DANIEL H. WAGNER

ASSOCIATES INC.

PROVIDING SOLUTIONS TO CRITICAL AND COMPLEX OPERATIONAL PROBLEMS USING MATHEMATICS AND COMPUTER SCIENCE.

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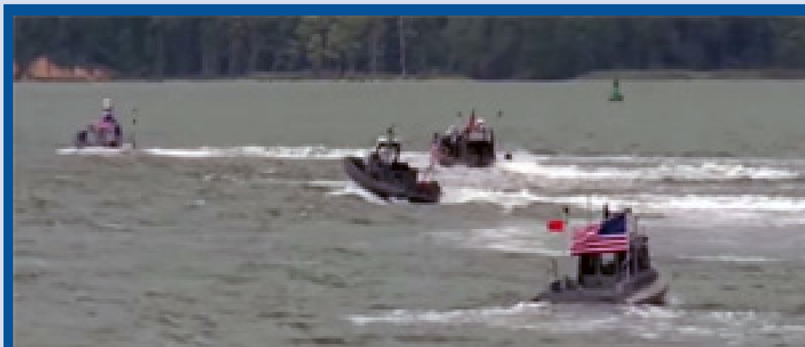
VISION

Serving our clients and country by solving problems that challenge and drive us to develop innovative analytics and robust software.

MISSION

Combine our advanced analytic expertise with the client's knowledge base to create innovative algorithms and state-of-the-art software solutions to operational problems, providing a competitive advantage for the customer. Provide a workplace that promotes professional growth, encourages collaboration, respects work/life balance, and maintains the joy of solving interesting problems.



Wagner's Decentralized and Autonomous Data Fusion Service (DADFS) was used to generate a Common Operational Picture (COP) across five Autonomous Surface Vehicles (ASVs), based on sensor data from each ASV, during the CNO Offensive Swarm demonstration in August 2014 on the James River. We are currently using DADFS in multiple ONR, DARPA, and OSD projects.

DADFS also associates and fuses on-board and off-board acoustic and non-acoustic data in the Undersea Warfare Decision Support System (USW-DSS), the Littoral Combat Ship Anti-Submarine Warfare Mission Package, and the SQQ-89A(V)15 Torpedo Defense Functional Segment (TDFS)

The Navy's MH-60R Anti-Submarine Warfare helicopter uses Wagner's Acoustic Mission Planner (AMP) to optimize dipping sonar and sonobuoy searches and to estimate target location.

WAGNER PROFILE

Daniel H. Wagner Associates, Inc. is an employee owned company founded in 1963. Our corporate office is located in Exton, Pennsylvania; with Divisions in Hampton, Virginia and Vienna, Virginia. Wagner Associates maintains a technical staff of the highest quality that designs, develops, implements, markets, and provides training for custom scientific software. We provide highly effective and useful solutions to complex and technically challenging operational problems for defense and non-defense customers. Wagner Associates is particularly experienced at implementing sophisticated mathematical algorithms in software modules that can be used effectively by military personnel in real-world operations. These tools are even more necessary now then in the past, due to the difficulty of countering threats such as quiet diesel submarines, torpedoes, and mines in complex littoral environments.

We work closely with our customers to ensure that their needs are satisfied and that they can effectively utilize our software products in performing their mission and achieving their goals. The systems we develop, such as data fusion, decision support, and resource optimization software, are often implemented using software agents, and assist their users to perform their tasks much more effectively through the use of sophisticated mathematical algorithms, advanced programming techniques, and quantitative operations research tools.

CORE COMPETENCIES

We offer high quality analysis and application of sophisticated mathematics to difficult problems for industry and government. Specifically, Wagner designed and developed the first Computer Assisted Search (CAS) systems (e.g., CASP; VPCAS; MEDSEARCH; PACSEARCH), and continues to be an industry leader in this area, with several fielded modules such as:

- Acoustic Mission Planner (AMP) in the Navy's MH-60R anti-submarine warfare (ASW) helicopter (page 5)
- Mission Optimization Web Service (which includes the Operational Route Planner (ORP)) in the Navy's Undersea Warfare Decision Support System (USW-DSS) (the AN/UYQ-100 Anti-Submarine Warfare Command and Control System) and the Littoral Combat Ship (LCS) ASW Mission Package (page 8) (page 12) (page13)
- Search Effectiveness and Optimization modules in the U.S. Navy's mine warfare planning and evaluation system, the Mine Warfare and Environmental Decision Aids Library (MEDAL) (page 15)
- DARPA Cross-Domain Maritime Surveillance and Targeting (CDMaST)

Wagner also developed one of the first effective multiple hypothesis data fusion systems and continues to be a leader in this area. These data fusion systems utilize our Maneuvering Target Statistical Tracker (MTST) (also used in the Tomahawk Weapon Control System (TWCS) and the Global Command and Control System (GCCS)). Wagner data fusion modules are currently deployed within:

- USW-DSS (both organic and cross platform) (page 7) (page 11)
- SQQ-89A(V)15 ACB-13/15 Torpedo Defense Functional Segment (TDFS) (page 7)
- PMW-150 Maritime Tactical Command and Control (MTC2) system (page 9) (page 10)
- ONR USV Swarms (page 6)
- More than 10 heterogeneous Autonomous Surface Vehicles (ASVs) (including Surrogate DARPA ASW Continuous Trail Unmanned Vessel (ACTUV), Combatant Maritime Vehicle (CMV), 11 meter Rigid Hull Inflatable Boat (RHIB), 7 meter RHIB, Northrop Grumman Oceanna, Textron Common USV, NOAA Survey Boat) (page 6) (page 14)
- Office of the Secretary of Defense (OSD) ASVs (page 6)
- DARPA Collaborative Operations in Denied Environment (CODE) Unmanned Aerial Systems (UAS) (page 6)

Wagner has also fielded several systems for reducing risk to friendly platforms including:

- Weather Aware Route Planner (WARP) (page 17)
- Dynamic Minefield Optimization (DMO) (page 18)
- Submarine Route Planner for Minimum Mine Risk (SRMR) in the APB-09 submarine Tactical Control System (TCS)
- MEDAL Risk Evaluation module

In addition, Wagner data fusion modules underwent successful test and evaluation on the Arizona/Mexico and Canadian border as part of the Border and Transportation Security Data, Sensor, and Alert-Fusion Center (BTSDSA-FC), and in the ONR Counter-Torpedo Detection, Classification, and Localization (CTDCL) system.

Additional Products listed by area:

Mission Planning/Search and Attack Optimization

- Collaborative Airborne Anti-Submarine Warfere (ASW) Mission Evaluation and Optimization (CAMEO) (page 19)
- Detection Avoidance System for Submarines (DASS) (page 20)
- Effective Mission Planning and Communication for Teams of Manned/Unmanned Systems in Complex Contested Environments (FOCUS) (page 21)
- State Estimation Tool for Underwater Systems (SETUS) (page 22)
- Automated Active Sonar Interference Avoidance Algorithms (ASIA) (page 24)
- Mission Optimization Web Service for Undersea Warfare Decision Support System (USW-DSS) and Theater Undersea Warfare Initiative (TUSWI) (page 13)
- Commander's Estimate of the Situation/Intelligence, Surveillance, and Reconnaissance Tactical Decision Aid (CES/ISR TDA) (page 29)
- Multi-Vehicle Mission Planner (MVMP) (page 30)
- Tactical Environmental Effects for Precision Guided Missiles (METPLAN) (page 31)
- Anti-Submarine Warfare (ASW) and Surface Warfare (SUW) Screen TDA
- Air Warfare (AW) Screen TDA
- Surface Warfare Tactical Decision Aid (SUWTDA)
- Gunnery TDA

Data Fusion/Tracking

- C2 Network Data Fusion, Synchronization, and Monitoring (C2DFSM)
- Feature Aided Association Module (FAAM) (page 28)
- Improved End-Fire Tracking Algorithms (IETA) (page 26)
- Anti-Torpedo Data Fusion and Optimization System (ATDOS) (page 23)
- Combat Air Identification Fusion Algorithm (CAIFA)/Composite Combat Identification (CCID) reasoning algorithm (page 27)
- Cooperative Organic Mine Defense (COMID) Data Registration, Association, and Fusion Module
- Ground Target Tracking and Identification System (GTIS) (page 35)

CORE COMPETENCIES (continued)

Modeling and Simulation

- Detailed ASV/USV Modeling and Simulation System (DAMS) (page 19)

Environmental Modeling and Data Fusion

- Adaptive Gridding for Passive and Active Acoustic Systems (page 27)
- Environmental Data Fusion for Mine Countermeasures (EDFMCM) (page 16)
- Tactical Environmental Effects for Precision Guided Missiles (METPLAN) (page 25)
- Current, Wind, and Wave Data Fusion (CWWDF)

Software Agents

- Generic information and multi-warfare area optimization services in the Federated Collaborative Decision Spaces (FCDS) system
- Information flow optimization and asset status services in the Decision Support for Dynamic Target Engagement (DS DTE) system (page 28)
- Network Monitoring and Management System (NMMS) for LCS (page 26)

Data Mining

- Environmental Data Fusion for Mine Countermeasures (EDFMCM) (page 16)

Mathematical Finance

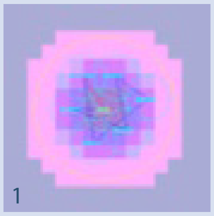
- Statistical arbitrage
- The Premier Retirement Planner (RSP3)
- Mean Variance Optimizer (MVO Library)

FIELDED SYSTEMS

Acoustic Mission Planner (AMP)

Embedded Near-Real-Time Data Fusion and Dynamic Search Optimization for the Navy's MH-60R ASW Helicopter

(FOR NAVAIR PMA-299 THROUGH SUBCONTRACT WITH LOCKHEED MARTIN ROTARY AND MISSION SYSTEMS – OWEGO)



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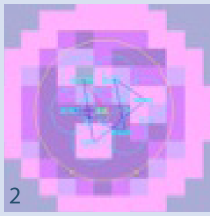


2

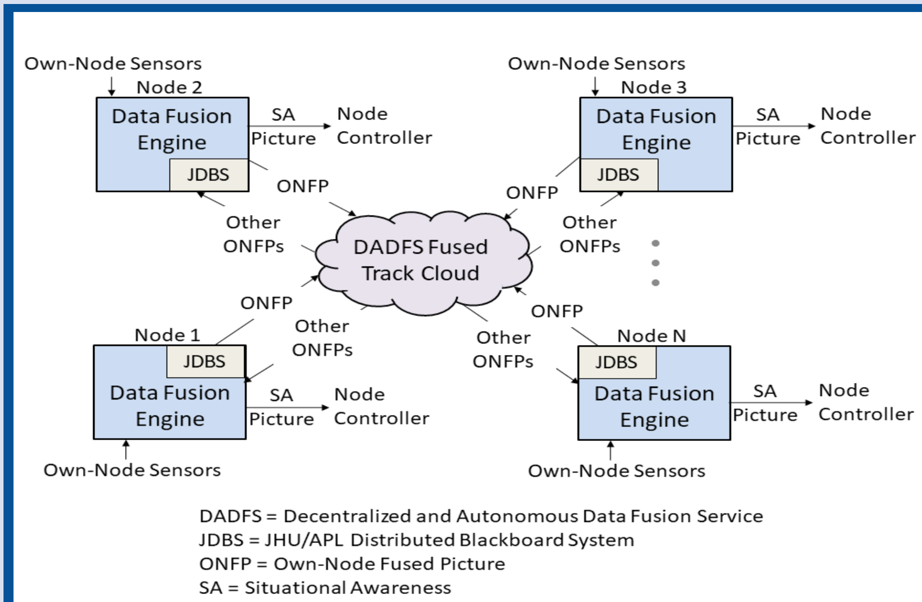
[1] Recommended ALFS pattern (small circles around each dip point), based on probabiity map generated by agent based simulation using an initial circular datum.

[2] Estimated target position at end of search, assuming the ALFS search does not detect the target.

- Finds a near-optimal search plan against subsurface targets for up to four MH-60Rs; including a complete route with dip locations for using the Navy's Advanced Low Frequency Sonar (ALFS) dipping sonar and sonobuoys drop locations
- Embedded data fusion and dynamic search optimization decision aid in MH-60R avionics
- Integrated into MH-60R shipboard Mission Planning System (MPS) Joint Mission Planning System (a Unique Planning Component)
- Has passed OPEVAL and continues to be enhanced
- Each deployment of the dipping sonar returns environmental data that can be used to update the acoustic detection field, allowing the embedded system to re-run the algorithm, potentially improving the overall ASW performance in the latter portion of the search
- Data fusion algorithm generates a 3-dimensional space-time target probability distribution using an agent based simulation with Bayesian weights that are updated in real time for "negative" search information from non-detection of the target of interest
- Optimization algorithm combines a local heuristic for path selection with a global optimization relaxation scheme based on Brown's algorithm ["Optimal Search for a Moving Target in Discrete Time and Space," S.S. Brown, Operations Research, Vol. 28, No. 6, Nov-Dec 1980]

Decentralized and Autonomous Data Fusion Service (DADFS) for Heterogeneous Unmanned Vehicles (UVs)

(FOR ONR, DARPA, AND OSD)

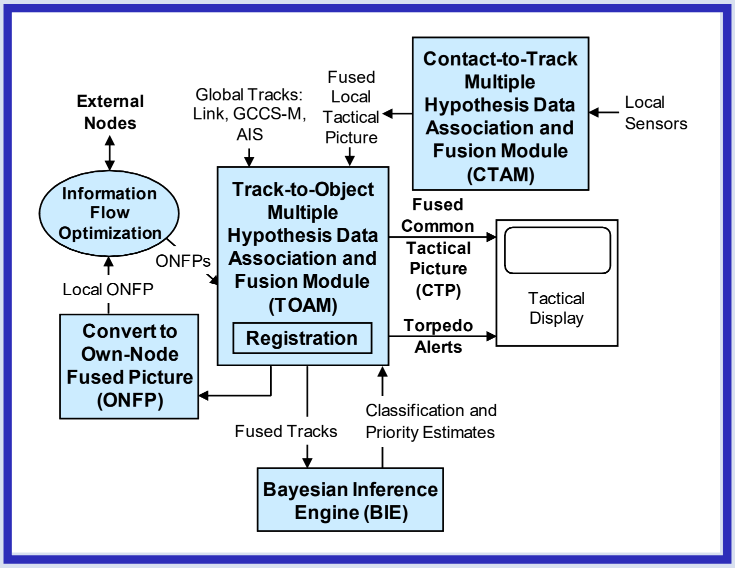


Note: Core algorithms have performed well on real-world data from four UV platforms, and in a 50 UV simulation.

- "Burns down the haystack" by significantly reducing clutter
- Alerts operators concerning high-interest tracks and prioritizes targets for operator investigation
- Improves track persistence
- Improves object classification and ID estimates (accuracy and latency)
- Minimizes latency and delay and is disruption tolerant
- Highly effective over Disconnected, Intermittent, and/or Low Bandwidth (DIL) Communications Networks
- Small hardware and software footprint (part of one PC104 card (104mm x 104mm))

Net-Centric Data Fusion (NCDF) for Undersea Warfare Decision Support System (USW-DSS) and SSQ-89A(V)15 Torpedo Defense Functional Segment (TDFS)

(FOR NAVSEA IWS 5A/5E)



- Low-cost system solution (straightforward integration of mature, extensively tested components) providing:
  - An accurate and fused Common Tactical Picture (CTP), utilizing all available networked sensor data
  - An automated multi-sensor system with a high probability of torpedo attack detection (PD) and a low false alarm rate (FAR)

- NCDF, CTAM and TOAM components have been integrated into Undersea Warfare Decision Support System (USW-DSS) Build 2 in order to provide automatically generated cross-platform track association recommendations and a common tactical picture

- NCDF, CTAM and BIE components are being integrated into a SQQ-89A(V)15 ACB-13/15 in order to provide more accurate torpedo alerts and a torpedo defense Situational Awareness picture

NCDF Technologies

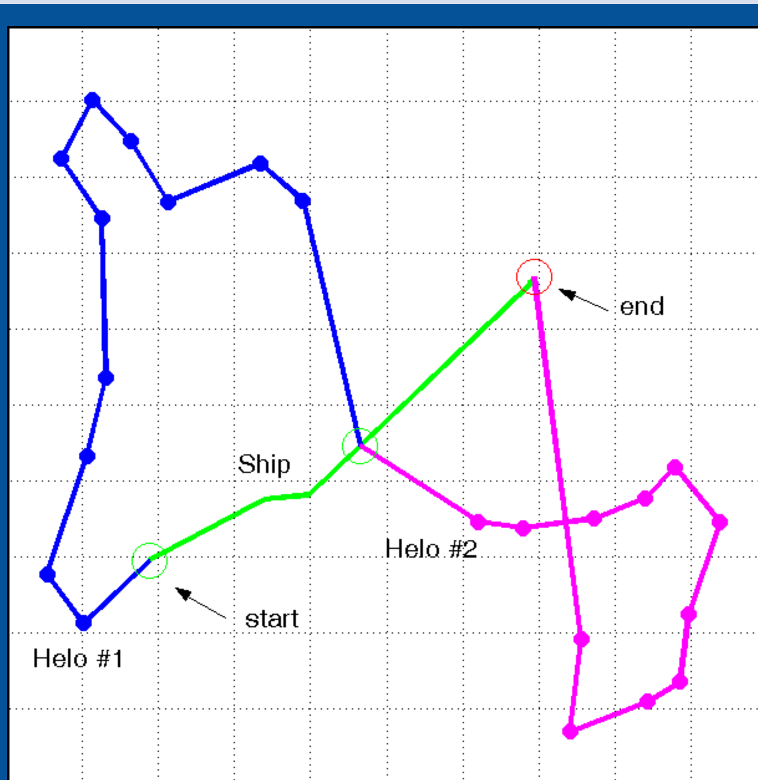
- Effective contact-to-track (aka report-to-track) fusion algorithm
  - Multiple hypothesis association
  - Gaussian sum tracker
  - Bayesian treatment of attributes/features

- Effective track-to-object (aka track-to-track) fusion algorithm
  - Uses all available track data (including entire track history) when determining association scores
  - Registration
  - Multiple hypothesis association, Gaussian sum tracker, Bayesian treatment of attributes/features

- Accurate and operationally effective Bayesian Inference Engine
  - Prioritization
  - Classification
  - Alerting

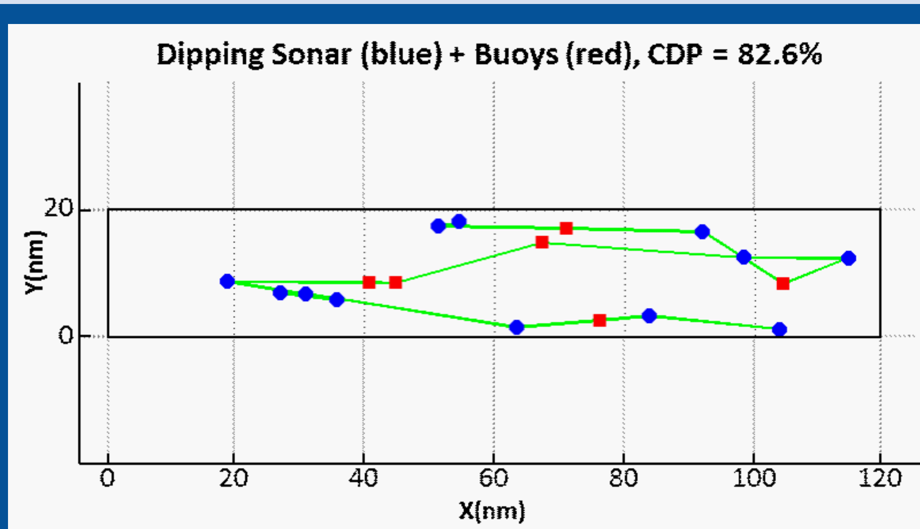
Coordinated Anti-Submarine Warfare (ASW) Mission Planner (CAMP)

(FOR NAVSEA IWS 5E AND PMS420)



CAMP Generated Optimal Search Plan for Ship (red), MH-60R #1 (green), MH-60R #2 (blue)

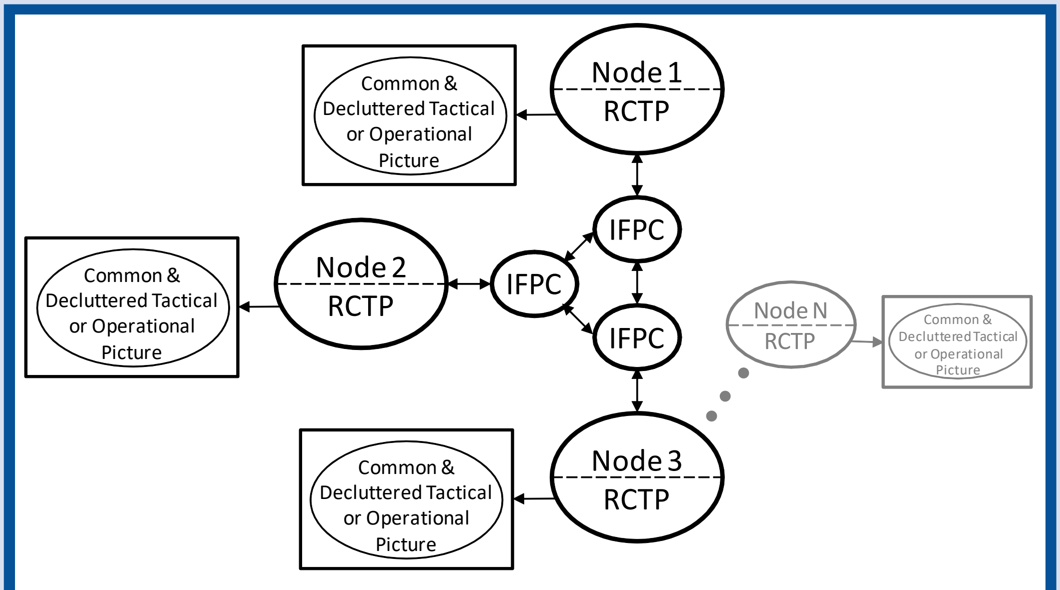
- User-friendly Coordinated Anti-Submarine Warfare (ASW) Mission Planner (CAMP) modules that utilize innovative search optimization techniques and algorithms to generate coordinated, jointly optimized ASW search plans for heterogeneous surface and air platforms that can be modified in near-real-time
- Transition targets include Aircraft Carrier Tactical Support Center (CV-TSC), Undersea Warfare Decision Support System (USW-DSS), and Littoral Combat Ship (LCS) ASW Mission Package
- Advantages include reduced time to search an area, reduced operator workload, and improved use of limited assets
- CAMP plans will improve situational awareness (SA) and threat assessment, increasing the probability of defeating threat submarines, and reducing the vulnerability of friendly forces



CAMP Optimized MH-60R Combined Dipping Sonar and Passive Sonobuoy Search

Common Tactical Picture Generation and Synchronization, and Information Flow Optimization, Over Disconnected, Intermittent and/or Limited Communications Networks (CTPoDIL)

(FOR ONR/PMW150 OPEN TRACK MANAGER (OTM)/COMMAND AND CONTROL RAPID PROTOTYPE CONTINUUM (C2RPC)/MARITIME TACTICAL COMMAND AND CONTROL (MTC2) (REPLACING GLOBAL COMMAND AND CONTROL SYSTEM-MARITIME (GCCS-M))



1. Create a decluttered, accurate, and near-zero latency Common Tactical Picture (CTP) or Common Operational Picture (COP) on each node based on all available information from all nodes and theater and national sensors.

2. Optimize the transmission of relevant information among nodes, within the constraints of disconnected, intermittent, and/or limited (DIL) communications links, while maintaining critical pedigree and both positional data and non-positional attribute data.

TECHNOLOGY COMPONENTS:

Relevant Common Tactical Picture generation (RCTP)

- Track-to-Object Multiple Hypothesis Data Association and Fusion Module (TOAM)
  - generates decluttered and more accurate CTP or COP
  - removes redundant tracks

- Information Flow Prioritization and Control service (IFPC)
  - filtering (determining when to send update)
  - compression (minimizing number of bytes in update)

TRANSITIONS:

- Transitioning to PMW 150 for Open Track Manager (OTM)/Maritime Tactical Command and Control (MTC2) (replacing Global Command and Control System-Maritime (GCCS-M)) and Distributed Common Ground Station - Navy (DCGS-N)
  - integrated IFPC into OTM as Zone Exchange – Optimized (ZEO)
  - integrated RCTP into OTM as correlator

Optimized Data Management Services (ODMS) for Operational and Tactical Environments

(FOR OSD, ONR, AND SPAWAR PMW150)

Example of Accurate and Deculttered Common Operational Picture (COP)

- ODMS provides robust, open architecture, modular components and services for automatically, efficiently, and very reliably associating duplicate or redundant tracks using multiple hypothesis techniques and all available kinematic (i.e., positional) and non-kinematic (i.e., attribute) data from disparate networked sources (e.g., distributed sensors, online databases, decision support systems)

- Conversations are maintained among nodes based on varying levels of domain content awareness, while abstracting the underlying data sources into a virtual data store

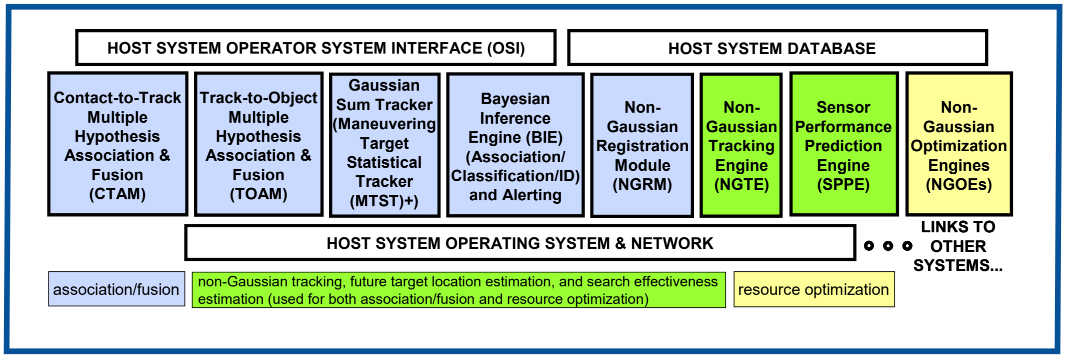
- Running with extensive operational fleet data, ODMS has reduced clutter while making no known merge errors on friendly or threat tracks, resulting in a more accurate COP. In addition, ODMS supports parallel processing in cloud environments

- Incorporating Optimized Data Management Services (ODMS) for Operational and Tactical Environments into the Maritime Tactical Command and Control (MTC2) system and other Navy C2 (DCGS-N) and Combat Systems will improve warfighting performance by providing a more accurate and less cluttered Common Operational Picture (COP), generated using significantly less operator time and at lower cost

Multi-Sensor Data Fusion System (MSDFS) for Undersea Warfare Decision Support System (USW-DSS)

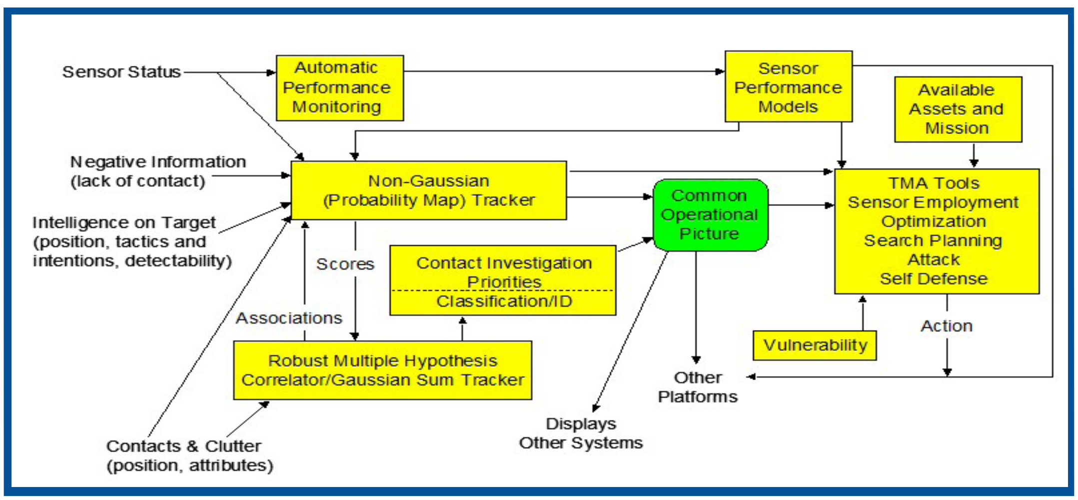
(FOR ONR AND NAVSEA IWS 5B/5E)

- System for accurately fusing all of the Anti-Submarine Warfare (ASW) and Surface Warfare (SUW) information available from large numbers of sensors
  - multiple hypothesis, Gaussian sum tracking, and non-Gaussian tracking techniques
  - computer resource optimization algorithms
  - high-performance, inexpensive hardware



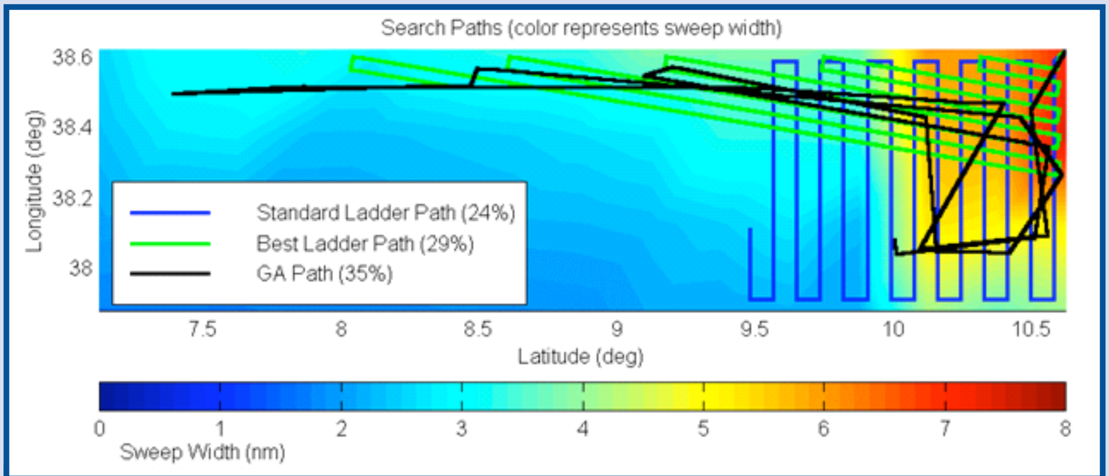
- Components incorporated into Undersea Warfare Decision Support System (USW-DSS) Build 2

- Components underwent test and evaluation aboard the USS Paul Hamilton, USS John S. McCain, USS Decatur and USS Milius as part of the SQQ-89 Improved Performance Sonar (IPS) Data Fusion Functional Segment (DFFS)



Operational Route Planner (ORP) for Undersea Warfare Decision Support System (USW-DSS)

(FOR NRL, ONR, NSWC-DD AND NAVSEA IWS 5E)

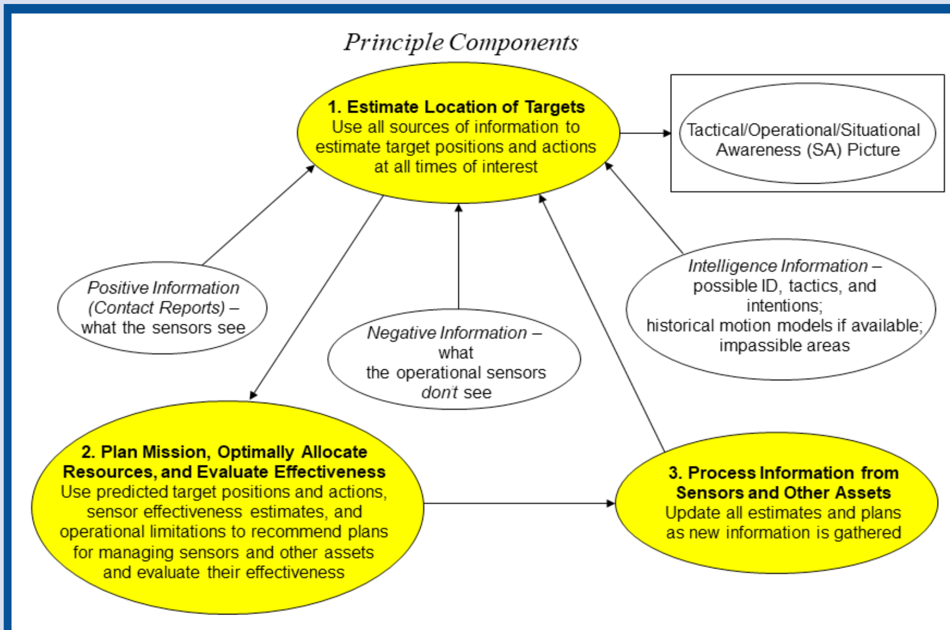


Colors indicate sweep width (2 times mean detection range)
Fixed starting point
Blue=Standard ladder search
Green=Best ladder path of 500 random orientations and spacings
black=ORP track

- Search-path planning module
- Transitioned to the Undersea Warfare-Decision Support System (USW-DSS)
- Finds near-optimal and environmentally responsive search plans for anti-submarine warfare (a search plan is a complete specification of the searcher's path and, where applicable, sensor depth)
- Flexible criterion for optimality; most commonly used measure of performance (MOP) is the cumulative detection probability (CDP)
- Produces a physically realizable path and uses realistic physical detection models, such as the sonar equation for acoustic sensors
- Uses a genetic algorithm (GA), with the goal of finding near-optimal search plans
- When evaluated in simple environments, where near-optimal solutions are readily discernable, ORP consistently produces the expected solutions
- When evaluated in complex, real-world environments, where no near-optimal solutions are known, ORP routinely outperformed standard Navy doctrine (the best available benchmark), often by 20-50% ["A Genetic Algorithm Applied to Planning Search Paths in Complicated Environments," D.P. Kierstead and D.R. DelBalzo, Military Operations Research, Vol. 8, No. 2, 2003]
- Fleet-tested in many sea trials, including SHAREMs and Fleet Battle Experiments (FBEs), where it consistently outperformed traditional Navy doctrine

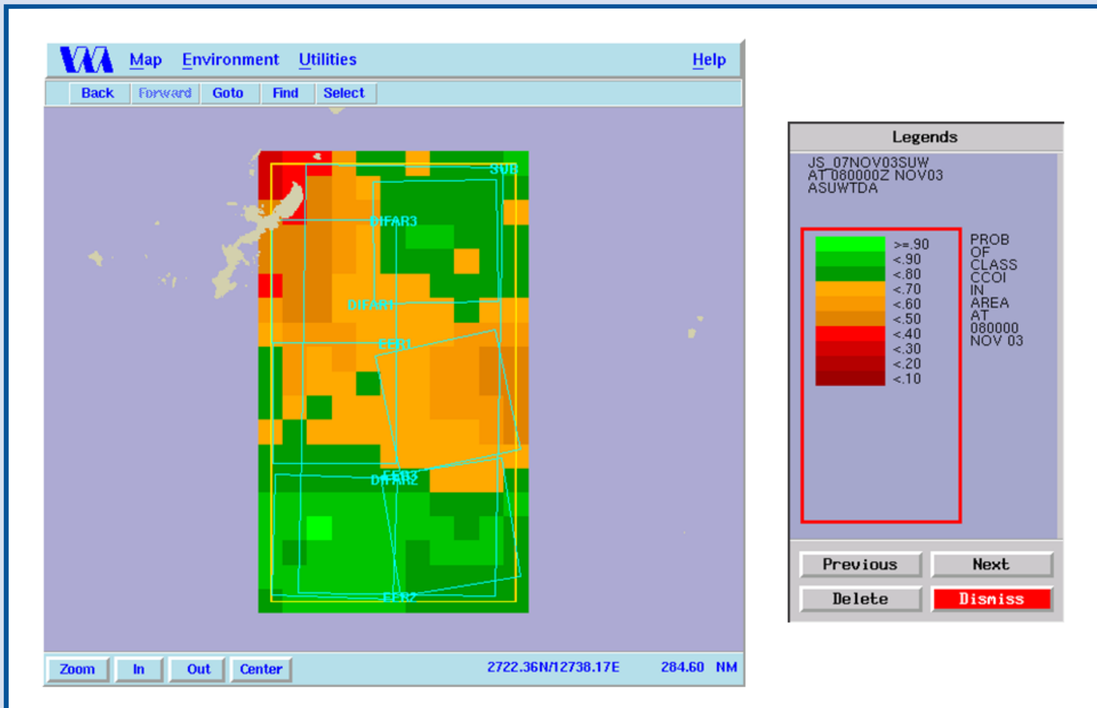
Mission Optimization Web Service for Undersea Warfare Decision Support System (USW-DSS)

(FOR ONR THROUGH SUBCONTRACT WITH LOCKHEED MARTIN HAWAII: TRANSITIONED TO USW-DSS, NAVSEA IWS 5E)



Principle Non-Gaussian Tracking Engine Components Used in Mission Optimization Web Service

- Transitioned to USW-DSS Build 2
- Originally installed at CTF-34 in Pearl Harbor as part of Theater Undersea Warfare Initiative (TUSWI)
- Uses detailed non-homogeneous environmental data generated by the Navy standard STAPLE system, non-Gaussian tracking algorithms, and non-Gaussian resource optimization algorithms to predict the future location of high-interest targets and to optimize search against these targets
- Allows the user to determine where and how to utilize assets such as ships, submarines, and aircraft when searching for threat submarines in an area of interest



Sample ASW Search Effectiveness Map Generated Using Mission Optimization Web Service

Object Avoidance for Unmanned Surface Vehicles (OAUSV) for NSWCCD and ONR Autonomous Maritime Navigation (AMN)

(FOR NSWCDD AND NAVSEA PEO SHIPS)

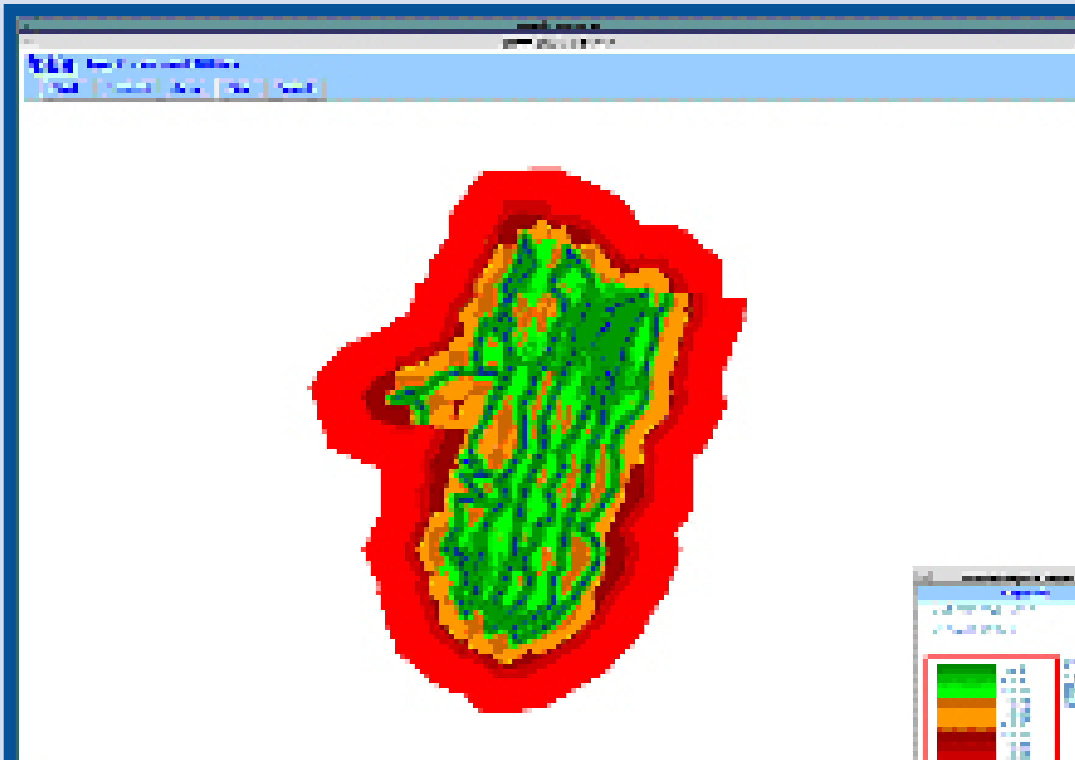
Object Avoidance Situational Awareness Screenshot (Sample Google Earth display of "World Map" data). Note: small red and green circles are Digital Nautical Chart (DNC) buoys/markers; green ellipses are from the Fused Tactical Picture (FTP) generated by Wagner's Data Fusion Engine (DFEN), other colored ellipses are raw sensor reports on buoys/markers; cyan dots show current Unmanned Surface Vehicle (USV) position along yellow waypoint track.

- Installed on seven heterogeneous Autonomous Maritime Navigation (AMN) vehicles (PowerVent, Combatant Maritime Vehicle (CMV), 11 meter Rigid Hull Inflatable Boat (RHIB), 24 foot RHIB, Northrop Grumman Oceanna, Textron/AAI Common USV, NOAA Survey Boat)
- Processes all available data in real-time
  - own-USV (on-board) sensor data
  - data from off-board systems (e.g., other ship's/aircraft/UVs' organic systems, Route Surveys, MCM systems)
- Dynamically generates a "World Map," an optimal route, and a real-time object avoidance plan
- Provides World Map, route, and recommended maneuver information to the Unmanned Surface Vehicle (USV) control system and its operators
- Uses the contact data fusion and environmental data fusion algorithms developed in our Commander's Estimate of the Situation/Intelligence, Surveillance and Reconnaissance Tactical Decision Aid (CES/ISR TDA) and Current, Wind, and Wave Data Fusion (CWWDF) projects for ONR to determine a recommended route for the USV that minimizes vehicle vulnerability.
- Analysis shows that the ability to utilize off-board data significantly improves the ability of the USV to maneuver around potentially threatening objects and dramatically reduces the number of false alarms.

Common Operational Picture Generated in Real-Time at Sea Using Data from Two Heterogeneous USVs (fused ellipses are green (based in fusing Ka-band radar from both USVs with DNC buoy data), raw Ka-band radar is orange, USVs (CMV and 7mt RHIB) are blue)
Note: Time Slice (~10 seconds) on historical Google Earth image
Note: Scale ~0.4 NM x 0.75 NM

Evaluation, Optimization, and Risk Assessment Modules for the Mine Warfare and Environmental Decision Aids Library (MEDAL)

(FOR ONR AND NAVSEA PMS-495)

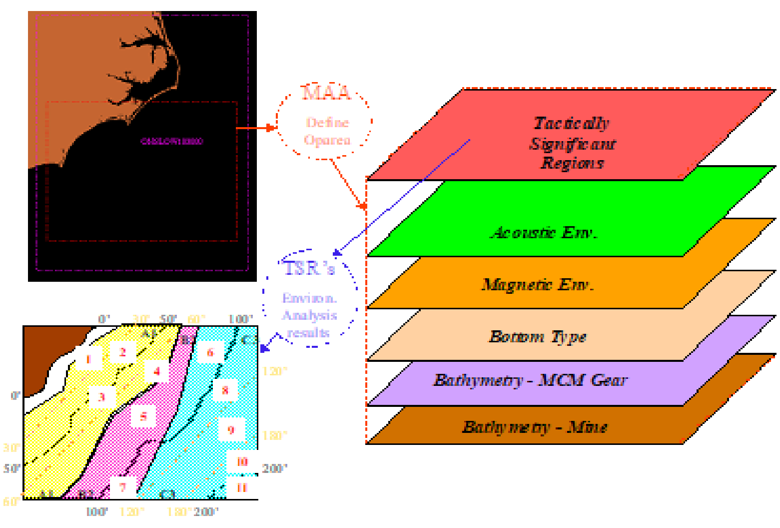


Sample Mine Warfare and Environmental Decision Aids Library (MEDAL) Search Effectiveness Map

- Optimizes both mine hunting and mine sweeping operations and computes the risk to multiple transitors from multiple mine types along any transit route or in any patrol area
- Evaluation algorithms accurately compute the effectiveness of both mine hunting and mine sweeping operations by multiple sensors, sweeps, and platforms
- JMCIS 2.2.0.5 version of MEDAL, hosted on a TAC-III computer, was initially fielded on the USS JUNEAU during RIMPAC 94 and Navy operators were trained in its use
- Subsequently, MEDAL was provided to all MCM units and staffs for use as their primary planning and evaluation tool
- Development has continued through the ongoing work on MEDAL Enterprise Architecture (EA)

Environmental Data Fusion for Mine Countermeasures (EDFMCM) for the Mine Warfare and Environmental Decision Aids Library (MEDAL)

(FOR ONR AND NAVSEA PMS-495)



Use of EDFMCM for Intelligence Preparation of the Battlefield

- Allows Mine Countermeasures (MCM) planners and operators to optimize their use of environmental data, resulting in:
  - more effective MCM plans
  - more accurate evaluation of the effectiveness of MCM operations
  - a more accurate assessment of the residual threat to shipping from mines that remain after MCM operations

- Includes a software agent/broker, that, without operator intervention, can obtain information via SIPRNET from external databases

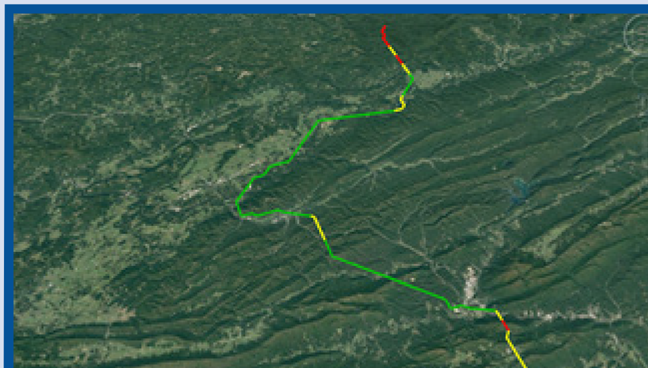
- Contains a tool set for retrieving and analyzing environmental data for use in assisting with naval mine counter measure efforts
  - Measurement optimization tool accurately extrapolates from a small (or large) set of environmental data (e.g., bathymetry, bottom description) to the entire area of interest and provides both an accurate estimate of error in the extrapolated data and an optimized list of recommended points at which to obtain additional data
  - Data fusion tool handles conflicts between data from different sources
  - Statistical tool provides the final analysis of how environmental data determines the effectiveness of sonars in detecting submerged mines and generates probability of detection (PD) curves and estimated false alarm rates

- Modules have transitioned to the Mine Warfare and Environmental Decision Aids Library (MEDAL) (the Global Command and Control System - Maritime (GCCS-M) mine warfare segment)

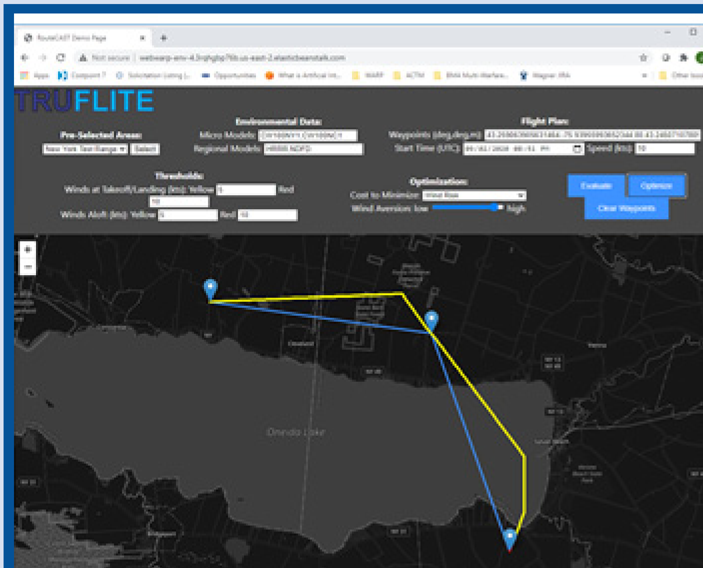
Weather Aware Route Planner (WARP)

(FOR NASA)

- Evaluates/Optimizes unmanned aerial system (UAS) flight plans based on weather risk
- Displays red/yellow/green route based on UAS-specific thresholds for parameters, such as wind speed and direction
- Started with freely available National Oceanic and Atmospheric Administration (NOAA) weather data; later incorporated sub-regional (micro-scale; 1km and below) weather models from TruWeather Solutions
- Integrated with open source mission planners / ground control stations (e.g., Paparrazi, ArduMP)
- Can communicate with UAS over MAVLINK to support dynamic evaluation/optimization based on actual flight
- Commercialized on Amazon Web Services (AWS) as RouteCAST, one of the TruFlite Core services offered with TruWeather Solutions



WARP UAS flight plan optimized based on wind speed and direction using micro-scale weather data; shown on Google Earth to highlight terrain-based wind effects



RouteCAST service deployed on AWS, using the best available weather data to optimize a UAS flight plan based on wind speed and direction

SYSTEMS READY FOR TRANSITION

Dynamic Minefield Optimization (DMO)

(FOR ONR AND PMS-495)

- Dynamic Minefield Optimization (DMO) evaluates and optimizes precision placement of mines and advanced sensors/effectors for multiple maritime minefields. It also evaluates and optimizes precision placed mine and sensor/effector delivery plans for multiple maritime minefields.
- Utilized Brown's algorithm and mixed integer programming
- Use of DMO will result in:
  - significantly more effective use of precision placed mines and sensors/effectors
  - significantly more effective use of precision placed mine and advanced sensor/effector delivery resources
  - higher probability of defeating threat submarines and surface ships
  - reduced vulnerability of friendly forces to threat submarines and surface ships
  - reduced planner time-on-task and much faster response to operational changes

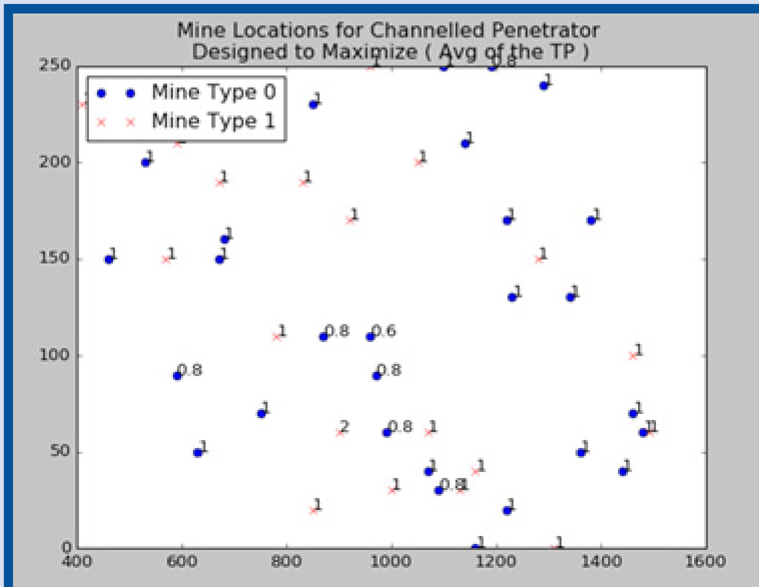
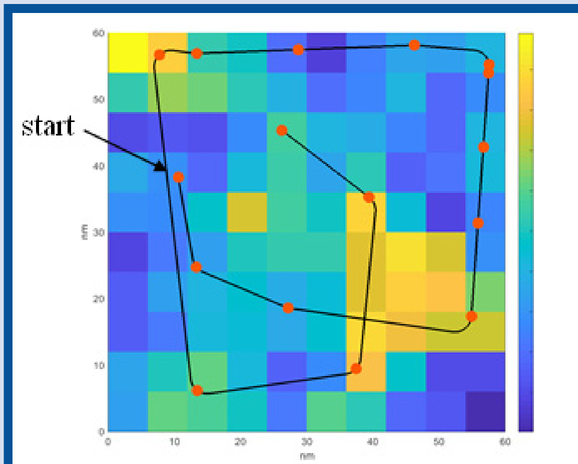


Figure shows Optimal Allocation of Mines and Ship Count Settings to Maximize Average Damage to Threat

Collaborative Airborne Anti-Submarine Warfare (ASW) Mission Evaluation and Optimization (CAMEO)

(FOR NAVAIR PMS-281)

- Leveraged the Evolutionary Machine Learning (EML) (aka Genetic Algorithm (GA)) used in Wagner's Operational Route Planner (ORP)
    - U.S. Navy's primary search optimization and mission planning module
- Focused on airborne Undersea Warfare (USW) and Surface Warfare (SUW)
- Jointly optimizes multiple USW/SUW sorties by MPRA (P-8), MH-60Rs, and Unmanned Aerial Systems (UASs)
    - detailed optimized sorties
    - threat platforms with modeled behavior and tactics
    - accounts for relevant environmental (e.g., acoustic conditions), platform/sensor, and target factors
- Environmental and tactical visualization techniques and displays
- Accounts for acoustic conditions and anticipated target behavior
- More efficient and effective use of limited search assets
- Better understanding of the acoustic environment and expected sensor performance
- Higher probability of detecting threat platforms
- Reduces mission planning time-on-task
- Reduces lengthy planning times for complex missions



Six Hour Search Problem against 5-knot Random Patrolling Threat Submarine.

Red Dots indicate locations of 16 Posts (co-located source and receiver). Color scale shows nominal relative detection range.

Increased Cumulative Detection Probability by 10 percentage points compared to a Uniform 4x4 Distributed Field (not shown).

Figure Shows Example Optimized P-8 Multistatic Active Coherent (MAC) Sonobuoy Pattern in a 60x60 nm^2 Gridded Test Environment

Detection Avoidance System for Submarines (DASS)

(FOR NAVSEA AND IWS 5A)

- Tests show DASS generation of accurate probabilistic models of counter-detection reduces friendly submarine vulnerability significantly (25% or more) compared to conventional (and manually intensive) approaches
- Overall Benefit: reduces vulnerability, increases situational awareness, reduces time-on-task
- Analyzes environmental conditions, databases and models – resolves uncertainty using a newly-developed technique: Area Statistics Machine Learning (ASML)
  - Data Driven Approach to quantifying uncertainty that is 1000s of times faster than Monte Carlo methods without sacrificing accuracy
- Near-Real-Time mode that processes multiple narrowband and broadband frequencies to produce accurate, up to the minute, vulnerability estimates
- Area Planning Mode that looks at key narrowband frequencies across a geographic region, allowing users to see high threat and low threat areas
- Route Planning Mode that evaluates plans, and suggests modifications that reduce vulnerability while still accomplishing mission objectives

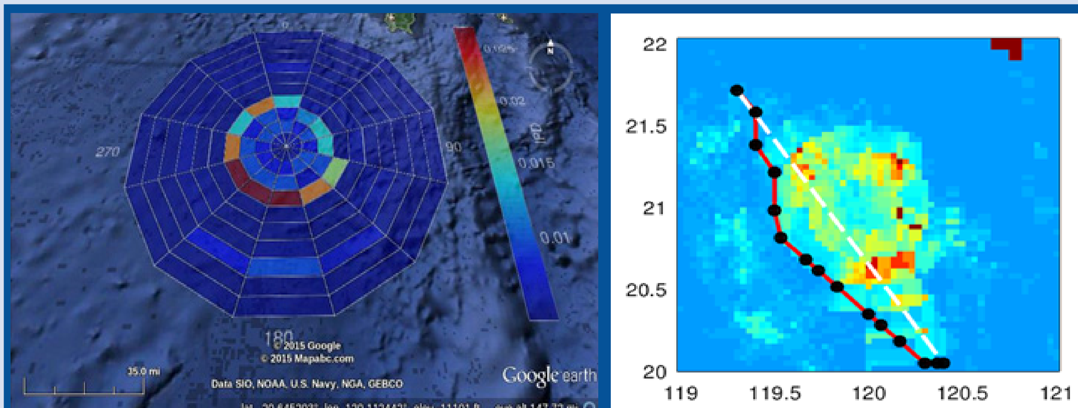


Figure shows: (left) Vulnerability of Friendly Submarine as Function of Bearing and Range, (right) Optimal Track to Avoid Counter-Detection

Effective Mission Planning and Communication for Teams of Manned/Unmanned Systems in Complex Contested Environments (FOCUS)

(FOR NAVAIR PMA-281)

- Mission planning tools based on formal methods (e.g., model checking, proofs, functional programming)
- Mission execution tools based on formal methods and data fusion
- Mission communication tools that don't just send data, but information in context
- Defines provably correct plans using formal methods (abstracting the mathematical framework for ease of operator use)
  - machine-readable mission plans at varied levels of abstraction that are provably correct will revolutionize military planning for manned/unmanned teamsNear-Real-Time mode that processes multiple narrowband and broadband frequencies to produce accurate, up to the minute, vulnerability estimates
- Supports provably correct dynamic re-planning based on all available information
  - during mission execution, the manned/unmanned team will be more agile and adaptable to the situation/enemy
- Improves communications by sending information in context
  - significantly reduces the number and size of messages required for C2; freeing up bandwidth when comms are available, and allowing the mission to continue when comms are limited or disrupted
  - small contextual messages limit the usefulness of each message to an interceptor

Figure Shows Example FOCUS Plan

State Estimation Tool for Underwater Systems (SETUS)

(FOR NAVSEA IWS 5A)

- Tests show significant improvement in tracking performance (e.g., > 50% improvement in threat range estimation) by using SETUS over approaches such as conventional particle filters
- Overall Benefit: reduces vulnerability, increases situational awareness, lowers time-on-task
- Analyzes environmental conditions, databases and models – resolves uncertainty using a newly-developed technique: Area Statistics Machine Learning (ASML)
- machine-readable mission plans at varied levels of abstraction that are provably correct will revolutionize military planning for manned/unmanned teamsNear-Real-Time mode that processes multiple narrowband and broadband frequencies to produce accurate, up to the minute, vulnerability estimates
- Supports provably correct dynamic re-planning based on all available information
  - data driven approach to quantifying uncertainty that is 1000s of times faster than Monte Carlo methods without sacrificing accuracyImproves communications by sending information in context
- Employs an Agent-Based Simulation with Bayesian Weights (ABSBW) to process positive information (successful acoustic detection of the target of interest (TOI)) and negative information (lack of acoustic detection of the TOI)
- Processes contact followers (CFs) across multiple narrowband and broadband frequencies to produce accurate full state estimates in near real-time, including range, bearing, depth, velocity and acoustic signature
- Acoustic signature estimates can be used to aid target identification and classification

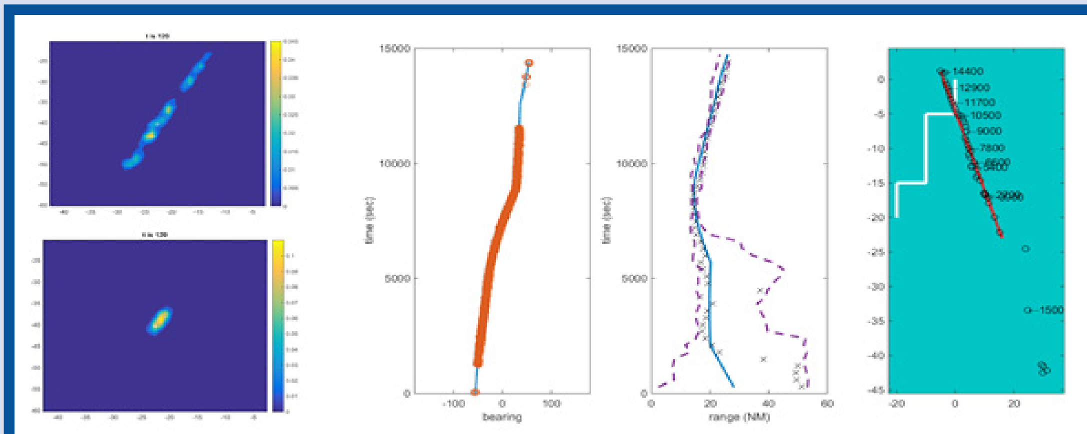
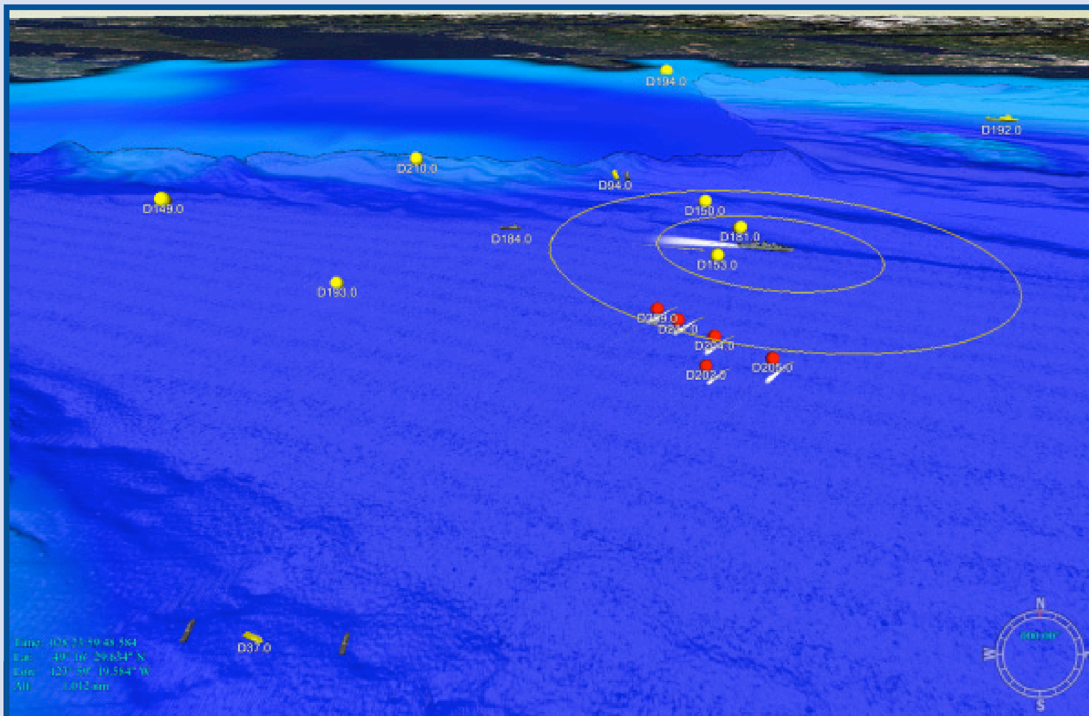


Figure shows: (top left) Area of Uncertainty (AOU) Using Standard Particle Filter, (bottom left) AOU Using SETUS, (center left) (mathematical) Bearing Estimate (with uncertainty) Compared to Ground Truth, (center right) Range Estimate (with uncertainty bounds) Compared to Ground Truth, (right) Sensor (red moving up and to the left) and Target (white moving down and to the left) Positions

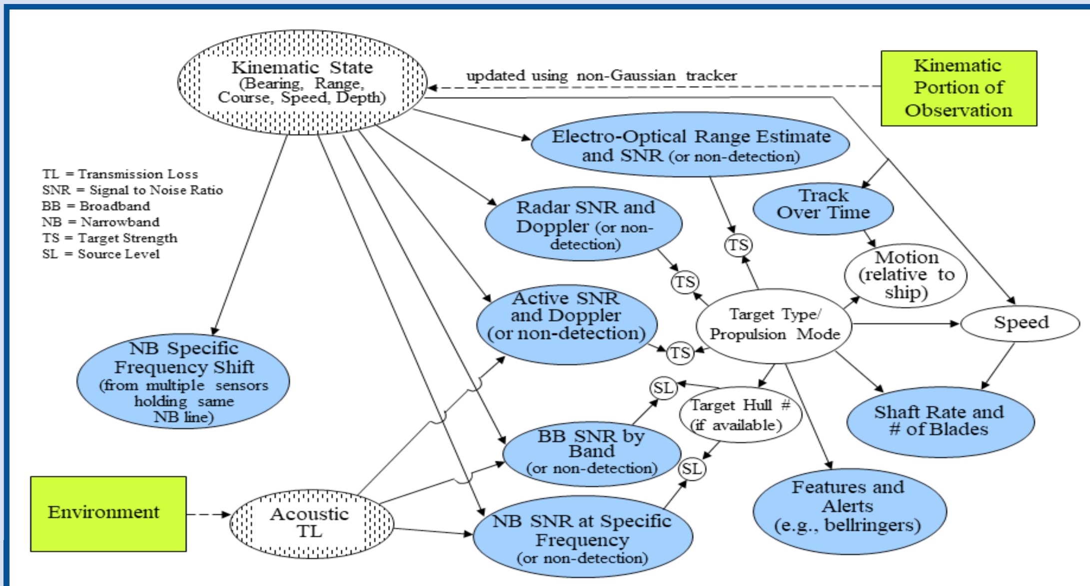
Anti-Torpedo Data Fusion and Optimization Systems (ATDOS)

(FOR ONR AND NAVSEA PMS-415)



Real-Time Alerts on All Five Weapons in Large Salvo

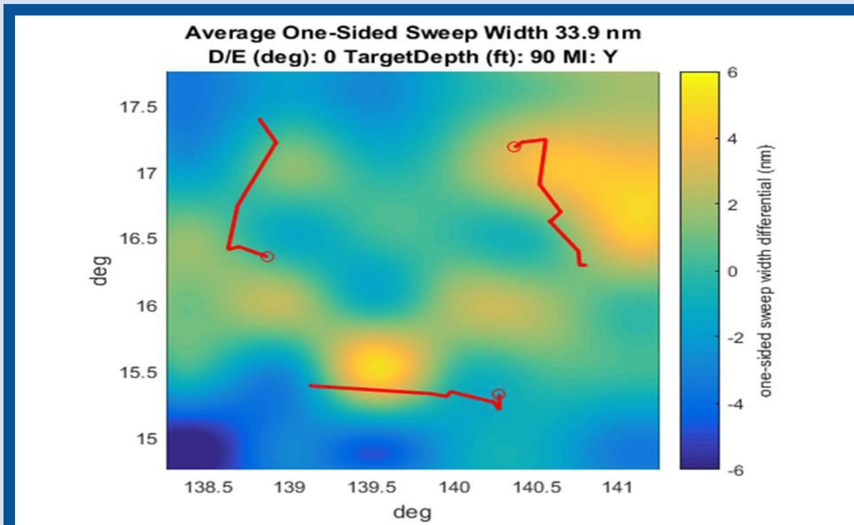
- Prototype system for fusing all available data concerning anti-torpedo defense
- Bayesian inferential reasoning for classifying targets and generating alerts
- Multiple hypothesis association and Gaussian sum and non-Gaussian tracking techniques
- Non-Gaussian optimization module for scheduling the use of active sensors to detect incoming torpedoes
- Very successful at-sea demonstration in January 2008
- Successfully processed data from several other sea tests



Bayesian Inference Engine (BIE) Notional Bayesian Network (BN) for Torpedo Defense and Anti-Submarine Data Association and Target Classification

Automated Active Sonar Interference Avoidance Algorithms (ASIA)

(FOR NAVSEA PEO IWS 5E)



Automatic Generation of Optimal Plan that Increases Cumulative Detection Probability (CDP) from 67% to 78%, due to Mitigation of Active Sonar Mutual Interference (MI).

Technology Developed:

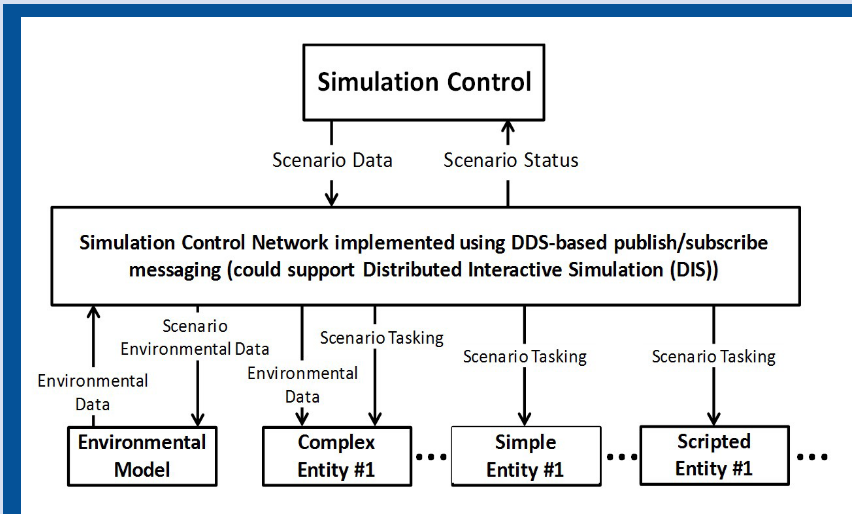
Active Sonar Interference Avoidance Plan (ASIAP) modules that optimally mitigate active interference among ship-based active sensors by automating and recommending search routes for ASW search and screening missions.

Warfighter Value:

1. Significantly more effective active sonar combined performance using optimal ASW search routes and screening patterns resulting in MI mitigation.
2. Higher probability of defeating threat submarines.
3. Reduced vulnerability of friendly forces to threat submarines
4. Reduced operator time-on-task and improved operator performance.

Detailed ASV/USV Modeling and Simulation System (DAMS)

(FOR ONR/NAVSEA PMS406)



Data and Process Flow for Detailed ASV/USV Modeling and Simulation System (DAMS)

Technology Developed:

1. Simulate an entire environment using an intuitive user interface.

2. Execute a complex scenario with all relevant information visualized in a browser.

3. Provide easily composed intelligent threat, friendly, and neutral entities including distributed data fusion to create accurate Common Operational Picture (COP) in Denied/Disconnected, Intermittent, and/or Low Bandwidth (D/DIL) communications environment.

4. Provide militarily effective Situational Awareness (SA) picture (e.g., quality of GPS, quality of off-board data, potential surprises, communication network status, accurate target location, capabilities and intent estimation).

5. Support evaluation of operationally relevant metrics.

Warfighter Value:

1. Cost-effective multiple vehicle systems of systems design and development.

2. Cost-effective multiple vehicle systems of systems testing.

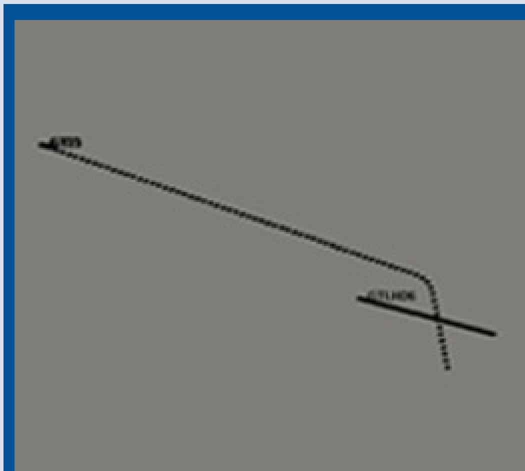
3. Cost-effective training with multiple vehicles.

4. Cost-effective multiple vehicle tactics development.

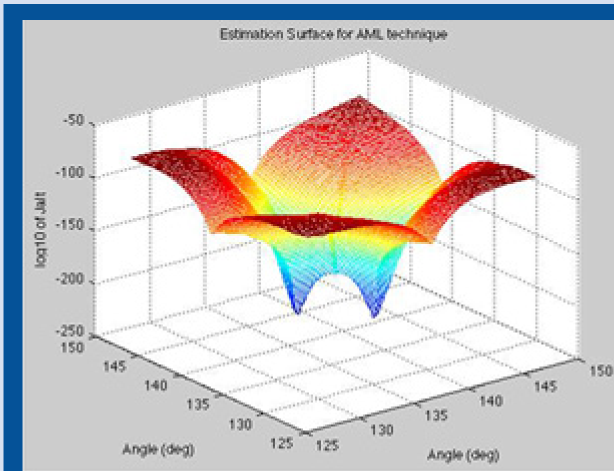
5. Cost-effective “operator or autonomous control system assistant” on vehicle.

Improved End-Fire Tracking Algorithms (IETA)

(FOR NAVSEA PMS415)



Sample Scenario

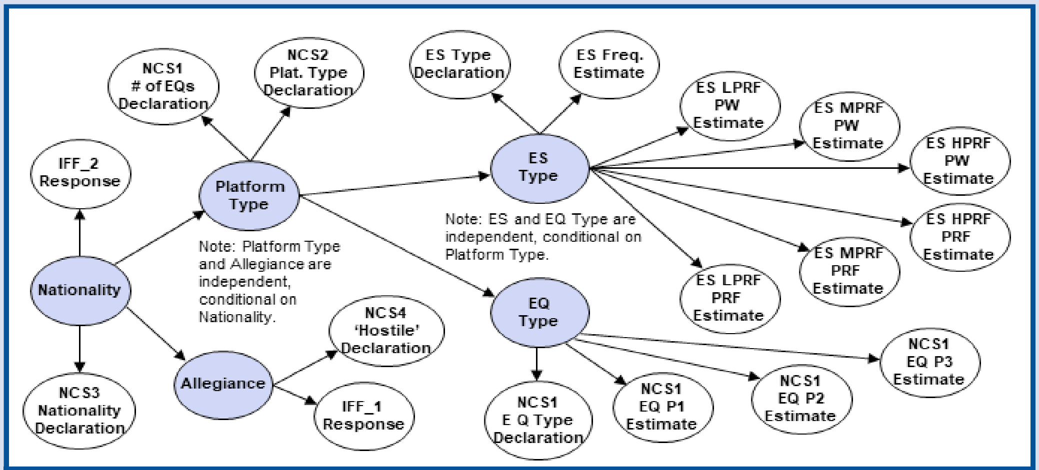


Asymptotic Maximum Likelihood Objective Fusion
(2 Torpedoes in End-Fire)

- Resolves torpedo and other acoustic targets in end-fire
- Automatically generates an accurate and operationally relevant passive acoustic Situational Awareness (SA) picture (including target classification estimates)
- Has successfully processed both simulated and real-world passive acoustic detections of torpedoes
- Accurately estimates target range using only passive acoustic data

Combat Air Identification Fusion Algorithm (CAIFA)/Composite Combat Identification (CCID) Reasoning Algorithm

(FOR ONR)



Combat Air Identification Fusion Algorithm (CAIFA)/ Composite Combat Identification (CCID) Reasoning Algorithm Bayesian Network

- Creates and maintains an accurate air picture through the fundamental objective of Composite Combat Identification (CCID) by providing common, theater-wide identification
- Resides within a GFE testbed that simulates the Cooperative Engagement Capability (CEC) and JTIDS networks as the basis for distributing Combat ID attribute and declaration information
- Improved Combat ID is obtained by fusing various ID attributes from single platform sources and sensors in a distributed network environment
- Core of the inferential reasoning engine used to estimate target ID is a context dependent Bayesian Network
- Uses sophisticated, tunable, robust methods for translating different forms of data uncertainty (e.g. confusion matrices, confidence values, parameter estimates) into a form usable in the Bayesian Network

Feature Aided Association Module (FAAM)

(FOR U.S. ARMY SPACE AND MISSILE DEFENSE COMMAND)

BEFORE

Based solely on kinematics, the ELINT detection shown in green (friendly emitter) incorrectly has its highest likelihood association with the nearest air track, D3, prior to D3 entering the Cyan Friendly Keep Out Zone.

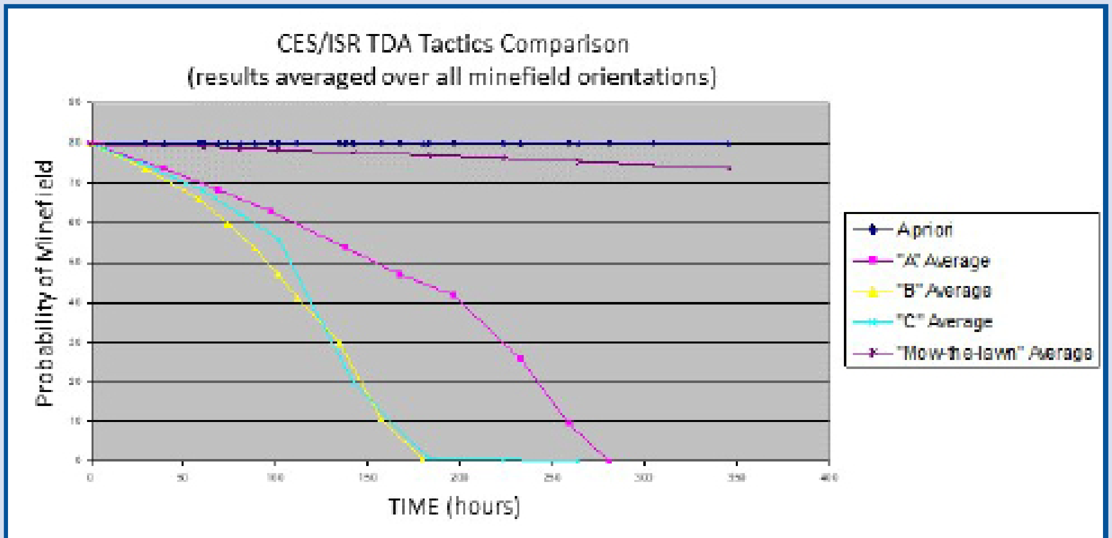
- Stand-Alone Software module for utilizing sensor kinematic and non-kinematic feature (i.e. attribute) data measurements to more accurately calculate a probabilistic ID estimate and measurement-to-track association likelihoods
- Probabilistic ID estimates are used to improve the data association step for tracking and fusion.
- Uses the taxonomy of air targets and the types of sensor measurements available for estimating the various features that characterize the targets
- Feature data includes ELINT parameters, IFF mode codes, Radar Cross Section, EO/IR parameters (size, shape, length), COMINT and other INTs
- Uses flight characteristics (Max Speed/Acceleration, Point of Origin, Friendly Keep Out Zones, Commercial Air Corridors)
- Capable of taking advantage of extensive knowledge base: Air Tasking Order, Friendly Keep Out Zones, Point of Origin, Flight Characteristics/Profile

AFTER

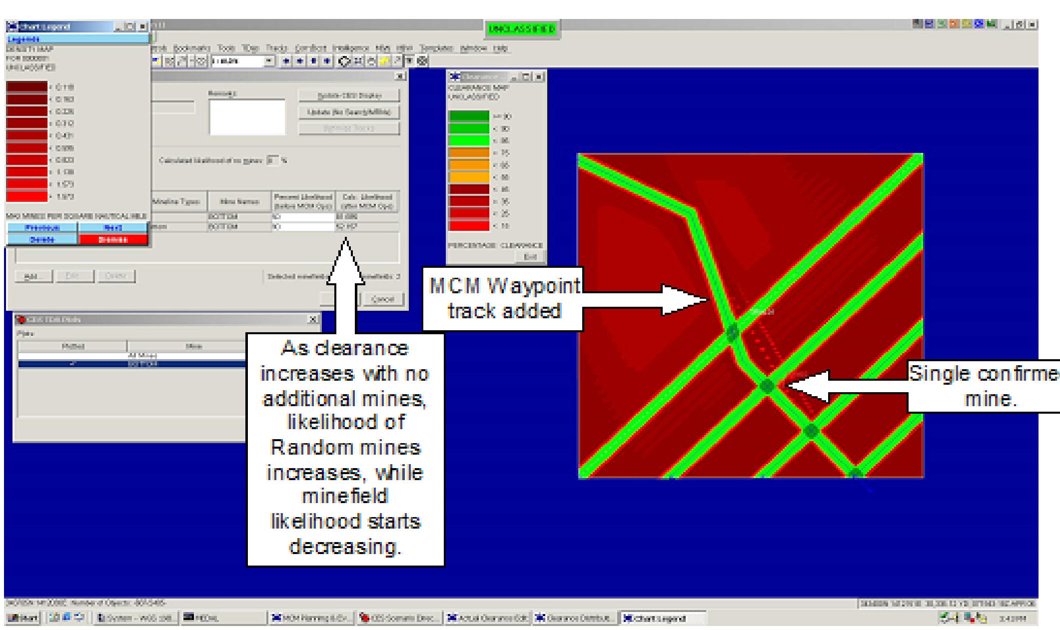
When track D3 enters a Friendly Keep Out Zone, this increases the probability that D3 is not friendly. Since D3 is probably not friendly, it also probably does not have a friendly radar, and thus FAAM updates the association probabilities. After this update, the friendly emitter has its highest likelihood association with D1, and so D1 becomes Friendly and track D3, becomes Assumed Hostile.

Commander’s Estimate of the Situation/Intelligence, Surveillance, and Reconnaissance Tactical Decision Aid (CES/ISR TDA)

(FOR ONR AND NAVSEA PMS-495)



CES/ISR TDA Tactics Comparison (results averaged over all minefield orientations)

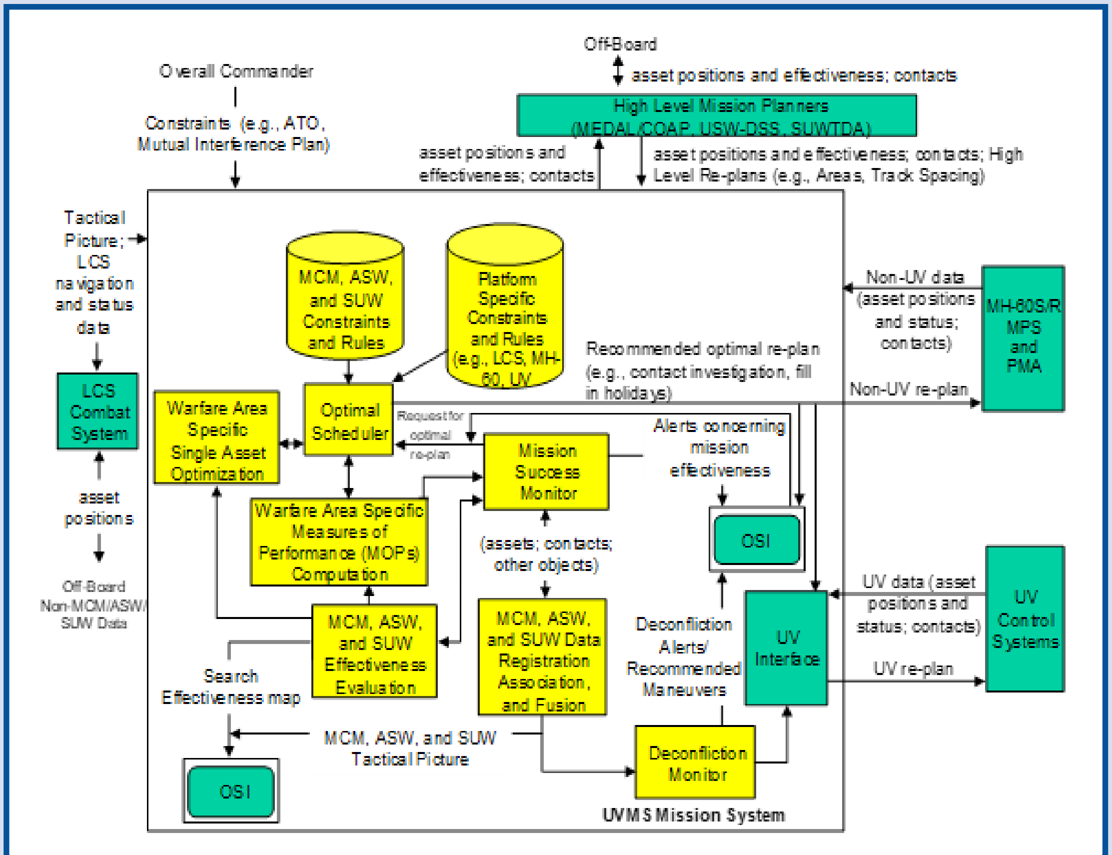


Search Effectiveness and Mine Density Plot Including Transit of Opportunity

- Utilizes all available intelligence, environmental, and system performance data in order to optimize and more accurately evaluate Mine Countermeasures (MCM) operations
- Level 2 (situational awareness) data fusion system designed to significantly improve mine warfare situational awareness within the maritime littoral region
- Creates hypothetical scenarios of the state of the threat, including patterns, placement, and types of mines
- Evaluates the mine warfare situation using information from Intelligence, Surveillance, and Reconnaissance (ISR) and other MCM operations
- Can be used to determine how best to utilize available MIW ISR assets to improve the situational awareness of MIW planners and operators
- Allows MIW planners and operators to:
  - develop more effective ISR plans
  - more accurately evaluate the effectiveness of ISR operations
  - more accurately evaluate the threat to shipping from mines that may be in a maritime littoral region of interest

Multi-Vehicle Mission Planner (MVMP)

(FOR NSWC-PC AND NAVSEA PMS-420)



Full Scale Unmanned Vehicle Management System (UVMS)/ Multi-Vehicle Mission Planner (MVMP) Data/Process Flow

- Optimally allocates Unmanned Vehicle (UV) assets in a typical Littoral Combat Ship (LCS) mission scenario
- Demonstration MVMP optimally allocates Unmanned Underwater Vehicles (UUVs) such as the Remote Environmental Monitoring Unit System (REMUS) or the Battlespace Preparation Autonomous Underwater Vehicle (BPAUV), Unmanned Surface Vehicles (USVs), such as the Remote Minehunting System (RMS) and Spartan Scout, and Unmanned Aerial Vehicles (UAVs), such as Fire Scout
- Could significantly improve the Navy's ability to utilize UVs for missions such as mine warfare (MIW), Anti-Submarine Warfare (ASW), and Surface Warfare (SUW) within the maritime littoral region
- Key to MVMP success is its ability to optimize assets within real-world operational constraints
- MVMP will be implemented as a Joint Architecture for Unmanned Systems (JAUS) and STANAG 4586-compliant component, pass information to individual UV control systems, and interface with existing high-level planning systems

Tactical Environmental Effects for Precision Guided Missiles (METPLAN)

(FOR NAVAIR)

METPLAN responds to user preferences for weather data, updates

METPLAN generates a color overlay of weather conditions on the planned route

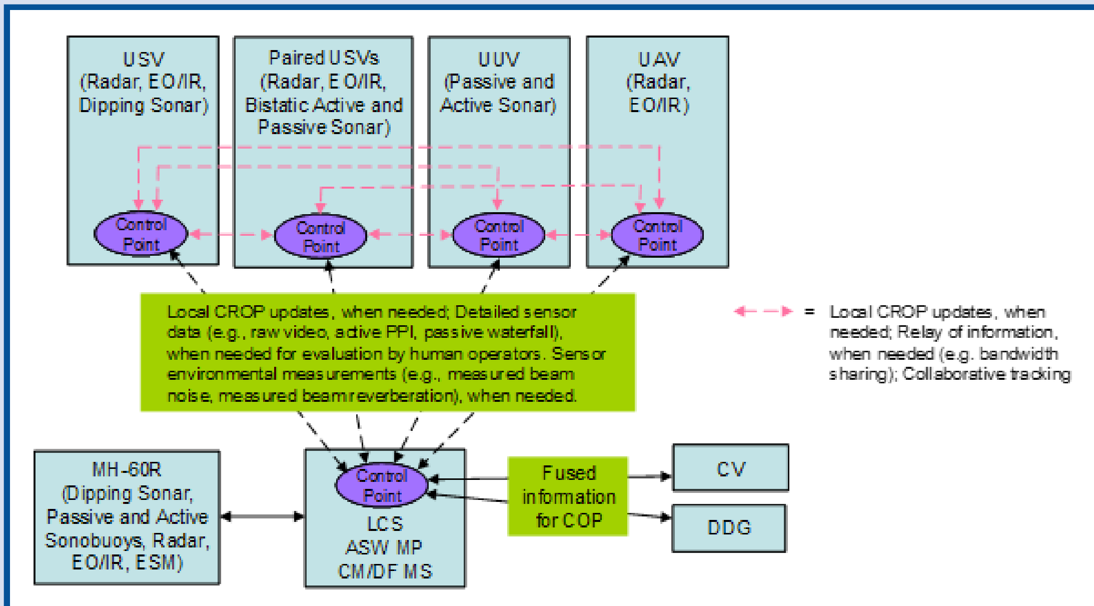
- Agent-based decision aid designed to increase the effectiveness of PGMs by automatically integrating environmental data, obtained from weather forecasts, aircraft-sensed weather conditions, and remote sensors, with weapon-specific and mission-specific environmental effects; and then using this data in the mission planning process
  - Determines the effects of various weather elements on missile and sensor performance
  - Automatically accesses best available weather data

- Benefits are more precise targeting, better "Go/No Go" decisions, and more effective use of precision stand-off weapons

- Applicable to all precision weapon employment

Network Monitoring and Management System (NMMS)

(FOR NAVSEA PMS-420)

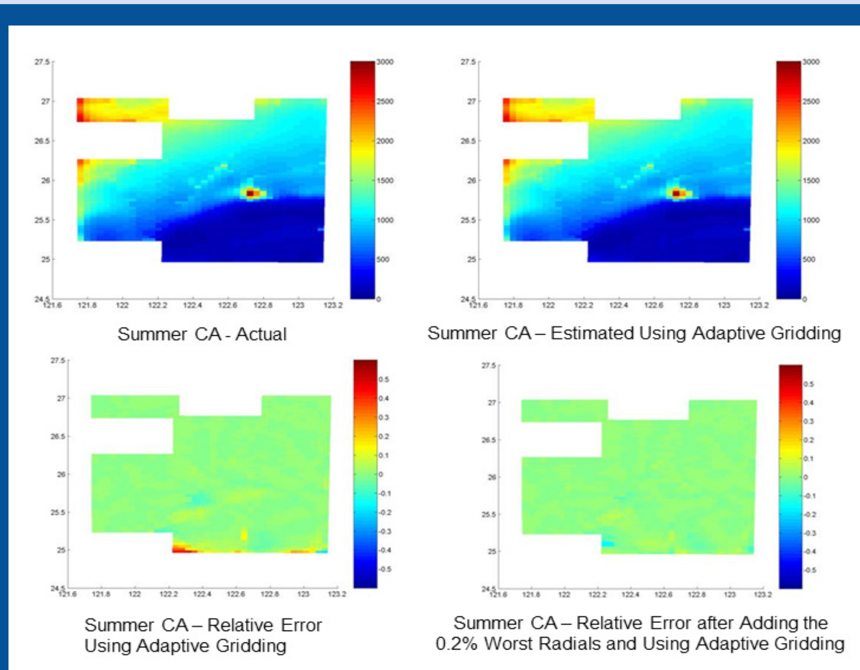


Network Monitoring and Management System (NMMS) Architecture

- Provides automated monitoring and control of federated sensors using a peer-to-peer (P2P) network
- Real-time monitoring of network performance, enabling optimization of communications bandwidth for all types of Unmanned Vehicles (UVs) with the Littoral Combat Ship (LCS)
- Automatic detection of network failure
- Automatic reconfiguration of remote links
- Context-sensitive recommendations/cueing for control of the devices on the network and use of bandwidth (e.g., any peer on the network can receive information/alerts from any other peer (configurable based on operational context); guided by mission priorities/commander's intent)

Adaptive Gridding

(FOR SPAWAR PMW-120)

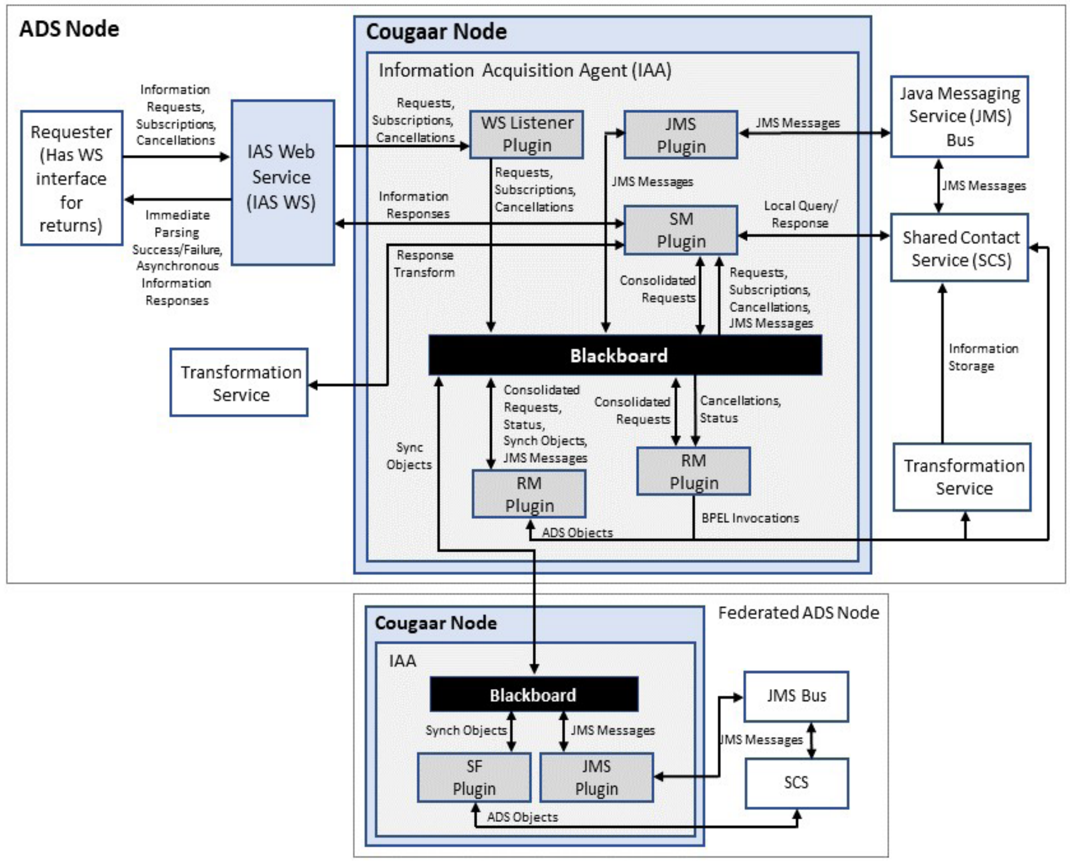


Example of Adaptive Gridding Effectiveness in the East China Sea.
Note: Coverage Area is defined as the area around a particular grid point with Signal Excess (SE) > 0.
Note: (Estimated CA – Actual CA)/Actual CA=Relative CA Difference.
Note: Initial Estimates generated with 3.8% of total number of radials.

- Developed algorithms for estimating Transmission Loss (TL) curves based on a small training set (~5%) of the total number of TL curves being used in search effectiveness calculations
  - initially focused on Anti-Submarine Warfare search planning
  - generates accurate TL data in a large operational area in hours (not days)
- Training set is generated using a Navy standard TL engine such as the Scalable Tactical Acoustic Propagation Loss Engine (STAPLE)

Decision Support for Dynamic Target Engagement (DS DTE)

(FOR ONR THROUGH SUBCONTRACT WITH SOLERS, INC.)



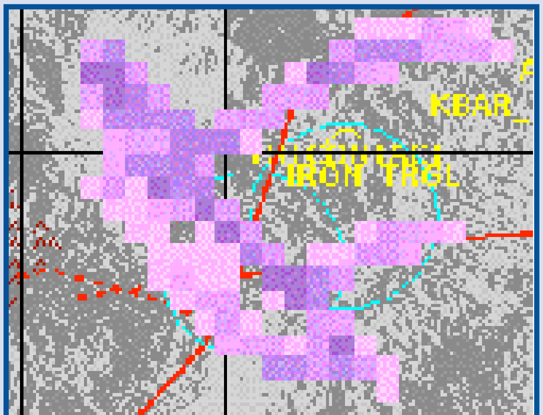
Decision Support for Dynamic Target Engagement (DS DTE) Information Acquisition Service Agent Architecture

- DS DTE is an agent-based decision support architecture for time-critical net-centric operations
- DS DTE uses Wagner's Information Acquisition Service (IAS), a peer-to-peer application distributed across the enterprise (in our initial implementation, across the strike group)
- IAS provides information flow optimization for high-volume requests/responses over limited bandwidth, including consolidation of redundant requests, invocation of the appropriate Information Processes (IPs) to access remote data sources, transformation services to provide information to requesters in appropriate formats, and synchronization of process state and information across distributed nodes
- IAS is built on the Cognitive Agent Architecture (Cougaar), a high-performance architecture developed for DARPA
- IAS is highly configurable, using JBoss Rules for information consolidation and Cougaar societies/communities for peer discovery and communications

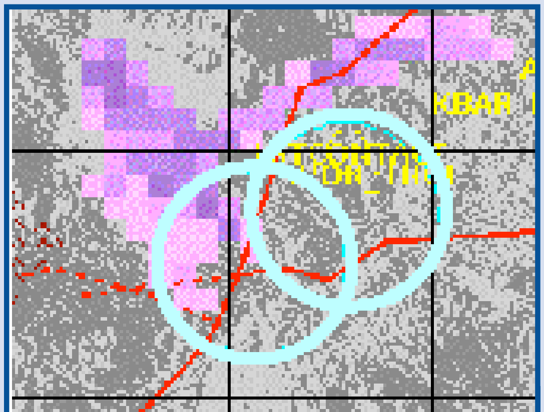
SYSTEMS UNDER DEVELOPMENT

Ground Target Tracking and Identification System (GTIS)

(FOR AFRL/IFEA)



The first map shows one target with multiple possible paths. This is taken from an actual National Training Center (NTC) scenario.



In the second map, the model has included the probability effects from two searches that did ot detect the target of interest (circles), showing that the most likely path of this unit is to the north.

- Fuses all available data using Bayesian inferential reasoning, multiple hypothesis association, and non-Gaussian tracking techniques
- Able to process data from large numbers of diverse Ground Moving Target Indicator (GMTI), Signals Intelligence (SIGINT), Imagery Intelligence (IMINT), Measurement and Signature Intelligence (MASINT), and Human Intelligence (HUMINT) sensors and sources
- Feasibility and effectiveness have been demonstrated using simulated data obtained from AFRL and CECOM
- Produces an accurate and complete situational awareness (SA) picture, easily used and interpreted at all command levels, that includes estimates of the past, current, and future locations of targets of interest and estimates concerning their classification/ID/intentions
- Especially important in urban, mountainous, and forested areas, where contact on the targets, even with a large number of sensors, will be intermittent

CUSTOMERS

Government (DoD)

- Office of Naval Research (ONR)
- Defense Advanced Research Projects Agency (DARPA)
- Office of the Secretary of Defense (OSD)
- Naval Sea Systems Command (NAVSEA)
- Naval Surface Warfare Center - Carderock Division (NSWCCD)
- Naval Surface Warfare Center – Dahlgren Division (NSWCDD)
- Naval Surface Warfare Center – Panama City (NSWCPCD)
- Naval Undersea Warfare Center – Newport Division (NUWCNPT)
- Naval Undersea Warfare Center - Keyport Division (NUWCKPT)
- Naval Air Systems Command (NAVAIR)
- Naval Air Warfare Center (NWAC)
- Space and Naval Warfare Systems Command (SPAWAR)
- Missile Defense Agency (MDA)
- Air Force Research Laboratory – Rome (AFRL-Rome)
- Air Force Research Laboratory – Wright Patterson (AFRL-Wright Patterson)
- Hanscom Air Force Base – Electronic Systems Center (ESC)
- Army Research Lab (ARL)
- Army Communications Electronics Command (CECOM)

Government (non-DoD)

- National Aeronautics and Space Administration (NASA)
- Department of Homeland Security (U.S. Coast Guard, Border Patrol) (DHS)
- Department of the Interior (DOI)
- Department of Justice (DOJ)
- Department of the Treasury (DOT)
- National Science Foundation (NSF)
- National Institute of Health (NIH)
- Department of Energy (DOE)

Commercial Defense

- Lockheed Martin
- Raytheon
- Northrop Grumman
- SAIC
- Boeing
- Textron
- John Hopkins University Applied Physics Laboratory (JHU/APL)
- NASA Jet Propulsion Laboratory (JPL)
- Pennsylvania State University Applied Research Laboratory (PSU/ARL)
- University of Texas Applied Research Laboratory (ARL-UT)
- Lincoln Labs
- Institute for Defense Analysis (IDA)
- University of Michigan
- George Mason University
- L3Harris Adaptive Methods
- Spatial Integrated Systems
- Global Technical Systems
- Oceaneering Technologies

Biotech

- Smith Kline Beechman
- Molecular Dynamics
- FinniganMAT
- Incyte Pharmaceuticals
- Stanford DNA Sequencing & Technology Center
- Applied Biosystems
- DNAX
- Affymetrics

Financial

- Charles Schwab
- Bank of America
- Morgan Guaranty
- Rumson Capital Management
- Deutsche Bank Securities
- Susquehanna Investment Group
- KPMG Peat Marwick
- California Federal Bank
- Glendale Federal Bank
- Huntington Advisors
- First Union National Bank
- VW Credit
- BMW

Other

- Virginia International Terminals
- Philips ARCO
- Technology Data Corporation
- Southeastern Pennsylvania Transportation Authority (SEPTA)
- Children's Hospital of Pennsylvania
- Lower Churchill Development Corporation
- Alamo Rent-A-Car
- Rockwell Automation

MANAGEMENT TEAM

Dr. C. Allen Butler, President, located at our Hampton office, joined the firm in 1987 and holds a Ph.D. in functional analysis/optimization.

Dr. Scott S. Brown, Vice President and Manager of the Exton division, joined the firm in 1976 and holds a Ph.D. in logic from Princeton University. The Exton division has a technical staff of five. four with Ph.D.'s in the mathematical sciences.

Dr. Reynolds Monach, Vice President and Manager of the Hampton division, joined the firm in 1980 and holds a Ph.D. in number theory from the University of Michigan. The Hampton division's technical staff consists of 22 employees with expertise in the areas of mathematics, statistics, and computer science, seven of whom hold Ph.D.'s in the mathematical sciences.

CORE ADVANTAGE

As a company and as individuals, Wagner Associates has received widespread recognition for outstanding contributions to both government and private industry. Wagner Associates invented (starting in 1972 with the CASP Search and Rescue system) and has continued to further develop the field of computer assisted search (CAS). These CAS systems use highly sophisticated mathematical algorithms to evaluate and optimize the effectiveness of Anti-Submarine Warfare (ASW), Surface Warfare (SUW), Air Warfare (AW), and Mine Countermeasures (MCM) and Search and Rescue (SAR) operations. In particular, the Navy has used these systems very effectively in real-world and exercise operations. These CAS systems were the first implementations of what are now known as "particle filters". Wagner Associates was also the originator of the IOU Kalman Filter (aka Maneuvering Target Statistical Tracker (MTST)), which has been utilized in many DoD systems such as the Global Command and Control System (GCCS) and the Tomahawk Weapon Control System (TWCS).

PERSONNEL

Wagner's 27 technical staff members have extensive domain and operational expertise in mathematical and other scientific disciplines. Twelve hold PhD's in the mathematical sciences and 8 hold Masters degrees. We have an experienced workforce with three quarters having five or more years of experience and one quarter having over 20 years of experience.

FACILITIES

All Wagner offices are cleared facilities and have state-of-the-art computer systems.

AWARDS

The DoD has repeatedly recognized the high quality of our work and the outstanding contributions of our staff to DoD projects.

- Navy's Distinguished Public Service Award
- Navy's Meritorious Public Service Citation
- Lanchester Prize of the Operations Research Society
- Rist Prize of the Military Operations Research Society
- 1999 National Tibbetts Award (Outstanding Contributions to SBIR Program)
- 1997 Army SBIR Quality Award