard devices.

## IX. Automatic Target Recognition

Automatic Target Recognition (ATR) systems are generally comprised of a Computer Aided Detection (CAD) and a Computer Aided Classification (CAC) component. The aim of these models is to highlight possible targets within the sensor data to the operator.

SeeByte CAD/CAC is integrated into SeeTrack and allows the user to browse, QA, modify and add/subtract to the output produced by the CAD/CAC. SeeByte has several CAD/CAC models available for demonstration. The current version integrated into SeeTrack uses a model-based approach to classify possible targets. SeeByte ATR also uses fast, supervised classification techniques, which provide a step-up improvement in processing speeds and results. This new model is trained using augmented data (real sidescan data, simulated targets) produced by the performance analysis service, enabling in-situ environmentally dependent re-training of the model. The model is therefore able to adapt to changing environments.

In parallel, SeeByte has defined a simple open interface that allows third party CAD/CAC models to be integrated into SeeTrack. External vendors may therefore reap the benefits of SeeTrack modular design and view the output from their CAD/CAC within SeeTrack, as well as benefit from the environmental analysis provided by the PATT module. This 3rd party integration has been demonstrated by Naval Surface Warfare Center Panama City Division, as well as by Space and Naval Warfare Center, Pacific, Marine Mammal Division.

## X. Conclusions

With the use of multiple sensors and assets, as well as the rapid emergence of new MCM and survey technologies, there exists a requirement for a single, integrated, intuitive interface to plan, visualize, analyze and report the work planned and completed, regardless of the platform used to acquire the data. COIN, and the SeeTrack Engine, provides a system that enables this functionality and interoperability in a common, portable, tactical application. Through the use of open standards and a modular architecture all COIN data may be exchanged with non-military operational assets and vice versa. Non-military collected data can be imported into COIN for Homeland Defense missions, as well as disaster response and humanitarian aid missions.

## ACKNOWLEDGMENT

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## REFERENCES

[1] SeeByte. SeeTrack Military, http://www.seebyte.com/Military
[2] S. Reed, Y. Pétillot, A. Cormack, PATT: A Performance Analysis and Training Tool for the assessment and Adaptive Planning of Mine Counter Measure (MCM) operations, in Proceedings of the Institute of Acoustics, vol 29, Part 6, 2007
[3] S. Savitz, Psychology and the Mined: overcoming psychological barriers to the use of statistics in Naval Mine Warfare, CNA Technical Report, CRM D0013693.A2, May 2006.