REVIEW AND RECOMMENDATIONS FOR CASP

Final Report to
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for
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by

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PREFACE

Under Contact DTCG23-01-F-TWV008, Dr. Stone was tasked to review the Coast Guard's Computer Aided Search Planning (CASP) program for accuracy and correct implementation and to recommend replacement of legacy functions with more current functions where applicable. This report presents the findings and recommendations of this review. Section 1 provides a summary of the review and recommendations. Section 2 reviews the existing system, and Section 3 provides more detailed recommendations.

INTRODUCTION

Dr. Stone's background in SAR includes participation in the development of the original CASP system, CASP 1.0, fielded in 1974 (see references [1] and [2]) and in the development of improved search planning modules for the updated CASP system, CASP 1.x, which was put into service in 1985. He has participated in numerous search operations for the U. S. Navy, including searches for Soviet submarines patrolling in the Atlantic and Pacific. He has developed computer search planning systems for the Navy and is presently involved in developing systems for use aboard U. S. attack submarines to track submarines and surface ships with passive sonar sensors. He has written books and numerous articles on search theory and optimization including the book *Theory of Optimal Search*, see references [3] and [4] and articles and reports on search theory and planning such as references [5] and [6].

1. SUMMARY OF FINDINGS AND RECOMMENDATIONS

This section provides a summary of the review and recommendations for the CASP system.

1.1 Summary of Review of the Existing System

For this review Dr. Stone visited the Coast Guard Operations Systems Center (OSC) in Kearneysville WV on December 2 and 3, 2002. During this visit he reviewed the existing CASP code and talked with the following people:

Lt Pete McCaffrey	OSC
John Shafer	OSC
Duane Robinson	OSC
Christie Sine	OSC
Doug Horton	OSC.

John Shafer and Christie Sine provided a demonstration of the use of CASP. This was augmented by discussions, via telephone, with Senior Chief LeComte and Kevin Jones from the SAR school in Yorktown Virginia.

Dr. Stone was provided with a digital copy of the CASP code for review at Metron. He also reviewed reference [7] which provides a history of the development of CASP and other search and rescue planning programs as well as a great deal of information about the functions and shortcomings of the existing CASP system.

The CASP system is now almost 30 years old. It has had one major update in 1985, from CASP 1.0 to CASP 1.x. The primary purpose of this update was to move CASP to the minicomputers at Governors Island. In the process a number of features were added and improvements made. Section 2.2.1 provides a summary of these improvements. Unfortunately some important features of CASP 1.0 were either removed or degraded. In addition, CASP 1.x has numerous limitations and problems. The most important of these are listed in section 2.2.2.

At the time of its initial deployment in 1974, CASP was an innovative and highly advanced search planning system. Now the situation is different. Even with the upgrade to CASP 1.x, the present system is out-of-date in the use of computer technology, environmental information, sensor modeling, and search planning capability. There comes a time in the life of any software system when it is no longer efficient to modify or add to the existing software. One has to start from scratch, using the lessons learned from the existing system, the latest capabilities in computer software and technology, and recent theoretical advances to design and develop a new system. That time has come for CASP.

1.2 Summary of Recommendations

The recommendation is to build a new system from scratch using modern computer design and technology, up-to-date environmental data products and sensor modeling, and new and more powerful optimal-search-planning techniques. A new system will supply the following benefits to the Coast Guard:

1. Provide a more intuitive and helpful user interface that will guide the user through the necessary choices in planning SAR search operations. This will encourage greater and more effective use of the system; thereby providing more benefit to the Coast Guard
2. Replace the Automated Manual Solution (AMS) and CASP 1.x with a single search planning system so that both near shore and open ocean searches are planned with the same tool. This will increase the use of the system and promote more effective use of the system.
3. Correct existing functionality. In particular, the new system should correct the problems cited in section 2.2.2 and in reference [7].
4. Deliver critical new functionality.
    a. Better use of the detailed environmental data products now available and better modeling of their effects on drifting objects, especially near shore, survivor life expectancy, and detection.
    b. Improved scenario generators that allow the user to better represent the information known about a distress.
    c. Improved modeling of the search sensors.
    d. Modeling of the movement of the search objects during search. This will include modeling the effects of search object motion on probability of detection and the probability distribution of the location of the search object.
    e. Improved search plan recommendations

i. Recommendations that account for multiple object types and survivor lifetime.

ii. Recommendations that account for object motion.

5. Provide code developed with modern software development systems and methods. This will produce more transparent code and a system that is more stable and maintainable than the present one. This will reduce long-term software cost to the Coast Guard. The system will be more extensible and capable of taking advantage of the latest computer technology to improve its performance.

2. REVIEW OF EXISTING SYSTEM

This section provides a brief description of the original CASP system and then discusses the state of the existing CASP system.

2.1 Original CASP 1.0

The original system, CASP 1.0, was programmed in FORTRAN in the early 1970s and fielded in 1974 on a CDC 3300 mainframe computer located in Washington DC. The system had a Monte Carlo design and was run in a remote-batch mode via teletype. The probability distribution for the location of a search object at a given time was represented by a file of up to 44,000 replications. Each replication had a position (latitude and longitude) and probability weight associated with it. This probability weight, *pfail*, is equal to the (prior) probability that all the searching to the date and time associated with the file will fail to detect the search object represented by this replication. To produce probability maps, a grid was imposed on the ocean. For each cell in the grid, CASP summed the weights of the all the replications located in that cell and renormalized to obtain the probability of the search object being in the cell. This produced a probability map which could be printed on the teletype. In the original version, there were no time tags on the replications themselves. The name of the file contained the time information and all points were assumed to have that time. Reference [1] presents a technical description of CASP 1.0.

Scenario Generation. CASP 1.0 was designed around scenarios. A scenario represents a plausible story for what happened in a distress incident. CASP 1.0 provided three modules, POS, TRK, and ARA designed to produce initial distributions for the location of the distress given a scenario description. POS produced a distribution of points obtained by drawing at set of points from a bivariate normal distribution around center point and then applying a random offset to each of those points. The center point would typically be the estimate of the last known (reported) position of the search object with the uncertainty in this estimate being represented by a bivariate normal distribution. The offset could represent an estimate of the displacement from the last known position at which the distress occurred. The distribution of the offset was uniform in an annular wedge specified by the user. TRK was used when the scenario involved a planned track for the search object and the distress was assumed to have occurred at some point along the track. The distribution of positions was produced using a uniform distribution along the track and normal displacement distribution across the track. ARA represents the scenario where the location information is that the distress occurred somewhere inside a polygonal region. The location distribution produced by ARA is uniform over this region. These scenarios could be combined in a weighted fashion to produce an initial probability distribution for the location of the distress.

Motion Updating. For CASP 1.0, current and wind files were represented by a grid of cells. For each cell there was a mean vector and an uncertainty that translated into a bivariate normal distribution of the current or wind vector in that cell. The module DFT performed the motion update to the time specified by the user. For each replication, DFT determined the cell in which the replication was located and made an independent draw from the wind and current distribution in that cell to determine the wind and current vector for the replication. The wind vector was multiplied by a leeway factor and then added to the current vector to obtain a total drift vector (velocity). The drift velocity was multiplied by an update time increment (up to 96 hours due to computational constraints) to determine the displacement of the replication for that increment. This process was repeated, with independent draws for the wind and current vector for each time increment, until the update time was reached. This process was repeated for each replication to produce the motion updated probability distribution.

Search Recommendations. Very simple search allocation tools were provided by CASP 1.0. For example, the system could list the cells in descending order of probability or recommend an effort allocation over the cells. However, these recommendations were theoretical ones and not operationally feasible. The SAR planner had to translate these recommendations into an operational search plan as best he could.

Updating for Search. CASP 1.0 had two search update modules, PATH and REC. RECtangle was used when the search effort was placed in uniformly spaced parallel paths. PATH evaluated searches consisting of a sequence of straight line segments. In each case, the search object distribution was usually motion-updated to the time of the middle of the search. If the replication was located in the effective area of the search pattern, the weight (pfail) on the replication was multiplied by the failure to detect probability calculated by PATH or REC. Note that this effectively assumes that the object was stationary while the search pattern was applied.

Reference [7] provides a more detailed description of CASP 1.0.

2.2 CASP 1.x

The existing system, CASP 1.x, resides on computers at the Operations Systems Center in Kearneysville, WV. It is accessed remotely from computer workstations using a using a GIS interface called the Command and Control Personal Computer (C2PC). This interface is grafted on top of the original CASP command line interface originally developed for the teletype and later adapted to a purely textual, menu-based interface. Requests and actions generated through the C2PC interface are translated into commands that run in batch mode on the computers at OSC. In fact, CASP can still be run directly by using these batch commands. In spite of this, the ability to display probability maps and search paths in color superimposed over nautical charts is a big improvement over the CASP 1.0 displays.

In remainder of this section, we list some of the improvements that are provided by CASP 1.x over the original CASP 1.0 and some of its shortcomings.

2.2.1 CASP 1.x Improvements

The following is a brief list of improvements in CASP 1.x over CASP 1.0

1. Additional information such as present time, object type, scenario type, as well as the time, position, and pfail value at time of last environmental analysis is included with each replication. This has numerous advantages. For example in CASP 1.0, the user had to create a new file each time an operation was performed because the only time information was embedded in the file name. This led to a large proliferation of files and file management problems for

the search planner. Such problems are now relatively rare with CASP 1.x.

2. Environmental data products for open ocean are now more extensive and more detailed. When new environmental analysis data is received the replications can be backed-up to the time of the previous environmental analysis and run forward from that point to a desired time. This allows the latest available analyses and forecasts to be used.

3. Drift updates now consistently use a one-hour time increment, providing more accurate drift trajectories. However, while the 100% correlated sampling technique now in use for obtaining wind and current values is an improvement over the previous uncorrelated sampling technique, a more sophisticated technique that better reflects the real-world environment is needed.

4. Multiple object types can be represented in the CASP distributions. One can use this to model a situation where the search object may be a person in the water, life raft, or a boat adrift. Each type can be subject to its appropriate drift and search update computations.

5. CASP 1.x uses a wider array of environmental data than CASP 1.0

6. CASP 1.x has a multiple rectangle search planner that produces near-optimal, feasible search plans for multiple SRUs.

2.2.2 CASP 1.x Limitations and Problems

1. The CASP 1.x POS scenario generator, called Gen_Pos has regressed to allowing only "circular normal" position distributions. In addition, Gen_Pos uses flat-earth geometry in place of the spherical geometry used in CASP 1.0.

2. The "circular normal distributions" in Gen_POS are *not* circular normal. Instead the user specifies a univariate normal distribution with mean zero and standard deviation σ for the distribution of distance from the center point. When a number is drawn from this distribution, its absolute value is used for the distance of the replication from the point. This is combined with a draw from a uniform [0, 360] distribution to determine the true compass direction of the position of the replication from the center point. This results in 68% of the replications being within 1 σ of the center point. For a true circular bivariate normal distribution, only 39% of the points are within 1 σ of the center point. A true bivariate normal distribution is a standard form that is known to represent two-dimensional error distributions in the real world.

The distribution generated by Gen_POS is not physically meaningful in this context.

Use of this incorrect distribution will produce searches that are too concentrated around the center point and may result in lives lost.

3. Search is still evaluated at the mid-search time as though the search object is stationary throughout the search. This leads to inaccurate probability maps and poorly planned searches, particularly in areas like the Florida Straits and Gulf Stream where drift rates are large due to strong currents. Strong tidal currents can produce similar problems.

4. CASP 1.x cannot optimize search against multiple search object types. When a search recommendation is requested, the user has to choose a single search object type against which to optimize the search.

5. Search optimizations are still static. They do not account for future object motion or possible change of object state. The latter is crucial in planning optimal survivor searches designed to maximize the probability of finding survivors while they can still be saved.

6. The user interface does not guide the user through the program. The set of choices and options is confusing and not intuitive. Even the programmers who maintain CASP at the OSC had to ask for help in navigating through the menu choices for planning a search.

7. There are numerous problems with the drift start time for replications and with the adrift status of the reps (see reference [7] for details).

8. The Gen_TRK module which replaces the TRK module of CASP 1.0 has regressed to allowing only rhumb-line tracks. CASP 1.0 also allowed great-circle track lines.

9. The Gen_ARA and Gen_TRK modules are unnecessarily complex and subject to a number of logical inconsistencies (see pp 42 – 45 and pp. 75-77 of reference [7]).

10. The use of locations and situations is confusing and not logical. For example, the user must first designate a set of search objects (types) and then a set of locations. Each location consists of one or more positions. A search object can then be combined with one or more locations to create a situation. However, you can't associate more than one search object (type) with a single location. A user might naturally want to do this if the last known position

represents a distress call and the search planner does not know whether the search object is a boat, life raft, or person in the water starting at this last known position.

11. Scenario generation capability is limited. It doesn't cover some of the natural ones for SAR planning. For example one can not generate a scenario in which a fishing boat leaves port, goes to a number of fishing grounds where it will spend time fishing, and then returns to port.

12. CASP 1.x does not work well near shore because the environmental data products that are made available to it do not have the high spatial and temporal resolutions needed for these areas.

3. RECOMMENDATIONS

In this section we provide more detail to the summary recommendation given in section 1.2. To do this we list the goals for the new system, then the philosophy that should guide the development of the system, and finally the features of the new system.

3.1 Goals for New System

Before embarking on developing a new system it is useful to list the goals for the system. These will provide a guide for us to determine the most important features to implement in the new system. The recommended goals are the following:

1. Provide a single system that replaces the existing CASP and AMS systems.
2. Provide a system that is easy and natural for a SAR planner to use.
3. Provide a system that produces more accurate probability maps and more effective search planning recommendations:
    a. More flexible and accurate scenario modeling
    b. More detailed environmental data products
    c. Better drift modeling
    d. Better sensor and search effectiveness modeling
    e Better search planning recommendations
        i. Moving Objects
        ii. Multiple state objects (optimal survivor search)

4. Provide a system that can be more easily maintained and operated by the USCG.

3.2 Philosophy of New System

We recommend that a simple but powerful philosophy guide the development of the new system. Namely, the logical structure and the features of the system should follow the structure and nature of the search planning process. The system should guide the user through the process of search planning in a natural sequence. This guidance could take the form of a wizard that suggests the next step to the planner at each stage in the process and provides feedback to the user as to which parts of the planning process have been completed and which ones need to be addressed.

3.2.1 Implications for Development Team

This approach has immediate implications for the nature of the development team and process. The team can not be limited to programmers and operational personnel. The team and process must be multi-disciplinary and include

1. Computer scientists: systems designers and developers, GIS experts
2. Operational personnel familiar with the SAR planning process and experienced in operational SAR cases
3. Mathematicians and search theory experts
4. Oceanographers and environmental data providers.

3.2.2 Description of Search Planning Process

The following is a description of the search planning process which can be used as a guide for developing the new system. The process follows these steps:

1. Gather data and information
2. Produce search scenarios/stories from this information and from these scenarios produce probability distributions representing the scenarios.
    a. Scenarios should be generated from stories
        i. Stories should start at a logical point, e.g., port departure
        ii. Proceed through a sequence of (possible) events such as way points, fishing areas, hazards, distress incident, etc

   b. Replications should contain a sample history of the development of the story. Each replication should contain its full history (or be capable of reconstructing it)
3. Identify search resources and obtain environmental predictions
4. Produce and revise search plans
5. Implement search plans
6. Update object location distributions for actual search and environmental conditions
7. Update scenarios for new information (debris, etc) if necessary
8. Go back to 3

3.3 Features of New System

This section lists the recommended set of features and capabilities for the new system. We group these features into the ten areas listed below.

1. Improved Monte Carlo design. The general Monte Carlo approach of CASP 1.x should be retained but extended to allow more flexible and realistic modeling of scenarios, search object motion, and sensor performance. In CASP 1.0, limited computer and disk memory required that each replication contain a very parsimonious amount of information. CASP 1.x improved upon this by adding some much needed information such as the present time, object type, and time since last analysis update to the location and pfail information of each replication. The new system should retain this information but take advantage of the substantial increases in computational power, computer memory, and storage capabilities to include enough information to reconstruct the past history of the replication. This would make it easy to include new scenario information (such as debris found during a search), updated environmental information, and corrected search information.

   Survivor lifetime should be added to each replication to allow for optimal survivor search planning. An appropriate survival model will be needed.

   The new system should provide for resampling of the search object distribution in cases where the probability becomes concentrated on a small number of points in the sample. See reference [8] for a discussion of resampling in sequential Monte Carlo systems.

2. A planning wizard for guiding the search planner in the use of the system.

3. Expanded Scenario Capability. The scenario generating capability should be expanded to include some of the common SAR scenarios that are now missing from CASP. For example
    a. The system should be able to generate a scenario in which a fishing boat leaves port, goes to a number of fishing grounds where it will spend time fishing, and then returns to port.
    b. Scenarios ought to allow for objects to change state and to encounter hazards.
    c. Scenarios should allow for multiple search objects of multiple types to be adrift simultaneously. A topic of considerable concern to the Coast Guard is that of Mass Rescue Operations such as those that would be required should a large cruise ship with thousands of persons on board experience a disaster at sea or a large aircraft with hundreds on board successfully ditch. Such incidents could produce many drifting survivors in lifeboats, life rafts, and in the water. Even with rapid alerting, rescue facilities might not be sufficient to recover all survivors before some drift away from the immediate vicinity of the incident. A search for multiple objects of multiple types would then be required.

4. Improved drift modeling, the ability to take advantage of the vastly improved environmental data products now available, and the flexibility to easily keep up with future environmental data product improvements.
    a. Obtain higher resolution current information near shore.
    b. Account for time and space correlation in drawing wind and current vectors for drifting replications.
    c. Implement the improved leeway model and greatly expanded leeway taxonomy recently developed by the USCG Research and Development Center (see reference [9]). Make the addition of objects and revision of model parameters simple and easy, requiring no changes to the software by, for example, using an external indexed file or database to store object type identifiers and corresponding leeway parameters that the software would query for leeway information.
    d. Use better interpolation techniques such as the inverse time technique.
    e. Provide correct handling of landed and adrift objects
    f. Add the ability to incorporate information from real time environmental measurements.

5. Provide a single search planning tool that performs well in both oceanic and near-shore environments and allows a smooth transition from one to the other whenever necessary.

   A prerequisite for near-shore usage is high resolution environmental data near shore, including land/shoreline location data, so the new tool can be used both for open ocean and near shore search planning.

6. Improved sensor and detection modeling
   a. Add the capability to model sensors using lateral range functions
   b. Add the capability to account for the effect of multiple sensors on the same platform
   c. Account for both the motion of the search platform and the search object during the search when calculating detection probabilities and posterior object location distributions

7. Search Plan Recommendations.
   a. Provide the capability to recommend (near optimal) searches for multiple object types and for survivor lifetime searches.
   b. Provide the capability to plan a sequence of (near-optimal) searches over time that account for the object's probable motion.

8. Reporting and Documentation
   a. Provide almost automatic reporting and documentation capabilities so that good records are kept for all searches that use CASP.
   b. Provide a smooth and virtually automatic interface to the USCG's SAR records database.

9. Implementation
   a. The choice of the computer language in which to implement CASP should be made by the Coast Guard based on its operational needs and computer capabilities. A good system can be developed in any modern, capable language, e.g., C^{++}, Java, or FORTRAN 90/95. Mixed language development is also quite feasible in the modern development environment. For example, both FORTRAN and C^{++} are well-known for their computational efficiency, availability of extensive mathematical libraries, and suitability for the highly mathematical algorithms that the new search planning tool will necessarily require. Fortran 90/95 has been substantially expanded and modernized to include many Ada-like, C-like, and object-oriented features

and capabilities (including vector operations) as well as parallel processing (when available). C^{++} is a popular object-oriented language often used to develop office automation tools, user interfaces, and computer operating systems.

Java is an object oriented language that provides a much improved development environment over C^{++}. Development times are faster, and there are fewer problems with the code because of features such as automatic memory management and array-out-of-bounds checks. Java provides for multiple threads for parallel processes and cross platform portability (even for the graphics) on Windows, Solaris, Unix, and Linux operating systems. Java performs computationally intensive chores almost as quickly as C^{++}. Java does not have the extensive mathematical libraries that are available in C^{++} or FORTRAN. (Metron's multiple-target, multiple-sensor tracker, which is in operational use on some US attack submarines, is written in Java and resides in a multiple CPU Linux system consisting of C^{++} and Java programs.)

Since each language has certain advantages, a mixed language development may be indicated. Integrated development environments for mixed FORTRAN/C^{++} system development are readily available. Mixtures of C^{++} and Java are common.

b. Similarly the choice of whether to implement CASP as a central system hosted on the computers at the OSC or a distributed system where computations are performed locally on work stations at operations centers is an operational decision for the Coast Guard. A good system can be developed for either implementation strategy since modern personal computers and workstations easily have sufficient computing speed and data storage capacity for implementing the envisioned search planning tool.

However, good geographic displays are essential for good search planning. Search planners will need an easy-to-use and highly responsive graphic and geographic interface to plot probability maps, manipulate search areas and search patterns, get feedback on probability of success values for alternative search plans they create or modify on the screen, display various environmental data, and perform a host of other activities needed for effective, efficient search planning. At the present state of technology and given the high workloads that are common in an operations center, it is likely that these functions will need to be performed on the user's local workstation rather than over a network on a remote host. This needs to be determined.

10. Training.

This is an important issue, but not one within the purview of this review except to say that the Coast Guard will have to continue to support the training of CASP users. However, there will be a clear advantage to training users on one search planning system rather than two as is currently done.

4. REFERENCES

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