Request for Quote
Search and Rescue Optimal Planning System (SAROPS)

1.0 BACKGROUND

The U. S. Coast Guard must plan searches for lost, missing, or distressed craft and persons in the marine environment. In those situations where searching is required, the search planner is faced with many factors whose values are not precisely known. Different combinations of these will produce different estimates of where and when the distress incident occurred and where the survivors are more and less likely to be when search and rescue units (SRUs) can arrive on scene. The number of factors about which some uncertainty exists makes planning a search a complex and arduous task.

Currently the Coast Guard employs two search planning decision support software tools—Computer Assisted Search Planning (CASP) and Joint Automated Work Sheets (JAWS). The former is based on early 1970s technology while the latter is based on even earlier 1950s paper-and-pencil technology. CASP is a limited Monte Carlo ("particle filter") model while JAWS is an automated version of earlier analytic manual methods. CASP is currently written in FORTRAN 77 (upgraded to FORTRAN 90) and hosted on Hewlett Packard HP 9000, L-2000 series servers with the HP-UX version 11.0 operating system. JAWS is written in C and runs in client-server mode on USCG LANs. Even though a computer with geographic information system (GIS) and graphical user interface (GUI) capabilities is used as a "front end" for both, the underlying methods, techniques, and algorithms that actually produce the displayed results are seriously out of date and severely limited in light of what is now possible at reasonable cost.

2.0 SCOPE

Significant advances have been made on several fronts since the basic methods for computing search planning solutions used in CASP and JAWS were updated. These include advances in search theory and optimal effort allocation algorithms, the quality and resolution of available environmental data products, and computer technology. The Coast Guard requires a single search planning decision support software tool that takes advantage of these advances.

The purpose of this project is to design and develop a basic but technologically current software tool that supports the search planning process. This basic tool will serve as a foundation for more advanced features that will be developed through a program of continuous improvement. Although some existing USCG SAR software may already possess capabilities similar to those required for this project, it is anticipated that no significant re-use of existing software elements, modules or algorithms will be feasible. This does not rule out the use of specific existing algorithms and tools into SAROPS when a significant savings can be realized and when the existing algorithm/tool can be shown to be correct. However, such opportunities are expected to be the exception rather than the rule.

The deliverable from this task should be new software that specifically addresses the Coast Guard's maritime search problem while not precluding later enhancements at reasonable cost to facilitate planning searches for survivors missing on land. The final deliverable from this task shall be a fully operational search planning tool that will pass the USCG software certification requirements for installation and operation on USCG equipment and networks.

The first step in defining the requirements of a search planning tool is understanding the problem that the tool is supposed to help the planner solve. Like most problems, a thorough understanding requires that it be viewed from several perspectives and levels of detail. One of these perspectives is a "process view." At a high level of abstraction, the search planning process consists of the following steps:

1) Create a Case when Alerted.
2) Gather Data, estimate associated uncertainties, and enter them into the Case folder or database (investigation). Revise as needed.
3) Enter Assumptions and associated uncertainties about needed but unavailable data elements into the Case folder or database. Revise as needed.
4) Analyze the Data and Assumptions from steps 2) and 3) to Define and Weight Scenarios. Review frequently and Revise as needed.
5) Estimate "initial" Probability Density Distribution(s) (PDD) based on Scenario definitions. Re-compute as needed based on revisions in previous steps. (Note: Pre-distress Motion, interaction with Hazards, initial (distress incident) State transitions, etc., should be included in the "initial" PDD estimation process.)
6) Estimate PDD for next search (based on "initial" PDDs from Scenarios, post-distress Motion (drift), probable post-incident State changes, previous Searching, etc.) This may require re-evaluating all activity to date, depending on revisions, if any, to data from previous steps. Often steps 2) – 4) will provide sufficient information the first time and will not be significantly revised in ways that affect the remaining steps as the search progresses. In other cases, proper revision of the "initial conditions" may be crucial. The "Review" process of step 4) is vital and necessary to prevent the condition known as "scenario lock" where the search planner pursues one scenario to the exclusion of others that are also plausible.
7) Estimate resource availability and capability (available Effort) for the next search.
8) Plan the next Search (usually an Optimal Survivor Search (OSS) is desired).
9) Promulgate the Search Plan.
10) Perform the Search Plan.
11) Evaluate the completed Search based on actual search activity and search conditions.
12) Repeat steps 2) – 11) until all Survivors are found and rescued or until active search is suspended pending further developments.
13) Close or "suspend" the Case, record, report and save all pertinent data.

The desired approach is that of using Monte Carlo ("particle filter") sampling methods to account for the uncertainties in the data and algorithms and produce probability density distributions on search object location over time. SAROPS must then develop a recommended near-optimal search plan that maximizes the probability of success subject to the constraint on available effort. "Success" is defined as locating survivors while it is still possible to recover them alive and transport them to a place of safety where they can receive any necessary medical attention. If the first search efforts fail, SAROPS must properly account for all previous searching when recommending the next near-optimal search plan. Recommended search plans must be operationally feasible in that SRUs must be able to perform them.

3.0 SYSTEM REQUIREMENTS

SAROPS is to be a search planning and decision support tool that will aid search planners in making the best use of limited search resources. The methods used by SAROPS are to be firmly rooted in scientific search theory. The approach to applying search theory to the search planning problem is to be a Monte Carlo (also known as "particle filter") simulation technique. In the most general case, the simulation must begin with a normal uneventful voyage, flight or trip as a basis. It must then simulate, based on parameters entered by the search planner and information obtained from various databases (e.g., weather data), distress incidents and their outcomes in terms of the search objects that may be a result of the distress incident. The times and places of distress incidents must be consistent with the voyage/flight/trip information. The software must then simulate the post-distress motion (e.g., oceanic drift) of the search objects spawned by the distress incident. A key feature of the simulation will be the ability to provide a near-optimal search plan for applying the available search resources in a way that maximizes the probability of successfully locating the search object(s). Another key feature will be the ability to properly account for the effects of previous unsuccessful searching when recommending subsequent search plans.

3.1 Outline

This section outlines the features and functions proposed for incorporation into this task's deliverable (Build 1) of the USCG's new Search and Rescue Optimal Planning System (SAROPS) for planning optimal searches for distressed persons and craft. Some additional features are already identified for inclusion in subsequent builds and are tentatively marked for Build 2. Implementations of Build 2 items are outside the scope of this task for the purposes of responding to this RFQ, but arranging for their subsequent inclusion at reasonable additional cost is within scope. SAROPS is designed to replace the present Computer Assisted Search Planning (CASP) and Joint Automated Work Sheet (JAWS) systems with a single unified system that addresses the requirements (and deficiencies) detailed in references [1] and [2]. More complete functional descriptions may be found in reference [2]. The remaining references contain background information essential to the successful development of software to support SAR search planning. The references listed in the appendices to reference [2] contain a wealth of information on algorithms, simulation techniques and other technical matters of importance to this effort. The remaining paragraphs in this section contain additional, but not exhaustive, amplifying information.

1. Architecture
    1.1. Three major subsystems

1.1.1. User Interface (GIS/GUI)
1.1.2. Environmental Data Retrieval
1.1.3. Search Planning Simulator
1.2. Hardware
1.2.1. USCG Standard Work Stations at user sites (Windows XP)
1.2.2. USCG Standard LAN Servers
1.2.3. USCG minicomputer/high-end server located at OSC
1.3. Network Architecture
1.3.1. Client/Server
1.3.2. Case database for SAROPS on LAN/WAN server
1.3.3. General SAR database (search objects with leeway, parameters, SRU types with endurance, sensor, etc. capabilities, sweep width tables, etc.)
1.3.4. Limited environmental data on LAN/WAN server
1.3.5. Main environmental database on central server at OSC accessed via CGDN+

2. Graphical User Interface (GUI)/Geographic Information System (GIS)
2.1. Wizard based interface
2.2. Minimize keystrokes
2.2.1. No manual environmental data entry required – use data on server (local or centralized)
2.2.2. Full-featured GIS/GUI suitable for use in high-pressure fast-moving atmosphere of a USCG command center with features/capabilities of particular interest to SAR search planning
2.2.3. Ability to predict preliminary search area for any U.S. waters within 5 minutes
2.2.4. Easy navigation among search planning activities
2.2.5. Ability to set vessel/aircraft waypoints (trip-builder) to link to distress events
2.2.6. Automatically perform most/all bookkeeping activities for effective use of SAROPS
2.2.7. Provide Integrated Situation Display (GIS/Chart/Environmental Data/Search Areas/SRU Assignments)
2.2.8. Two-way data exchange with MISLE, Rescue 21 (loosely coupled)
2.3. Chart support- NOAA based (vector/raster)
2.4. Deployment using ESRI® GIS mapping engine
2.5. Display Environmental Data
2.5.1. Provide visualization of environmental database contents
2.5.2. Provide visualization of derived environmental data (e.g., tidal currents derived from NOAA tables)
2.5.3. Provide visualization of near-real-time data from deployed sources (e.g., SLDMBs)
2.6. Animated Display Capabilities
2.7. Display recommended search plans/areas/patterns
2.7.1. Allow user to easily modify on screen using graphics tools
2.7.2. Support all standard search patterns in *IAMSAR*, *NSS, USCG Addendum*
2.7.3. Provide feedback on impact of modifications (e.g., POS changes)
2.7.4. Put in standard form(s) for transmission to SRUs
2.7.5. Ability to select from static SRU database (i.e., select SRU type from location).
2.7.6. Deploy SRUs by simple drag and drop techniques

- 2.7.7. SRU deployment screening tools for fast optimal assignment analysis
- 2.8. Display probability maps
  - 2.8.1. Allow display options by
    - 2.8.1.1. Scenario
    - 2.8.1.2. Search Object Type
    - 2.8.1.3. Other states (e.g., underway vs. adrift, etc.)
- 2.9. Reporting
  - 2.9.1. Comprehensive reporting system
  - 2.9.2. Web-based html reports for automatic web server distribution
  - 2.9.3. Reports to MISLE

3. Environmental Data Retrieval Subsystem
   - 3.1. Databases structured for model's use
     - 3.1.1. Near-shore and off-shore
     - 3.1.2. Water Currents
     - 3.1.3. Wind
     - 3.1.4. Manual data entry for single/multiple point sources. User-supplied data optional, but goal is to provide best available data automatically. System will scan USCG databases automatically for best available near-real-time/forecast data for the region. Minimum or no need for manual environmental data entry.
     - *3.1.5. Allow for expansion to automatically look for and obtain data from other sources via internet and restructure as necessary for model's use. (Build 2)*
     - *3.1.6. Other types of environmental data (Build 2)*
     - 3.1.7. Blend data elements near boundaries between data sets to produce realistic results
   - 3.2. Water Current Data
     - 3.2.1. Ability to accommodate regular and irregular spatial/temporal grids
     - 3.2.2. Automatic linkage to FNMOC national global/regional model data at OSC
     - *3.2.3. Automatic linkage to other regional/coastal model data (e.g., NOAA Great Lakes Environmental Research Lab) (Build 2)*
     - 3.2.4. Use of non-gridded data (e.g., SLDMBs, NOAA tides) to form gridded data sets
     - *3.2.5. Automatic links to near-real-time data (CODAR, PORTS, CO-OPS, USGS, NDBC) (Build 2)*
     - 3.2.6. Total Water Current includes:
       - 3.2.6.1. Sea current (geostrophic)
       - 3.2.6.2. Tidal current
       - 3.2.6.3. Local wind driven current
       - 3.2.6.4. Other currents (e.g. major river outflow)
   - 3.3. Wind Data
     - 3.3.1. Automatic linkage to FNMOC global wind data at OSC
     - *3.3.2. Automatic linkage to NOAA/NOS Spatial Wind Analysis/Forecasts (Build 2)*
     - *3.3.3. Automatic linkage to regional mesoscale wind model data (Build 2)*
   - 3.4. Other environmental factors (gridded products if available, obtain from user if not)
     - 3.4.1. Visibility
     - 3.4.2. Cloud Cover/Ceiling
     - 3.4.3. Sea State/Wave Height
     - 3.4.4. Air Temperature *(vs. altitude in Build 2 or later)*
     - 3.4.5. Wind chill factor

3.4.6. Sea Surface Temperature
3.5. Accommodate various scales/resolutions automatically
3.5.1. Global
3.5.2. Regional
3.5.3. Local
3.6. Global Land Database
3.7. Expansion of environmental data products (e.g., sea state, air and water temperatures) and uses (e.g., survival model) (Build 2 and beyond)

4. Search Planning Simulator

4.1. Local database for storing and retrieving data related to the case and storing parameters used by SAROPS (search object types with leeway coefficients, SRU types with endurance, sensors, etc., sweep width tables, etc.)
4.2. Monte Carlo ("particle filter") event-driven simulation
4.2.1. Simulation clock resolves time to nearest whole second
4.2.2. Model pre- and post-distress motion
4.2.3. Maintain proper relationships among events in both space and time
4.2.3.1. Non-distress events
4.2.3.2. Distress events
4.2.3.3. Search events
4.2.3.4. Other State Transition events
4.2.4. Information used to generate positions, times, environmental data, etc. include both means and uncertainty distributions that will be sampled in Monte Carlo fashion.
4.2.5. Re-generate search object probability density distributions if/as needed
4.2.6. Provide portable system-independent pseudo-random number generation that passes tests for randomness, lack of dimensional correlations, etc.
4.2.7. Allow "fast" (fewer particles) and "comprehensive" (more particles) solution option
4.2.8. Allow for cases in marine, terrestrial (stationary object), or both environments
4.2.9. Use appropriate mathematical and statistical algorithms, sampling techniques, modeling/simulation methods, etc.
4.3. Scenario Analysis/Generation (Maritime, Aeronautical, Terrestrial)
4.3.1. Pre-distress behavior model (location, time, motion based on intentions)
4.3.1.1. Voyage/flight/trip simulation (includes visits to positions and/or opareas) (*terrestrial motion model Build 2 or later*)
4.3.1.2. Position plus DR or offset
4.3.1.3. SARSAT/DASS position
4.3.1.4. Line(s) of Position (DF, Flare, LORAN, etc.)
4.3.1.5. Area (op area, area derived from multiple lines of position, etc.)
4.3.1.6. Positions and OpAreas may have "layover" or "dwell" times
4.3.1.7. Any combination of great circle and rhumb line routes ("Unknown" handled by two or more scenarios)
4.3.2. "Reverse Drift" – given an object's position/time (e.g., debris), estimate where/when it could have gone adrift
4.4. Object attributes/states/weights
4.4.1. Unique object identifier

4.4.2. Source scenario
4.4.3. Type of object
4.4.4. Weights
4.4.4.1. Initial weights (e.g., relative scenario weights)
4.4.4.2. Ability for user to modify weights at any time
4.4.5. Trajectory data
4.4.5.1. Initial position/time
4.4.5.2. Intermediate positions/times
4.4.5.3. Present (in simulated time) position/time
4.4.5.4. Present (in simulated time) course/speed
4.4.6. "Last analysis" time and complete state as of that time
4.4.7. Probability of non-detection (Pfail)
4.4.8. Object states (not all-inclusive)
4.4.8.1. Distressed or not-in-distress
4.4.8.2. Underway/airborne
4.4.8.3. Adrift
4.4.8.4. On/over land
4.4.8.5. Anchored
4.4.8.6. Aground
4.4.8.7. Remaining lifetime (viable if > 0, expired if <= 0)

4.5. State changes
4.5.1. From not in distress to distressed
4.5.2. From alive to expired
4.5.2.1. Default to infinite lifetime in Build 1 but allow simple time-based decay with uncertainty distribution to be added if desired
4.5.2.2. Incorporation/interface of/to Canadian Environmental Survival Model (Build 2)
4.5.2.3. Incorporation of other survival models (e.g., non-hypothermic) (Build 2)
4.5.3. Post-distress search object types (selected from database or user defined)
4.5.3.1. Motion characteristics (leeway, glide factors) by type – obtain from data base/user
4.5.3.2. Detection characteristics (factors affecting sweep width) by type – obtain from database/user
4.5.3.3. Relative transition probabilities by type – obtain from database/user
4.5.4. Hazards (agents for state change from not-in-distress to distressed)
4.5.4.1. General – distribution on time at which distress could have occurred
4.5.4.2. Fixed for some time interval (polygon or circle) (Build 2)
4.5.4.3. Moving on given trajectory at given speed(s) (polygon or circle) (Build 2)
4.5.4.4. Transition probabilities for craft/hazard encounters (allow for expansion to include exposure times) (Build 2)
4.5.4.5. Model diverting/other "behavioral" changes in motion resulting from encounters with or attempts to avoid hazards (Build 2)
4.5.4.6. Topography (e.g., mountains as hazards to flight) (Build 2 or later)

4.6. Motion modeling – Drift
4.6.1. Total water current
4.6.2. Leeway

- 4.6.3. Land recognition
  - 4.6.3.1. "Sticky" shore
  - 4.6.3.2. "Slippery" shore
- 4.6.4. Restore to "last analysis" state for drift updates

4.7. Search Evaluation

- 4.7.1. SRU tracks for assigned search patterns
  - 4.7.1.1. Accommodate all standard search patterns
  - 4.7.1.2. Accommodate Track Line search
  - 4.7.1.3. Estimate SRU tracks based on assigned pattern
  - *4.7.1.4. Allow automated entry of actual SRU tracks (e.g., download from GPS tracking device) when available (Build 2)*
  - *4.7.1.5. "Fit" standard patterns to search areas that are regular or irregular polygons (e.g., one or more sides of search area bounded by coast line/depth contour) (Build 2)*
- 4.7.2. Estimate effective sweep width values using tables and methods given in references [5], [6], and [7]
- 4.7.3. Use lateral range functions consistent with effective sweep width values from references [5], [6], and [7]
- 4.7.4. Account for simultaneous motion of object and search platform
- 4.7.5. Compute posterior Probability of Success (POS) and Cumulative Probability of Success (POS_{cum}) values
  - 4.7.5.1. Over all object types
  - 4.7.5.2. For each object type separately
  - 4.7.5.3. For each scenario separately
- 4.7.6. Update replication status (Pfail) based on computed CPAs with SRUs

4.8. Near-optimal Search Plan Recommendations

- 4.8.1. Myopic plans for multiple SRUs/rectangular areas and multiple target states
- 4.8.2. Compute and use appropriate POD vs. effort functions (e.g., inverse cube, exponential, "logodds," other) from corresponding lateral range functions
- 4.8.3. Use generic/static SRU database
- 4.8.4. Use myopic "snapshot" method initially for planning (but not evaluation)
- 4.8.5. Estimate POS for "myopic" search plan using "snapshot" method
- 4.8.6. Account for previous searching (use search-adjusted Pfails)
- *4.8.7. Compute minimum effort required to achieve desired POS (Build 2)*
- *4.8.8. Allow for expansion to optimal search for moving object (Build 2)*
- *4.8.9. Allow for expansion to optimal survivor search (Build 2)*
- *4.8.10. Allow for expansion to multiple simultaneous search objects (Build2)*

3.2 <u>Architecture</u>

3.2.1 Software

The desired software architecture at the highest level is viewed as consisting of three major subsystems addressing three primary functions. These are:

- The user interface through which the search planner carries out scenario definition, search planning and search evaluation functions, and through which the user provides case-specific data required to carry out these functions.

- The environmental data retrieval subsystem that provides environmental data needed to compute drift trajectories, effective sweep widths, and estimated survival times and to simulate environmental hazards.

- The Search Planning Simulator where most computation is done. This subsystem simulates events and processes germane to scenario generation and analysis, search planning and evaluation, and generates near-optimal search plans for the amount of searching effort available.

This is a "logical" view. It is not required that the structure of the final design strictly follow this view as long as the necessary functionality and flexibility is provided. Ease of maintenance and flexibility to accommodate modifications and enhancements must be an integral part of the design, however.

3.2.2 Hardware

User workstations are Intel® based and use MS-Windows® operating systems. The current standard operating system for workstations in the Coast Guard is Windows XP®. At present, installations have only a single screen, but dual screen installations are a possibility.

3.2.3 Network

The local area/wide area network in use will be the Coast Guard Data Network (CGDN+).

3.3 User Interface Subsystem

The user interface must be carefully designed to support the search planning process. A "wizard" style interface that will lead the user through the search planning steps in a logical fashion is required. However, the "help level" of the "wizard" interface should be adjustable so that novice users can obtain more detailed guidance while advanced users can forgo detailed guidance in favor of more rapid data entry and use. It should also be possible for users to go directly to data entry modules in any order. If the user leaves the interface at any point during a SAR case, the place where the user left shall be saved and when the case is next accessed through the user interface, it will automatically return to the point and state where the user left it previously. In all cases, the user interface should minimize the number of keystrokes and amount of data that must be entered by the user. This can be done by careful matching of GUI data entry modes to the inputs the user must enter, and by providing mechanisms for obtaining data from other sources (e.g., the USCG's MISLE Response system) in an automated fashion. There is a strong desire to prevent the need for duplicate entry of the same data into multiple USCG automated systems. However, SAROPS must be able to operate independently of data received from outside sources other than the user should the need arise.

The GIS for the user interface shall use the ESRI® mapping engine and shall include full support for ESRI® data formats. Compatibility with NIMA's ESRI®-based Commercial Joint Mapping Tool Kit (CJMTK) is highly desirable.

The user interface must provide full interactive graphic and geographic support for displaying and modifying search plans recommended by the simulator or accepting, modifying and evaluating search plans developed by the user. The interface must be highly interactive and responsive to user actions as the search plan is developed on-screen. Functions include but are not limited to:

- Display of simple vector shoreline maps with land and water "filled" with different user-selectable colors. Global capability required.

- Display of nautical charts. The tool should be capable of displaying electronic nautical charts for any part of the globe for which such charts are available. This includes all common projections described in reference [9]. At a minimum, all USCG AORs must be covered.

- *Optional display of aeronautical charts (Build 2)*

- Overlays of USCG static data including boundaries for Area, District, Group and Station areas of responsibility, locations of USCG fixed assets (stations, air stations, bases, group offices, Rescue 21 National Distress Radio System high (antenna) sites, district offices, area offices, etc.) with information on associated mobile assets (e.g., type of aircraft and number of each assigned to an air station). Note: Much of this and other static USCG data may be readily available from MISLE or other USCG sources in ESRI® data format.

- Overlays of other static data of SAR interest (hospitals, hyperbaric chambers, etc.) provided by the USCG.

- Display of color-coded probability maps that can be annotated with cell probabilities as a layer superimposed on an appropriate chart/map background. The ability to condition probability maps on search object attributes and/or states selected by the user is required.

- Display of other similarly gridded data sets such as recommended coverage/effort density, for example.

- Display of search areas and patterns with ability to translate, rotate, expand, shrink, etc, while maintaining proper relationships among pattern, track spacing, and search area boundaries. All standard search patterns in references [5], [6], and [7] must be supported. If a probability map has been selected, the display shall include probability of containment (POC) values for each search object type represented in the map. These values shall be kept dynamically updated as the search area is modified on the screen by the user. If an SRU has been associated with the area and the search endurance, search speed and sweep width are known, the probability of success (POS) for that area and the overall POS for all search areas currently displayed shall also be kept dynamically updated in response to user modifications. Also, if an SRU has been associated with an area, the search pattern computed for the area must contain the maximum number of complete legs that the SRU can complete within its given search endurance and speed parameters. Nominal Coverage, POD, and POS values are to be computed from this information.

- Display of environmental data including vector fields from environmental databases, self-locating datum marker buoy (SLDMB) drift tracks, etc.

- Animation of computed drift and estimated SRU movements.

- Standard GIS tools such as range and bearing between two points, position of cursor in latitude and longitude (dynamically updated as cursor moves), pan, zoom, range rings, range rectangles, icon selection and placement, etc.

- Standard GUI tools such as cut, paste, copy, etc. displayed entities.

- Miscellaneous tools such as LORAN time difference/latitude-longitude conversion, graphical display of COSPAS-SARSAT reports of EPIRB/PLB/ELT position and position error data, estimation of area containing a flare that was sighted, direct access to sweep width estimation, "Drag and drop" SRU selection, on scene endurance estimator for selected SRU, etc.

It is strongly recommended that the developer become familiar, to the extent feasible, with the user interfaces to all of the following: the Canadian CANSARP system, the Applied Science Associates SARMAP system, the United Kingdom's SARIS/UK CG3 system, and the USCG JAWS system in conjunction with USCG field operations personnel to catalog functions provided and assess USCG preferences.

3.4 Environmental Data Retrieval Subsystem

Initially, the environmental data retrieval subsystem shall be capable of accepting data in at least three modes:

- From gridded environmental databases hosted at the USCG's Operations Systems Center, Kearneysville, WV,

- As gridded or non-gridded predictions or observations from an automated source such as NOAA Tidal Current data from tide "stations" in the area, NOAA's Great Lakes Environmental Research Laboratory (GLERL), Coastal Ocean Dynamics Application Radar (CODAR), and SLDMB data maintained at OSC for SLDMBs that are adrift in the area at the time, with the ability to expand to other sources at a later date, and

- As gridded or non-gridded manual inputs from the search planner.

At a minimum, the environmental databases hosted at the USCG's Operations Systems Center, Kearneysville, WV, shall consist of the environmental data products currently received from the

USN Fleet Numerical Meteorology and Oceanography Center (FNMOC), Monterey, CA, twice a day, a global climatological sea current file, regional climatological sea current files for the Florida Straits and Georges Bank areas, and SLDMB data currently received from SLDMBs deployed when directed by USCG search planners. The FNMOC products are currently received in standard gridded binary (GRIB) format from FNMOC and then re-formatted into a data format more suitable for USCG applications by software developed and maintained by the USCG. If significant benefit can accrue by translating from GRIB to some other format, specification of such a beneficial format would be within the scope of this task, but not development of the necessary software.

Non-gridded data shall be mapped to a local grid in a manner consistent with known principles of oceanography and meteorology so the simulator may always draw from gridded data sets. A simple interpolation or "blending" scheme will be required to provide realistic transitions from one product to another at grid boundaries whenever necessary. It is anticipated that at some future date blending of data from multiple sources will be done at a central site to ensure product sets used by SAROPS are consistent. In the ideal case, the central site would be a site, such as FNMOC, already equipped to fuse data from multiple sources to produce a single, coherent data product. However, in the meantime, some "engineering solution" to the problem of using data from multiple sources will be needed within SAROPS, probably as part of the environmental data retrieval process. Responses to this request for quote should contain a high-level and not too technical description of recommended "engineering solutions" to the problems of gridding non-gridded data and blending data sets or at least ensuring realistic drift trajectories near boundaries between data sets from different sources.

The environmental data retrieval subsystem shall be capable of drawing data from databases and grids of varying spatial and temporal resolution. Given a position and a time, the environmental data retrieval subsystem shall obtain the best estimate of the requested data item (e.g., wind vector) and its uncertainty distribution that are available in the database(s) to which SAROPS has access. If/when appropriate, this estimate may be an interpolated value computed by the environmental data retrieval subsystem from data contained in the database(s) from which the data is/are being drawn. This subsystem shall also return the identity, spatial resolution and temporal resolution of the database(s) from which the estimate was obtained.

3.5 Search Planning Simulator

The Search Planning Simulator is the heart of the system and where most of the computation is done to simulate pre- and post-distress craft/survivor behavior, hazard behavior, and search craft and sensor behavior, and where near-optimal search plan recommendations are developed. The simulator is to use a Monte Carlo ("particle filter") event-driven simulation technique to account for the many possible combinations of values allowed by the uncertainties about the various problem parameters.

3.5.1 Case database

Data related to a case where SAROPS is used shall be stored in a local database. Parts of this database may be populated from the user interface or external sources such as MISLE or Rescue 21. Similarly, extracts from this database may be used to populate parts of the MISLE database.

It is not intended that SAROPS be a complete case management system. However, there will be case data necessary to the use and operation of SAROPS that will need to be stored, retrieved, and tracked during the case and a database for that purpose is needed. It must be possible to "hand off" a case to another facility where SAROPS is available at any time.

3.5.2 General SAR database

Various SAR-related data that is used directly by SAROPS in performing simulations need to be available locally. These include items such as a database of search object types with leeway coefficients, SRU types with data on various characteristics such as endurance, sensors, etc., sweep width tables with corresponding lateral range curve descriptors, etc. Since it may be necessary to add, delete, or modify information about search objects, SRUs, etc. from time to time, the databases and the modules that use them must be designed to accommodate such changes with minimal effort.

3.5.2 Monte Carlo Event-Driven Simulation

The simulation must begin with the time and position where the craft or persons were last known to be safe. This is necessary to "set the stage" or define the initial conditions for the problem. SAROPS is to then provide assistance to the search planner's scenario definition and analysis efforts to estimate where and when the craft or persons subsequently became distressed, as well as where they might be if still en route not in distress. Next, the probability density distribution on search object location is to be computed for a given time or period of time based on simulation of post-distress motion (drift) when the distress incident occurred on or over water. When a distress occurs on or over land, SAROPS (Build 1) shall assume the search object is stationary. Given information on the available search resources from which available effort may be computed, SAROPS shall produce and display an operationally feasible near-optimal search plan. After the search planner has made any desired adjustments to the search plan, the final plan shall be delivered in a form suitable for transmission to the SRUs assigned to perform the search. Based on information from after-action reports, SAROPS will properly account for the effects of searching on the probability density distribution, taking care to account for the simultaneous motions of SRUs and drift motions of individual "particles" (now called "replications" in CASP). Finally, SAROPS shall report nominal POD, POS, and cumulative POS values to the search planner. SAROPS will support repeating the search planning process any number of times while keeping track of the effects of all searching done to date with respect to the given SAR incident.

Terrestrial capabilities shall be limited to allowing appropriate portions of the marine model to be used over land. No special provisions for the handling of incidents on land are within the scope of Build 1, except that the sweep width values and correction factors for aerial search over land from reference [5] shall be included.

3.5.3 Scenario Analysis/Generation

The pre-distress motion model shall be, at a minimum, based on the search planner's estimates of the course(s) and speed(s) made good and their associated uncertainties, together with estimates of initial position, way points, "lay-over" times, destination position, etc, and their associated uncertainties. This information will normally be based on the missing craft's intentions as obtained by interviewing persons familiar with the craft and crew. Note that initial positions, "way points" and destinations may be polygonal areas where the craft intended to conduct operations (e.g., fishing) for some period of time or they may be specific positions with associated positional uncertainties. Both positions and areas may have associated "lay over" or "operations" time intervals and associated uncertainties.

Pre-distress motion modeling for craft or persons on over land shall be limited to allowing the aeronautical and marine models used on or over water to be used on or over land as well. For example, an aircraft's last known position and intended track may be over land. Simulating the possible locations for a forced landing would be treated the same as it would for a case over water. A later enhancement might include such things as topography and other factors peculiar to flying over land, but these are beyond the scope of Build 1.

Land recognition is required for pre-distress position and motion models. The user must be able to choose whether to use or ignore portions of a distribution that initially fall on land. The user must be able to choose whether to use or ignore portions of the distribution that are initially in the water but subsequently encounter land. Provision for extending "land recognition" to include water depths greater than zero (e.g., to simulate groundings) in later builds should be included in the design. Similarly, provision for extending "land recognition" to heights greater than zero (e.g., to simulate aircraft encounters with mountains) in later builds should be included. At a minimum, there shall be nothing in the SAROPS design to preclude later incorporation of these "land recognition" extensions at reasonable cost.

It is anticipated that more detailed and sophisticated pre-distress motion models may be added in subsequent builds. Build 1 of SAROPS shall be designed to allow for such improvements at reasonable cost.

SAROPS shall allow the user to assign relative weights to alternative scenarios to represent the levels of confidence the user has in each. The user shall be allowed to modify these weights and add or delete scenarios at any time. The impact on POS and POS_{cum} values for each object type present shall be computed and displayed automatically.

SAROPS shall also have the ability to estimate the place and time where an object that is located adrift may have come from. Typically this will be some type of debris or object from a missing craft and answering the question, "Where and when could this item have come from?" can prove very helpful in narrowing the possible times and places for the distress incident to have occurred. This in turn can often significantly reduce the size of the area that must be searched and lead to more timely location and rescue of survivors.

3.5.4 Object Attributes/States/Weights

A major feature of the SAROPS model will be simulating event chains with respect to simulated objects. It will be necessary to "tag" these objects with appropriate attributes to identify the object and various characteristics of the object related to motion, detection, survival, etc. At a minimum, "place holders" for all attributes, states, and weights listed in part 4.3 of the outline shown in section 3.1 above shall be provided, regardless of whether they will be used in Build 1.

3.5.5 State Changes

A major class of events affecting search objects are those involving changes in the object's state. The most obvious of these is the change in state from not in distress to distressed. For Build 1, the environment shall be considered uniformly hazardous based on exposure time since the craft or person was last known to be safe.

Another type of transition is from alive to expired. This is especially important for persons in the water (PIW). For PIW this will be a simple but conservative decay model based on Figure N-14 of reference [5]. The "decay" can be such that survivor lifetime is infinite (e.g., survivor is in a boat in the tropics) and this will be the Build 1 default for all survivor types, including PIW. The decision on whether to allow users access to non-infinite survivor lifetime options prior to incorporation of a more sophisticated survival model in Build 2 has not been made. At a minimum, the simple model will be a "place-holder" for the more sophisticated model to come.

A distress incident can "spawn" or generate one or more types of search objects. For example, a distress incident involving a vessel could generate distressed persons in the water, life rafts and lifeboats, as well as the vessel itself in a disabled and adrift state. Each type of object would have its own motion, detection, survival and other characteristics. SAROPS shall be able to accommodate the entire leeway taxonomy reported in reference [8]. When more than one object type can be "spawned" by a distress incident, the user shall be able to specify their relative probabilities of occurrence.

Other than the general requirement for assuming the world is a "universal" time-based hazard, simulation for hazards will not be a requirement for Build 1. However, if more detailed hazard modeling at any level can be included at little or no additional cost, such an enhancement may be included as a separate line item with any associated cost.

3.5.6 Post-distress Motion Modeling

Post-distress motion modeling for drifting objects shall be based on current USCG methods and data. Mean down-wind and cross wind leeway factors and standard deviations for normal distributions about those means have been developed for the objects listed in the taxonomy of reference [8] and will be provided. Leeway rate estimates for winds above six knots are simple linear equations. Below six knots linear interpolation between zero and the leeway for a wind of six knots is used. Leeway cross wind components are bimodal but symmetric to the down wind direction. That is, there is a mean cross wind component to the right and another with the same magnitude to the left of the down-wind direction. Each has the same standard deviation. Field experiments have shown that objects tend to have leeway either to the right or to the left of the down wind direction and that the distributions to the right and left are equal. Although jibing or tacking behavior has not been confirmed once the object has "chosen" one tack or the other, the leeway model must be capable of accepting a jibing or tacking frequency (or period) and an associated uncertainty distribution. The leeway model must then be able to sample from the jibing/tacking distribution appropriately when computing drift updates. The standard method of adding leeway and total water current vectors to obtain a drift velocity vector shall be used.

For Build 1, objects on land are assumed to have no post-distress motion. However, this may change with later enhancements and the software design shall allow such enhancements to be made at reasonable cost at some future date.

Total water current consists of the vector sum of those “currents” present in the region, including average sea current (mostly geostrophic), local wind-driven current (due to wind stress on the water surface), tidal current (near shore), and other currents (e.g., major river outflows, etc.). Water current products received from environmental data providers may represent total water current or they may represent any one or combination of the component currents, depending on the specific product in question. SAROPS shall recognize environmental products by source and content. If it is necessary to add local wind-driven current to a product, the local wind-driven current shall be computed from the same surface wind data that is used to estimate the leeway, regardless of the wind data’s or current data’s source.

Drift updates shall use a time step that is appropriate to the temporal and spatial resolution of the environmental data sets being used. However, the time step for drift updates should not exceed one hour. Data samples used to compute drift motion shall be obtained using appropriate sampling and interpolation techniques. Issues to consider include realism in drift trajectories, sampling frequency, appropriate levels of correlation among successive samples and boundary conditions where an area covered by one environmental data product meets or overlaps an area covered by another product.

When dealing with simultaneous sets of events, such as simultaneous drift motion and movement of searching SRUs, it may be necessary or appropriate to use irregular, event-driven time steps for drift motion. The drift algorithms shall be capable of handling irregular time steps and computing drift positions to the nearest second of time whenever required.

Drift update algorithms must recognize land and take appropriate action when a drift trajectory encounters land. Two options are “sticky shore” where the simulated drifting object stops at the shoreline (or very close to it) and never moves again, and “slippery shore” where the object moves along the shore (as in a long-shore current) with an appropriate direction and speed. SAROPS shall be capable of either option or a mixture of the two (some object types may “stick” while others may “slip” within the same SAR problem). Provision for allowing “land recognition” to include water depths greater than zero (e.g., to simulate groundings) in later builds should be included.

SAROPS must automatically restore objects to their state as of the time when “analysis” or actual observed data expired and use of predicted or forecast data became necessary. The reason for this restoration is so that later “analysis” data products and observations may be used to increase the accuracy of the drift trajectory as time passes and such data become available.

3.5.7 Search Evaluation

Search evaluation is an area that provides one of the greatest opportunities for improvement over previous search planning software. SAROPS must accommodate all standard search patterns found in references [5], [6], and [7], including track line searches. SAROPS must correctly account for the simultaneous motion of search objects and SRUs during the performance of a search. Initially (Build 1), this will be probably be most easily accomplished by using appropriate lateral range detection functions and computed closest points of approach (CPAs) for sensor platform's assigned tracks. The sweep widths of the lateral range functions used must correspond to the sweep widths obtained using the tables and correction factors in references [5], [6], and [7] with the same inputs. In the future actual SRU tracks may become available via on-board tracking devices (e.g., GPS receivers) that can provide frequent waypoints to a computer when the SRU returns following completion of a search assignment. The SAROPS design shall make it possible to add, at reasonable cost, the capability to receive and use such data for search evaluations.

3.5.8 Near-Optimal Search Plans

SAROPS shall produce near-optimal search plans based on the computed probability density distributions, scenario weights, mix of search possible object types and states, uncertain sweep widths, etc. The term "near-optimal" is used to allow SAROPS plans to be operationally feasible approximations to plans that are perfectly optimal in a mathematical sense but are not operationally feasible. Initially (Build 1), near-optimal search plans may be based on "myopic" optimization as of a specific point in time (e.g., mid-search time) or based on the "average" probability density map over a period of time when SRUs are to be on scene searching. In either case, the optimization problem is equivalent to that of a static situation involving no search object motion and no "look ahead" to see how changes in the "myopic" search plan could benefit future search plans. However, the software shall be constructed in such a way as to allow expansion to optimal plans that account for search object motion and "look ahead" analysis, such as Brown's algorithm or Stone's generalized search optimization technique.

3.6 General Software Engineering Issues

SAROPS is to be implemented in a MS-Windows environment compatible with USCG systems and network architecture. After that requirement has been satisfied, SAROPS is to be portable at the source code level across hardware platforms to the maximum extent that is both technically feasible and cost-effective in terms of life cycle management. Unavoidable additional system dependencies shall be clearly identified to the government as soon as the need for them becomes apparent. If it is determined that they are truly unavoidable or avoidance is determined to be too costly, such dependencies shall be isolated from the rest of the software to the maximum extent feasible in order to ease porting of SAROPS from one platform to another.

The programming language used shall be a recognized standard subject to government approval and only standard features and constructs shall be used unless the government explicitly approves an exception. Such approved exceptions are expected to be extremely rare.

Although no arbitrary size limit will be imposed, modules should be small, clear, concise, and coherent. Substantial attention should be given to achieving appropriate modularization for SAROPS as a whole. All "calls" and "is called by" relationships shall be documented.

All variables shall be explicitly declared as to type and size. Meaningful variable names shall be used. All variables used shall be explicitly defined in terms of the real-world entities they represent. Each module shall contain an alphabetical list of variable names used in that module. Each variable shall be labeled as to whether it is an input, output, input/output, local or global.

The source code shall be easy to read, follow, modify reliably, and maintain. “Hard-coded” values (initial values, constants, etc.) peculiar to SAROPS are to be avoided. Instead, such values should reside in files or databases from which they can be read or loaded at an appropriate point to a location with an appropriate scope or visibility.

It is anticipated that most general data required by SAROPS that is not specific to the case will be stored in local databases. However, the locally stored data will normally be limited to that which is related to the user’s area of responsibility (AOR). (Exceptions would be when a user is acting as a backup or alternate site for another user.) Much of the general data will be extracted from larger databases at centralized sites. For example, environmental data for a user’s AOR might be obtained automatically by a background process on a regular interval keyed to the update schedule for the global and regional environmental databases maintained at a central site such as OSC. Information on SRU status for the various units in the user’s AOR might be retrieved in a similar fashion from central databases such as MISLE or AOPS. If this approach is used, the user shall have access, when appropriate, to local databases for the purpose of entering more timely information, such as SRU status updates known to the user but not yet “known” to the central database.

The U. S. Coast Guard SAR Program expects to be substantially involved in all aspects of the SAROPS development process. Although not explicitly required, the Unified Modeling Language™ (UML) software development paradigm provides a good model. Of particular interest is the “use case” method for ensuring the software design is complete and meets the user’s needs.

3.7 Documentation

Documentation shall be in accordance with best industry practices. It must be sufficiently robust and detailed that competent persons other than the developers may reliably maintain, enhance, and modify SAROPS. “Competence” in this context means competence in both the topics that pertain to the portion of SAROPS being maintained, enhanced or modified and competence in software maintenance and engineering. It is not intended that the documentation be so detailed that it could be used as a teaching or training resource for persons not familiar with the appropriate subjects. For example, only persons already intimately familiar with search theory should do maintenance, enhancement, or modification on modules that implement algorithms for optimal effort allocation and the documentation should be written accordingly.

The architecture of SAROPS as a system shall be clearly documented. Each module shall also be clearly documented. Algorithms taken from specific sources shall have those sources referenced.

3.8 Inspection, Test, and Evaluation

The SAR Program will retain the right to inspect work in progress and test completed modules and sub-systems at any time during the SAROPS development effort.

Each module, sub-system, and the completed Build 1 of SAROPS shall be tested to demonstrate that it correctly performs the function(s) for which it was designed. For example, the contractor must demonstrate that modules designed to generate random values having a given type of distribution pass standard statistical tests for showing that the generated values have the required distribution. As another example, the contractor must show that modules for computing a new position on/over the earth's surface based on a direction and distance from another position on/over the earth's surface function correctly. At the sub-system or system levels, adherence to their respective functional requirements must be similarly demonstrated.

The government shall have a minimum of 90 days for "beta testing" SAROPS under operational conditions. This may include deployment of tracked objects to evaluate the system's predictive capabilities. All deficiencies found during beta testing shall be corrected.

4.0 Government Furnished Equipment/Information

The government will provide copies of references [1] – [8]. The government will provide access to existing Coast Guard systems germane to the SAROPS development effort, as needed.

5.0 Period of Performance

The Coast Guard desires to commence work in fiscal year 2003 and have SAROPS version 1.0 completed before the end of fiscal year 2005.

6.0 Instructions for Responders

More than 30 years of government experience with computer-based search planning systems has shown that no single vendor is likely to possess expertise in all of the diverse fields required for this type of application. It is abundantly clear to the government that software development skills alone will be insufficient to guarantee success. Therefore, the government expects responders to propose a team approach using subcontractors with appropriate levels and types of expertise. In fact, government analysis indicates that the bulk of the effort will require highly specialized skill sets not common to typical software developers.

6.1 Understanding the Requirements

Responders shall show a full understanding of the Coast Guard's search planning support requirements.

6.2 Capabilities

Proposed teams must demonstrate that they possess expertise and experience with the following:

- Search theory and its practical application to maritime search problems, including knowledge of associated probability, statistics, mathematics, and numerical methods disciplines.

- Environmental sciences, particularly physical oceanography.

- Development of GUI and GIS user interfaces using MS Windows® and the ESRI® mapping engine and data formats.

- Development of simulation software and systems that model a mixture of natural and human-directed processes germane to the maritime search planning problem.

- Modeling/simulation of the drift of objects in the near-shore and off-shore marine environments.

- Modeling/simulation of sensor performance as it affects posterior probability density distributions on search object location (Bayesian update).

- Development of "Tactical Decision Aids" and similar applications.

Demonstration of requisite levels of expertise in these areas shall be accomplished by providing descriptions of past performance for the prime and each subcontractor (all of which shall be identified) in these areas and descriptions of current intellectual assets, including resumés for key personnel.

6.3 Technical Approach

Responders shall propose a technical approach and show a high-level project plan for accomplishing the development of SAROPS. Responders shall show the approximate distribution of types and levels of effort among the team members.

The "team approach" must include involvement of a representative cross-section of USCG field operations personnel who will be SAROPS users. The intended user base includes the staffs of command centers at the Area, District, and Group levels. In general, Groups will use SAROPS in the early stages of a case. In the event the case is not successfully resolved within the first 24-48 hours, the duties of SAR Mission Coordinator (SMC) will normally be passed up the chain of command to the appropriate District/Area. Responders shall provide their views on how best to involve the user base and ensure end-user requirements are identified and met.

7. USCG SAR Program Points of Contact

7.1 USCG SAR Program: Mr. R. Schaefer, 202-267-1089, rschaefer@comdt.uscg.mil

7.2 SAROPS Technical Issues: Mr. J. Frost, 202-267-6702, jfrost@comdt.uscg.mil

References

[1] *Review and Recommendations for CASP.* Metron Report to USCG Operations Systems Center 10 February 2003.

[2] *Elements, Modules, and Algorithms Needed for Planning Optimal Searches: A High Level Overview*, Potomac Management Group Report to U. S. Coast Guard Office of Search and Rescue by J. R. Frost, 26 August 2002.

[3] *Modeling of Leeway Drift,* Applied Science Associates Report for the United States Coast Guard, April 1998.

[4] *Review of Search Theory: Advances and Applications to Search and Rescue Decision Support*, Soza & Company, Ltd. Report to U. S. Coast Guard Operations (G-OPR), NTIS # ADA 397065, by J R. Frost and L. D. Stone, September 2001.

[5] *International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual*

[6] *National Search and Rescue Supplement to the IAMSAR Manual*

[7] *U. S. Coast Guard Addendum to the National Search and Rescue Supplement*

[8] Allen, A. and J. Plourde (1999), *Review of Leeway: Field Experiments and Implementation*, U. S. Coast Guard Research and Development Center, NTIS # ADA 366414.

[9] Bowditch, N. (2002), *The American Practical Navigator: An Epitome of Navigation*, National Imagery and Mapping Agency, Pub. No. 9, http://www.irbs.com/bowditch/