DEVELOPMENT AND APPLICATION OF A FAMILY OF GENERAL EXPERT SYSTEMS

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P. A. D. de Maine and K. D. Bradley

Department of Computer Science and Engineering
Auburn University
Auburn, AL 36849-5347

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Prepared by:

Dr. P.A.D. de Maine and K. D. Bradley

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Computer Science and Engineering Department
108 Dunstan Hall, Auburn University
Auburn, Alabama 36849

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CONTENTS

I. INTRODUCTION

The objectives for this document are to:

(i) Describe the ongoing work of developing a family of general expert systems that can be used to solve many problems for different applications or disciplines.

(ii) Suggest the potential use of some of these systems in United States Navy applications.

Fully operational versions of two of the thirteen systems, CURFIT and FRANS, are available for demonstration. Financial support is needed to complete the design and implementation of selected members of the proposed family of expert systems and to design specific applications for the next generation of United States Navy requirements.

II. THE FAMILY OF GENERAL EXPERT SYSTEMS

Recently it has been noted [1] that these four problems, common to many disciplines, can be solved by applications of combinatorial mathematics, with the rules and interpretation uniquely defined by the discipline or application.

1. Evaluating systems of equations.

2. Construction, decomposition, alteration, and combination of graphs.

3. Identification of entities.

4. Classification of entities.

The first two problems require predictive capabilities to help design experiments.

The family of expert systems that has evolved [1] consists of four principal systems, for solving the four class problems, and nine Artificial Intelligence Systems Support Tools, AISST, that are used by the principal systems or on a stand-alone basis. (See Figure 1) The nine AISST systems perform special tasks like high-speed retrieval or transporting high-level language code. There are prototypes for ten of the thirteen systems and four of the prototypes are available for production use [2]. Two of the four, REF FILER and INTEGRAL, are commercially available.

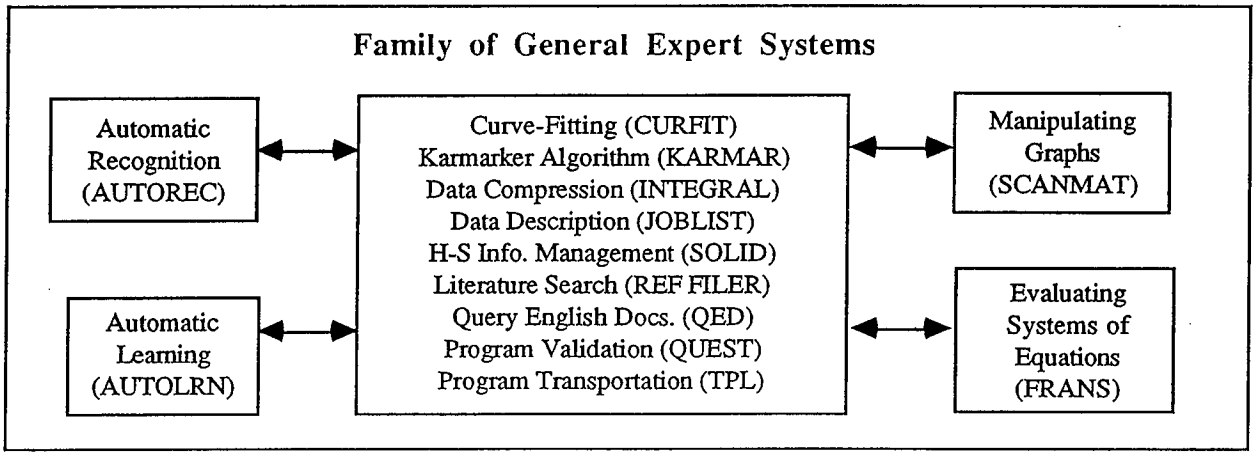


Figure 1. Proposed Systems. The individual systems are described in [1] and their status in [2]. SCANMAT, QUEST, and REF FILER are the work of Z. Hippe, D. Brown, and SOFT FOCUS, Inc. respectively.

There are four types of Expert Systems (Defined as systems that can be easily used to discover non-obvious knowledge): Conventional, Auto-deductive, Conventional Adaptive Learning, and Auto-learning. Conventional systems require examples of the related state-of-the-art knowledge to construct the rule (viz. knowledge) base or determine classification parameters. They essentially mimic the perceived way humans think and are generally incapable of predicting unprecedented events (events that cannot be predicted from the state-of-the-art alone). Automatic systems are applications of combinatorial mathematics in which the rule base or classification parameters, for the learning systems, are determined by mathematical rules. Such systems can predict unprecedented events. The four principal expert systems in the proposed family [1] are classed as automatic. FRANS and SCANMAT are auto-deductive systems, while both AUTOLRN and AUTOREC are auto-learning systems. Several of the Artificial Intelligence System Support Tools are conventional expert systems.

Interfaces for such general systems, that can be invoked either on a stand-alone basis or by another expert system, must satisfy two conflicting sets of requirements. The interfaces should be easy to use (user-friendly), interactive, and support a language that restricts their use to a comparatively narrow class of user. From the system viewpoint, interfaces should be flexible and, for real-time applications, be interactive with respect to both user and the inference engine, sometimes called the model base. These requirements are met with a two-tier design that contains an Interactive User-Friendly Interface, IUFI, and a System Interface, SI [3].

Systems that could be particularly relevant to United States Navy applications are described next. FRANS, AUTOLRN and AUTOREC are automatic systems (i.e. they can predict unprecedented events). CURFIT, INTEGRAL, JOBLIST and SOLID are AISST

systems.

II.1 Curve-Fitting System (CURFIT):

In the CURFIT method, the traditional question, "Do these data fit (or describe) the equation?" is replaced by "Do these data describe the equation to within certain user specified limits?". The input for CURFIT consists of the trial equation and values for the observables with their associated user-stipulated Maximum Tolerances. Values for the variables in the trial equation and their associated Error Bounds are computed. The error bounds are the maximum acceptable deviation for every value of each variable and, together, they define a vortex that can be constructed about the data-points. Thus a trial equation with N variables has an associated N dimensional error bound vortex.

CURFIT is an asymptotic method in which conventional curve-fitting methods are used to compute the median curve from the data-points. The vortex is then used to reject spurious data (i.e. legally rejected data-points) and to detect unsuspected curvature (i.e. data-points that consistently diverge from the median curve). The domain of the trial equation is altered to eliminate curvature, the median curve is recomputed, and the Maximum Possible Errors in the median values for parameters are then computed from the worst case configuration for the deviations of the accepted data-points. This process is repeated with a new domain until all data-points have been considered. A perfect fit occurs only when there is a single domain, there are no rejected data-points and the maximum possible errors are vanishingly small.

The unambiguous "goodness of fit" criteria are:

A. The maximum tolerances for all the observables.

B. The data-points that were legally rejected. There are no illegally rejected data-points because they lead to partitioning into overlapping domains and are eventually incorporated into at least one domain.

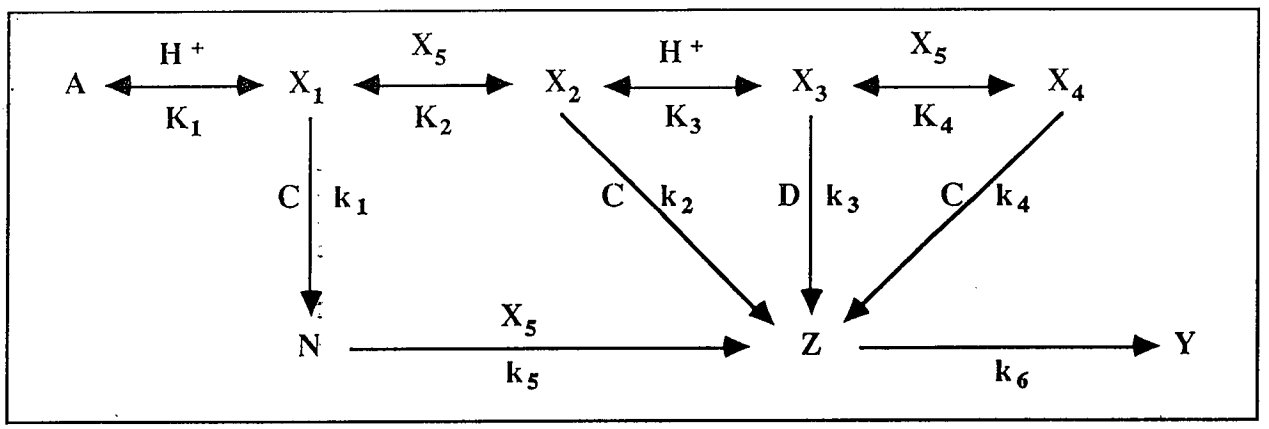
C. For each domain, the range of every variable together with the median value for every parameter and associated maximum possible errors.

The current operational version of CURFIT, which is available for both IBM PC AT/Clones and VAX computers, can solve any continuous equation that does not have integrals or derivatives. The proposed final version will solve any equation.

II.2 Modeling System (FRANS):

The current fully operational version of FRANS is a general software system designed to handle reaction models with any combination of first order ordinary differential (e.g. rate) and nonlinear (e.g. equilibrium) equations. No specific assumptions are made aside from the Law of Conservation of Mass/Energy. Parameters may be multi- or single-valued. The CURFIT system is an intrinsic part of FRANS. When finally complete, the FRANS system will process questions about systems with <u>any</u> combination of <u>any</u> equations.

To illustrate the use of FRANS, consider this chemical reaction network for the mechanism of a four-component condensation in Peptide Synthesis.



Here, K_i and k_i are equilibrium and rate constants, respectively. A, C, D, H^+, N, X_i, Y and Z designate chemical species. The arrow (----->) represents a time dependent first order ordinary differential equation. $A \xleftrightarrow[K_1]{H^+} X_1$ denotes the chemical equilibrium equation: $K_1 = [X_1]/[A][H^+]$. [] denotes the chemical concentration of the enclosed species. The parameters are equilibrium constants, rate constants, and concentration-time data for the chemical compounds or intermediates in the reaction scheme.

Pertinent questions are:

(i) For what combinations of parameters must values be given so that the FRANS system can compute values for all unknown parameters?

(ii) What information is needed by FRANS in order to compute the value for k_1 and concentration-time values for Z?

(iii) If k_5 and k_6 are very large (i.e. the reactions are fast) and data for H^+, X_5 and C are given, what parameters can be computed?

For such mathematical models there are two question types: prediction and computation questions. Prediction questions seek information about various combinations of parameters for which data are required so that one may compute values for any subset of the parameters and test the validity of a proposed model. Total solutions to prediction questions are those in which all parameters are either given or computed. Partial solutions are not restricted to separately identified submodels of the mathematical scheme and contain at least one parameter that is neither given nor computed. This predictive facility is of paramount importance because it can be used to help design experiments that will yield data for successful tests of a proposed model. Computation questions result in the calculation of values for constant and/or variable parameters, and if possible, tests of the validity of a proposed model. Simulation questions are those in which only values for the variable parameters (e.g. concentrations) are computed. In processing computation questions, FRANS first uses the predictive facility to determine which parameters are computable, the minimum set of equations, and the order in which they should be solved, then uses the input data to calculate values for parameters. An integral part of FRANS is its Error Detection and Corrective Action (EDCA) algorithm that determines the computational accuracy of every computed value and assures only those values specified by the user as acceptable are displayed.

II.3 Data Compression System (INTEGRAL):

INTEGRAL reversibly compresses/decompresses <u>any</u> digitized data at high speeds without the loss of even a single binary bit of significant information. The current version yields savings as high as 99.98%, with a median between 60% and 80%, at decompression speeds as high as 470,000 bytes/second (3,760,000 BPS or BAUD) on the IBM 360/67(1). With the IBM 370/168, savings are the same but compression and decompression speeds have exceeded 3,200,000 and 8,000,000 BAUD, respectively.

The INTEGRAL Family has been implemented in IBM Basic Assembler, the "C" programming language, and is now being implemented in hardware [1,2].

II.4 Data Management System (JOBLIST/SOLID):

JOBLIST/SOLID is a high speed data management system that has bounded search times, i.e. the amount of time to process any query is small, independent of the size or

number of different databases and the form of the question asked. The DESCRIBE data-description language is designed to present information in an easily-understood form. The DESCRIBE system, still to be implemented, will convert information coded in the DESCRIBE language to a general data structure called JOBLIST.

A partially implemented JOBLIST system creates, maintains, and manipulates the JOBLIST data structure. The DESCRIBE language describes both information and the operations that are to be performed. The JOBLIST system constructs the internally used data form and executes all arithmetic and manipulative operations. The JOBLIST system uses the SOLID system to retrieve and update information in the data-bases (or libraries).

The SOLID system manages information and, in particular, processes both retrieval and update requests received from the JOBLIST system. Its mathematical basis is the JOBLIST data structure. SOLID has three interdependent files, REGFILE, AFILE and MFILE, that can be accessed independently of one another. MFILE contains the referenced information in compressed form. AFILE is a keyed-entry file that yields the so-called machine address to the compressed items of information in the MFILE. REGFILE is a simulated communications network whose "information paths" are described by the queries. The file structure and performance data for the SOLID system have been discussed in [1].

A prototype of the SOLID system, coded in IBM Basic Assembler, was used as a part of the highly successful PENNRAMS system for processing patient health-care information. In experiments with the PENNRAMS prototype on an IBM 360/67 the maximum in-core search times were 0.0001 seconds for both explicit and non-explicit queries with a single access to random access storage. The VAX 780 version is described in [1].

A planned extension of the JOBLIST/SOLID system to develop an intelligent information management system will use the two automatic learning systems, AUTOLRN and AUTOREC, and the techniques of neural networks [4].

II.5 Learning Systems (AUTOLRN/AUTOREC):

AUTOLRN is a fully automatic learning system in which classification is done without any reference to human perception. It would be useful for solving the classification problems that are the basis for most identification and retrieval systems. Moreover, by deliberately over-specifying the initial choice of candidate "significant observables", it could also be used to determine causal relationships.

The AUTOREC learning system requires a human definition of the entities that are to be recognized. Typically such systems would be used to identify partial or complete images - the classic pattern recognition problem. The basis of the proposed AUTOREC system has been described elsewhere [5]. Here it is sufficient to note that in AUTOREC, the conventional scene analysis will be extended to obtain one and two dimensional "minimal views" that are stored in the MINIMAL VIEW LIBRARY. Entities, which can be real (like a picture) or abstract (like the behavior of a function), are defined in the ENTITY LIBRARY in terms of minimal views or combination(s) of minimal views, called "composite minimal views". This approach leads to a very much smaller database and simplifies the problem of identifying entities.

III. POTENTIAL NAVAL APPLICATIONS

The future of any technically oriented organization like the United States Navy is in automated systems. The advantages of automated systems are numerous. The systems described above are designed to achieve accurate results while maximizing speed and security.

Portability of these systems is achieved with the TPL system [1,2], one of the nine Artificial Intelligence System Support tools. Although some specialized hardware may be necessary, the plan is to provide the software part for a fully operational system. The goal is to put the package into an off-the-shelf "Tempest" approved computer and connect the interfaces. The system would have several backups plus full local and remote reboot capability if the backups fail.

A major problem encountered by the Navy is what to do if the systems fail or are damaged. The answer is to design a system with enough backup that only a catastrophic failure or ship destruction would destroy the system. There will be provisions to remotely boot the system via the Global System (described below) if all systems are lost.

Another major issue is cost. The best way to save money is to develop a family of software systems that function equally well in small and large system environments. The previously described family of software systems perform equally well in both environments so that only the interfaces need be unique. The following sections describe possible applications of the family of Automated Systems. The basic exploratory work resulted in the existence of prototypes that have established their feasibility [2].

III.1 Automated Combat System

Reference [6] defines an application of the family of general expert systems called an Automated Classification, Identification, and Information (ACII) system. This system functions similar to a distributed operating system with independent sections communicating via message passing. The Unit ACII uses three systems to determine classification. The Sensor Evaluator coordinates the unit's internal detection equipment to identify a contact. The Automated Tracking Unit maintains the "most likely" location of all known units in the operating area. The Knowledge Acquisition Unit attempts to make a classification if the other units cannot. It also provides automated tactics evaluation and determines changes to present knowledge concerning the hostile force. The Information Analysis and Control Unit coordinates the operation of the three systems. It also interfaces with the unit's display system to exhibit the information and handle queries and provides automatic report generation to the Global ACII System discussed below and to other local units much like the Naval Tactical Data System. The segmented Knowledge Base provides various types of information to all four systems. The ACII system can be employed on ships, submarines, aircraft, and at intelligence gathering units ashore. The ACII system can be enhanced to include weapons systems and weapons decision making and form an Automated Combat System.

III.2 Global ACII System

The Global ACII System retrieves evaluated information from all the units in its theater of operations. It further evaluates the information based on global knowledge. The Global ACII System then transfers the information to all units in the affected operating area including the initiating unit. It also uses the information to update all relevant headquarters and other associated commands.

The Global ACII System concept will permit real-time evaluation of the tactical environment. All levels of command from the local commanders to the Joint Chiefs of Staffs will have a picture of the tactical situation. Command decisions, evaluations, etc. could be exchanged at significantly increased speed.

Real-time evaluation of tactics is a function of both the Global ACII System and Unit ACII Systems. Long hours of writing Lessons Learned could be significantly reduced. Tactics would be evaluated in real-time. The AUTOLRN system would continuously select the best tactics. Commanders and other officers would be able to retrieve and review the best tactics from the Global System as well as updating the system with new and improved tactics. Decisions could be made using the latest information. Rules of Engagement

changes could be implemented within seconds by inserting them in the Global ACII System. Intelligence forces would also be able to insert the latest tactics employed by enemy forces and new counter tactics.

The Global ACII System will also permit certain unique training capabilities. If training requires a three Battle Group operation with only one Battle Group actually at sea, the other two can be simulated using the Global ACII System. For example, in the Pacific Ocean area, one Battle Group could be deployed, another Battle Group could be simulated using the facilities at the Multi-threat Team Trainer at Point Loma, and the third simulated using the Combat Information Centers of the next deploying Battle Group. The Global ACII System would reposition units appropriately. Another alternative training exercise would be to have the deployed Battle Group (call it BG-A) operate with the next deploying Battle Group (call it BG-B) by allowing the Global ACII System to reposition BG-B to BG-A's area of operations. The Force Tactical Communications would be conducted using satellite circuits.

Vessels undergoing refresher training or other predeployment training could be assigned as part of another operating group and function with that group while being thousands of miles away. All types of training exercises could be run from the Global ACII System. Ships and submarines could do major parts of their training without leaving the ship or getting underway. A task force preparing for deployment with units in several different ports could perform their task force training without having to transit to the local training command. The reduced underway time would save operating funds, keep morale of the personnel higher, and eliminate several costly training bases and commands. Once the system incorporates Automated Engineering, Automated Damage Control, etc. into the system, full scale training could be performed in home ports.

III.3 Other Fleet Uses

On ships the same family of general expert systems could be applied to Automated Damage Control, Automated Engineering Systems including main propulsion and auxiliaries, and Automated Supply Systems. Because of the integrated and flexible security features, the same systems can be incorporated to include personnel databases, medical databases, etc. to be accessed only by properly authorized personnel. The Captain of the ship could switch the same terminal from the tactical situation to access the binnacle list, review personnel records, review old officer fitness reports, draft and send communications messages, review correspondence and make revisions, etc.

Other shipboard systems could use the general expert systems. AUTOREC and

CURFIT could be used to upgrade the radar display performance. A system that evaluates "Rules of the Road" situations providing recommended actions if a collision situation exists would be useful to Navigators.

From the development of ACII, the Report Generator could be enhanced (i.e. create new applications) to include Casualty Reports (CASREP), Operational Reports (OPREP), and other related reports that only require filling in blanks from a screen (similar to Electronic Mail systems). One system application development (ACII) therefore leads to several more.

III.4 Manpower, Personnel, and Training

In a request for proposals and concept papers from Manpower, Personnel, and Training [7], several areas of interest are related. Under the heading of methodological issues, the general expert systems apply. Under manpower modelling, FRANS and AUTOLRN could be incorporated for forecasting and modelling formula evaluation. AUTOLRN could be employed for formulating and maintaining assignment systems, etc. CURFIT and FRANS would be useful for the Personnel Measurement requirement. SOLID and JOBLIST are ideally suited for the secure, high-speed Database Manipulation requirements.

III.5 Shore Commands (Staffs, Training Commands, Fleet Bases, Air Bases, etc.)

The applications developed for shipboard and aircraft use apply equally to shore based commands. The Local Area Network (LAN) or MILNET can be adapted to run the same applications afloat and ashore so personnel trained in either environment would perform equally well. Having personnel using the same systems afloat and ashore would improve the efficiency of the individual and require fewer man-hours lost due to retraining. Staffs would be able to better interact with the fleet by using the same systems.

Developing new applications for specific shore use would also be possible. The Navy Sea Systems Command could use AUTOLRN, CURFIT and FRANS for engineering evaluations. The Navy Training Command could use AUTOREC and AUTOLRN to develop new training concepts as well as CURFIT and FRANS to evaluated the new concepts and their performance. Numerous commands could have applications developed utilizing the general expert system family.

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HANDOUT - Expert Systems

This document contains a summary of ongoing work to realize a family of thirteen general expert systems that can be easily used by experimentalists in many different disciplines to help design experiments and process data. There are four principal expert systems and nine so-called Artificial Intelligence System Support Tools, AISST, that are used by the principal expert systems. However, each AISST can be used alone for specific tasks, and many are really expert systems.

Section I shows the relationships among the thirteen component systems and Section II describes the task of each system, its status and availability. Here are listed the four phases in a system's development.

In the Conceptual Design Phase the conceptual basis of the proposed system is specified in non computer terms.

In the Detailed Design Phase the detailed design, which includes data structures and needed algorithms, is specified.

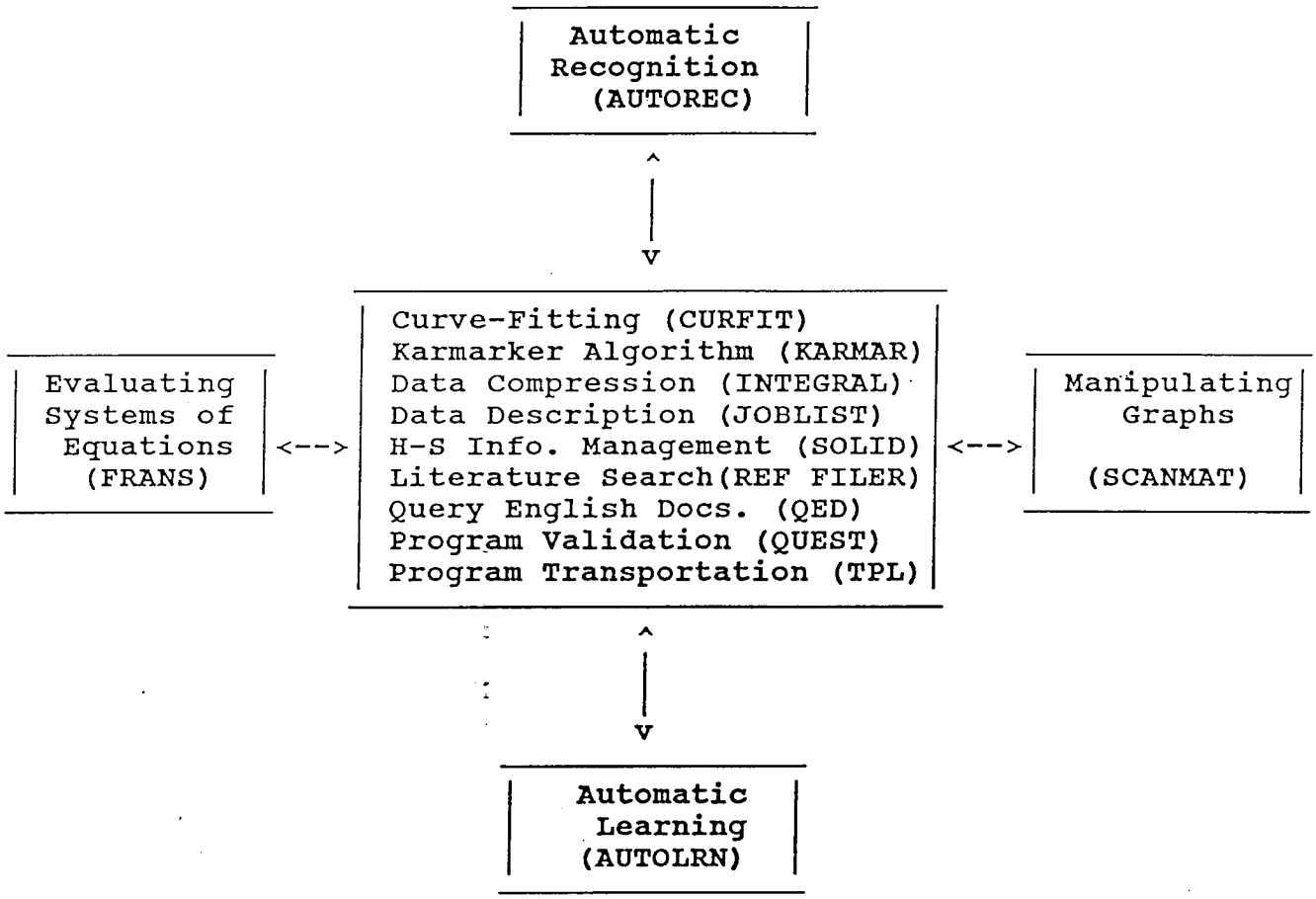
In the Operational Prototype Phase, preliminary versions of the system are available to selected users.

In the Fully Operational Prototype Phase a copy of the system is available to all who request it.

At this time there are prototypes for ten of the thirteen systems. The other three (AUTOLRN, AUTOREC and KAMAR) are in the design phases. Five (FRANS, SCANMAT, CURFIT, INTEGRAL, and REF FILER) are in the Fully Operational Prototype Phase, and four (FRANS, SCANMAT, CURFIT and REF FILER) are available for the IBM PC AT and its clones. FRANS, SCANMAT and CURFIT are also available for the VAX 11/780 and its clones.

Key references are listed in Section III, and information about obtaining the AT and VAX versions of the available systems is given in Section IV.

I. FAMILY OF GENERAL EXPERT SYSTEMS



REF FILER, QUEST and SCANMAT are systems developed by SOFT FOCUS, D.B. Brown and Z.S. Hippe respectively (See Section III for references).

II. DESCRIPTION OF COMPONENT EXPERT SYSTEMS

1. FRANS — Solves any system of any combination of equilibrium and rate equations.
   STATUS — The VAX and IBM AT prototype are fully operational.
   AVAILABILITY — The versions for AT and VAX 11/780 clones are available.

2. SCANMAT — An application of the Ugi-Dugundji mathematical model for chemical synthesis by Z. Hippe.
   STATUS — The VAX and IBM AT prototypes are fully operational.
   AVAILABILITY — The versions for the VAX 11/780 and AT clones are available.

3. AUTOLRN — A planned implementation of a general Automatic Adaptive Learning system for determining controlling parameters and classification.
   STATUS — The detailed design is now being done.
   AVAILABILITY — Not available.

4. AUTOREC — A planned implementation of a general Automatic Adaptive Learning System for identification.
   STATUS — The detailed design has been completed.
   AVAILABILITY — Not available.

5. CURFIT — Uses user specified estimates of the reliability of raw data to unambiguously determine whether the data are described by a user specified non-linear equation.
   STATUS — The VAX and IBM AT prototypes are fully operational.
   AVAILABILITY — The versions for the VAX 11/780 and AT clones are available.

6. KARMAR — A planned implementation of the Karmarker algorithm.
   STATUS — If AT & T complete the reported implementation then this task will be abandoned.
   AVAILABILITY — Not available.

7. INTEGRAL — A propriety system that substantially reduces the storage needed by compressing any information at very high speeds. A hardware prototype is now being implemented.
   STATUS — Fully operational versions coded in IBM BAL and in Language C.
   AVAILABILITY — Commercially available from Prof. J.D. Irwin, Electrical Engineering Department, Braun Hall, Auburn University, Auburn, AL 36849, U.S.A.

8. JOBLIST — A context free language for describing data. It is the basis of the SOLID system.
   STATUS — The VAX 11/780 FORTRAN coded prototype is operational.
   AVAILABILITY — Not available.

9. SOLID — A high-speed data management system that is both information and question-type independent, and has bounded search times (i.e. independent of the amount of information in the system).
   STATUS — The VAX 11/780 FORTRAN coded prototype is operational.
   AVAILABILITY — Not available.

10. REF FILER — A propriety retrieval system useful for the management of literature references. It is available from SOFT FOCUS for about $40.
   STATUS — Fully operational AT clone version.
   AVAILABILITY — Commercially available from SOFT FOCUS, P.O. Box 390961, Mountain View, CA 94309, U.S.A.

11. QED — A system for determining the information content of English language documents.
   STATUS — The VAX 11/780 PROLOG coded prototype is operational.
   AVAILABILITY — Not available.

12. QUEST — A system by D. Brown for checking the validity of programs.
   STATUS — The VAX 11/780 FORTRAN coded prototype is operational.
   AVAILABILITY — For information write to:
   Prof. D.B. Brown
   Computer Science and Engineering Department
   106 Dunstan Hall
   Auburn University
   Auburn
   AL 36849
   U.S.A.

13. TPL — A system for the automatic transportation of high-level language code (i.e. FORTRAN) between different machine environments (e.g. VAX to AT).
   STATUS — The VAX 11/780 FORTRAN code prototype is operational.
   AVAILABILITY — Available from the U.S. Army Strategic Defense Command (U.S. ARMY STRATEGIC DEFENSE COMMAND, P.O. Box 1500, Huntsville, AL 35807-3801, U.S.A)

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[16] "QUEST - Query Utility Environment for Software Testing", D.B. Brown, K.D. Haga and O. Weyrich, Int. Test & Eval. Assoc. 1986 Symp. Proc. pp 38-43 (1986).

TPL:

[17] "TRANSPORTING HIGH-LEVEL LANGUAGE CODE BETWEEN DIFFERENT COMPUTER ENVIRONMENTS", S.M. Jodis and P.A.D. de Maine, 26th. Ann. Conf. of the Southeast Region, Association for Computing Machinery, Mobile, April 21-22, 1988, 77-83 (1988).

[18] a. "A Transportable Programming Language (TPL) System I. Overview", P.A.D. de Maine, S. Leong and C.G. Davis, Int. J. Comp. and Information Sciences 14, #3, 161-182 (1985).

b. "A Transportable Programming Language (TPL) System II. The Bifunctional Compiler System", S. Leong, S. Jodis, K. Sullivan, O. Jiang and P.A.D. de Maine, I.E.E.E. Trans. on Software Engineering (in Press).

IV. AVAILABILITY OF VAX AND PC AT VERSIONS

Three (FRANS, SCANMAT and CURFIT) of the thirteen systems are available for use on the IBM PC AT and VAX 11/780 and their clones. The AT version of REF FILER can be obtained for less that $40 from SOFT FOCUS, P.O. Box 390961, Mountain View, CA 94309, U.S.A. The other three systems (FRANS, SCANMAT and CURFIT) can be obtained from either of the following:

P.A.D. de Maine
Computer Science and Engineering
Department
108 Dunstan Hall
Auburn University
Auburn
AL 36849
U.S.A.

Prof. Dr. hab. Z.S. Hippe
Ossolinskich 5
35-328 RZESZOW
Poland

The prices quoted below are in U.S. dollars. Prices in the Polish currency can be obtained from Prof. Hippe.

IV.1 Computing Resources Required

The minimum resources required are for the AT versions is an AT or clone with 1 MByte of memory, ten MBytes of direct access storage, a floppy drive, a printer, a math coprocessor, Hercules graphics, and the DOS (at least version 3.2) operating system. For the VAX versions the AT must be coupled directly or indirectly to a VAX 11/780 or clone.

The recommended resources for the AT versions are an INTEL 80386 or 80286 based clone with 4.5 MBytes of memory, 40 MBytes of random access storage, a 5.25 inch 1.2 MByte floppy drive, a math coprocessor with the highest possible speed (12 MHertz and 16 MHertz for the 80286 and 80386 machines respectively), a printer, Hercules graphics, and the DOS operating system. Also recommended are an Irwin Magnetic tape drive (for high-speed backups) and a 1,200/2,400 internal modem (for communicating with other machines).

IV.2 CURFIT and FRANS Systems

A modified version of CURFIT is used transparently by FRANS. CURFIT can be used on a stand alone basis to unambiguously determine whether data are described by a user stipulated equation.

The complete documentation for either the VAX or AT versions of both the CURFIT and FRANS systems is $100.00. The documentation consists of:

1. Copies of all source and load module libraries. The load modules libraries contain installation instructions and tests. The formats available are 720 KBytes 3.5" or 1.2 MByte 5.25" floppy diskettes. PLEASE BE SURE TO STIPULATE THE FORMAT.

2. Reprints of the key papers that have appeared or are in press.

3. Copies of the seven manuals.

The seven manuals are:

1. "Operation and Logic Manual for the CURFIT System", P.A.D. de Maine, Report No. 2 of the Series: Automatic Systems for the Physical Sciences, Computer Science Department, The Pennsylvania State University, University Park, PA 16802 - 250 pages (1976).

2. "CURFIT Interface Users Manual", P.A.D. de Maine and M.M. de Maine, Report No. 16 of the Series: Automatic Systems for the Physical Sciences, Computer Science and Engineering Department, Auburn University, Auburn, AL 36849 - 36 pages (July/1989).

3. "CURFIT Interface System Manual", Betty C. Cartee, D. Head, P.A.D. de Maine and M.M. de Maine, Report No. 9 of the Series: Automatic Systems for the Physical Sciences, Computer Science and Engineering Department, Auburn University, Auburn, AL 36849 - 243 pages (July, 1989).

4. "Logic Manual for the User Interface of the CRAMS System", M. Stubican and P.A.D. de Maine, Report No. 4 of the Series: Automatic Systems for the Physical Science, Computer Science Department, The Pennsylvania State University, University Park, PA 16802 - 60 pages (1976).

5. "Operation Manual for the CRAMS System", P.A.D. de Maine, Report No. 5 of the Series: Automatic Systems for the Physical Sciences, Computer Science Department, The Pennsylvania State University, University Park, PA 16802 (1980).

6. "Systems Manual for the CRAMS System", P.A.D. de Maine, Report No. 6 of the Series: Automatic Systems for the Physical Sciences, Computer Science Department, The Pennsylvania State University, University Park, PA 16802 - 125 pages (1980).

7. "User's Manual for the FRANS Interactive User-Friendly Interface", M.S. Wojtyna and P.A.D. de Maine, Report No. 15 of the Series: Automatic Systems for the Physical Sciences, Computer Science and Engineering Department, Auburn University, Auburn, AL 36849 - 9 pages (15 April 1988).

IV.3 SCANMAT System

The procurement policy for SCANMAT will be similar to that for CURFIT and FRANS. The complete documentation will consists of:

1. Copies of the source, object and tests.

2. Reprints of key papers.

3. Copies of manuals.

AUTOMATED CLASSIFICATION, IDENTIFICATION, AND INFORMATION (ACII) SYSTEM

by

Kenneth D. Bradley

This document defines the conceptual design of an Automated Classification, Identification, and Information System (ACII) for Navy vessels (vessels being defined as ships, submarines, and aircraft) implemented as a group of Expert Systems. The ACII system will perform the following functions:

1. Classify and, if possible, identify other vessels within an operating area.

2. Coordinate internal and external queries and information exchanges.

3. Generate new information based on events occurring during operations.

The ACII system will be designed for the next generation of Combat Information Systems. The system will be adaptable to the present and near future systems via interfaces. This report uses existing systems to explain the movement of information and sensor evaluations to ensure that classified information is not used.

BACKGROUND

The next generation Combat Information Center or Combat Control Center will require rapid, secure, fully evaluated information before receipt by decision makers. The development of an automatic system to coordinate information flow, produce evaluated information, and provide recommendations is an application of expert systems, advanced data retrieval techniques, and reliable, rapid communications. The next generation Naval Warfare Environment must have fast, reliable inter-area and ocean area exchange of combat information.

There are large amounts of information generated by fixed and non-fixed sensors throughout an operating or ocean area that must be shared. Examples are:

1. Navy ship and submarine movements via their reporting system.

2. Contact information from submarines, surface ships, and aircraft.

3. Intelligence photographs of non-friendly nation vessel movements out of ports.

4. Other services contact reporting and information generation (Air Force AWACS and KC-130 / Coast Guard ships and aircraft).

5. Commercial ships and aircraft movement reporting.

6. Other intelligence sources.

External information could be consolidated, continuously updated and evaluated, tailored to specific operating area need, and exchanged for use in decision making. Internal information could be evaluated using rules developed by the most experienced Navy experts available.

Besides the improved information flow, the automatic system solves other problems. If a fleet unit detects a sub-surface contact, the ACII automatically knows whether to identify it as friendly or unknown. If the contact is friendly, prosecution is not attempted preventing hostile forces from detection by elimination (They know where their sub-surface units are.) If the contact is unknown, a report is automatically generated and submitted, eliminating the need for a manual contact reporting system. Additionally, movement reporting would also be eliminated as a vessels position is periodically updated to the central information center. Numerous other manual reports (OPREP / RAINFORM / CASREP / etc.) are eliminated, changed, or enhanced by this system.

EXPERT SYSTEMS

The goal of this project is to build a family of expert systems that can easily be adapted to solve any shipboard or aircraft information evaluation problem. The major emphasis will be on solving combat information problems. Expert systems are conventionally defined as computer programs that solve classes of problems. They can be used to acquire new knowledge by a person familiar with the subject area. In this paper, an expert system is used to discover non-obvious knowledge, thereby eliminating database systems with obvious inference schema. R. K. Belev, in "Knowledge Representation for Decision Support Systems," North-Holland, Amsterdam, 1985, identified the five components of an expert system as a user friendly interface, model base, rule base, text base, and data base. This contrasts with the traditional user interface, inference engine, knowledge base, and database. In the Belev scheme, the model base defines the method for deducing new knowledge from the rule base and data base. The text base contains instructions for communicating with the user interface in an easily understood, familiar language. In the traditional identification scheme, the inference engine would be a combination of the model base and part of the knowledge base, while the text base is part

of the rule or knowledge base.

With the Belev scheme, expert systems can be classified into three principal categories defined as follows:

1. Conventional Expert Systems - The rule base is constructed using current knowledge to predict events within the defined expertise. The conventional expert system must be continually updated to maintain current knowledge.

2. Automatic Deductive Systems - An ADS is a special class of expert system. Its model base is a mathematical model. Its rule base is either an integral, indistinguishable part of the mathematical model or generated by the system itself from fundamental laws of science like the Conservation of Mass/Energy.

3. Automatic Adaptive Learning Systems - Automatic learning systems are used to classify or identify objects and entities. The model base is one or more clustering algorithms used to compute classification parameters for a known set which is then used to classify unknown sets. Adaptive learning systems augment known sets with unknown sets that have been classified. The classification parameters are recomputed to improve the predictive capabilities. There are two types of automatic adaptive learning systems. The Automatic Learning System does not require human input to determine classification parameters or to identify objects and entities. The Automatic Recognition System typically requires a description of the object or entity for recognition.

There are two related adaptive learning systems, AUTOLRN and AUTOREC, presently under investigation at Auburn University as defined in reference 1. The AUTOLRN and AUTOREC systems are implementations of general automatic adaptive learning systems for determining controlling parameters, classification, and identification.

ARTIFICIAL INTELLIGENCE SUPPORT SYSTEMS

There are also two related artificial intelligence support systems being investigated at Auburn University, JOBLIST and SOLID. JOBLIST/SOLID is a high speed data management system that has bounded search times, i.e. the amount of time to process any query is small, independent of the size or number of differennt databases and the form of the question asked. They are defined in references 2 and 3. The JOBLIST system creates, maintains, and manipulates the related data structure. It constructs the internally used data form and executes all arithmetic and manipulative operations. The JOBLIST system uses the SOLID system to retrieve and update information in the databases. The SOLID system

manages information and processes both retrieval and update requests received from the JOBLIST system. It is fully described in references 4 and 5. Its mathematical basis is the JOBLIST data structure. SOLID has three interdependent files (REGFILE, AFILE, and MFILE) that can be accessed independently. MFILE contains the referenced information in compressed form. AFILE is a keyed-entry file that yields the machine address of the compressed items in the MFILE. REGFILE is a simulated communications network whose information paths are described by the queries, i.e. there is no directory. The file structure and performance data are discussed in references 4 and 6. A prototype of the SOLID system was used as part of the highly successful PENNRAMS system, reference 6, for processing patient health-care information.

OVERALL ACII SYSTEM OPERATION

The overall ACII system operation involves creating a central information storage and evaluation unit, the Ocean Area Automatic Classification, Identification, and Information (ACII) System, to feed specific information to fleet units in their area of operations based on their need to know. If a Battle Group is operating in the Sea of Japan, it has access to all information on friendly and possible non-friendly contacts (not previously identified or known hostile) in that area and adjacent operating areas. The information would be transferred via a secure communications link to the unit's ACII Knowledge Base and Automated Tracking unit for access by the fleet unit and fleet commanders with access based on the individual need to know.

Figure 1 is a block diagram of the Ocean Area ACII System. It communicates with fleet units, fleet commanders (via the flagship's ACII), and headquarters commands. The Navy Communications System's network is used to transfer information to and from the

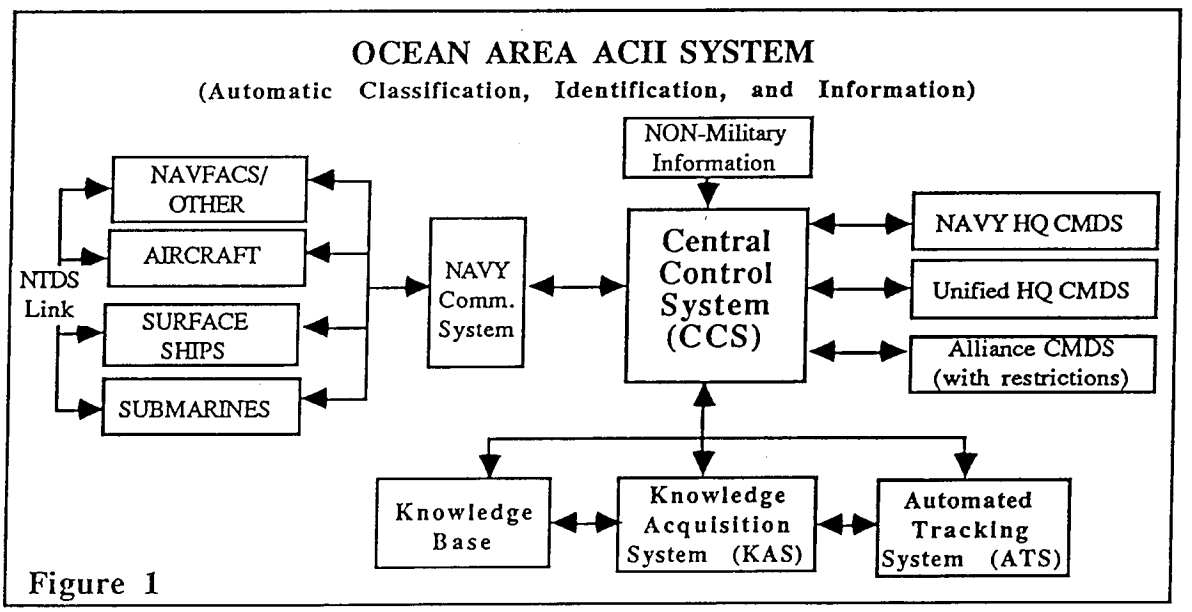

Figure 1

Ocean Area ACII system and fleet units. The contact and movement information from the fleet units to the Ocean Area Knowledge Base, Figure 2, is the foundation of the overall system concept. Fleet units are the Sensor Evaluator (part of the fleet unit system) of the central unit. The Central Control System (CCS) coordinates information flow. The CCS determines the information needs of the individual unit or headquarters command based on location, readiness condition set, etc. The CCS handles queries, transfers reports to the appropriate agency, and coordinates new information development. The Knowledge Acquisition System (KAS) continuously evaluates information to determine patterns like type of vessels operating in a specific area, new tactics employed by a group of contacts, or new types of units. The Knowledge Base contains information on aircraft, ships, submarines, naval tactics, etc. The Automated Tracking System (ATS) tracks all types of vessels including military and commercial surface ships and aircraft and submarines. It also provides a combinatorics matrix of course and speed changes for vessels to determine the probability of it being in a certain operating area.

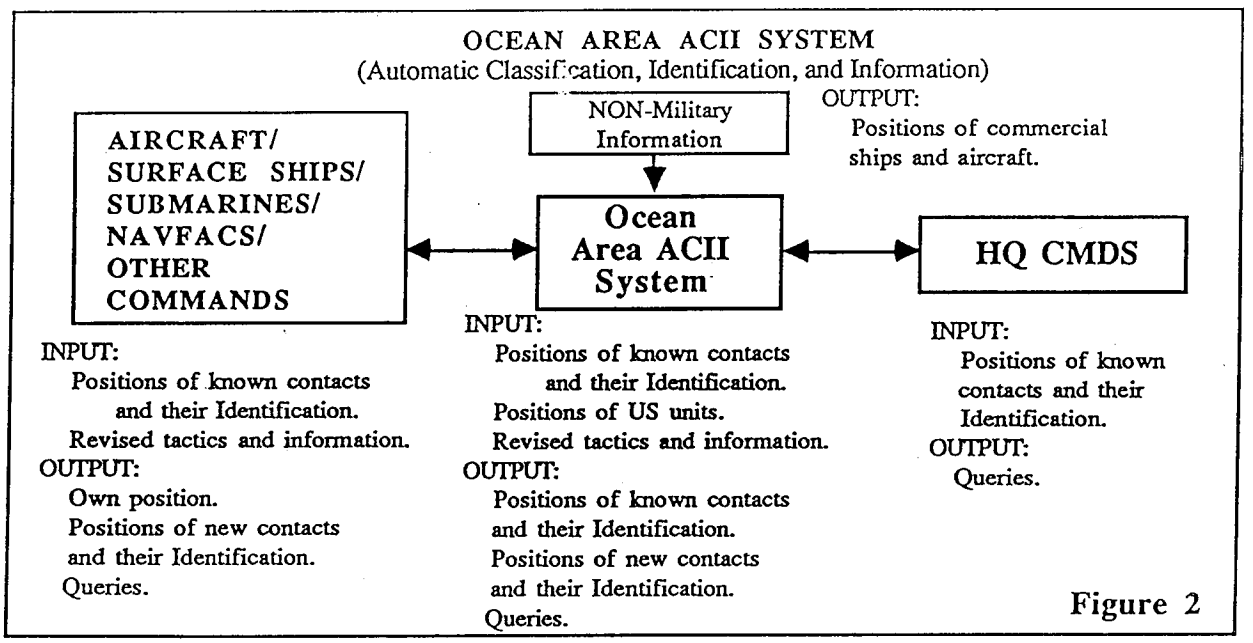

Figure 2

An example of information flow would be the CCS taking information from the ATS and Knowledge Base, developing contact reports for fleet units in an area with probability location and search area defined. A low probability contact would be stored in the fleet unit's Knowledge Base. A medium to high probability contact would be added to the unit's Automated Tracking module based on the contacts highest probability location or last confirmed location, and then this information is displayed on the fleet unit's threat matrix.

The Ocean Area ACII System would require a large multiprocessor computer system and communications network. As each Ocean Area commander (like Commander in Chief,

Pacific Ocean) already has a major computer system and the Navy's Communications System has adequate satellite networks, specific hardware requirements are not provided. The software for the Ocean Area ACII System would use algorithms similar to those developed for the unit ACII system.

UNIT ACII SYSTEM

The Unit ACII System, Figure 3, is a block diagram of the primary system for ships, submarines, and aircraft. It is similar to the Ocean Area ACII System. There are several significant differences like the Sensor Evaluator and the interface with the Movement and Ocean Evaluation Unit (MOE). The details of the individual blocks will be presented separately.

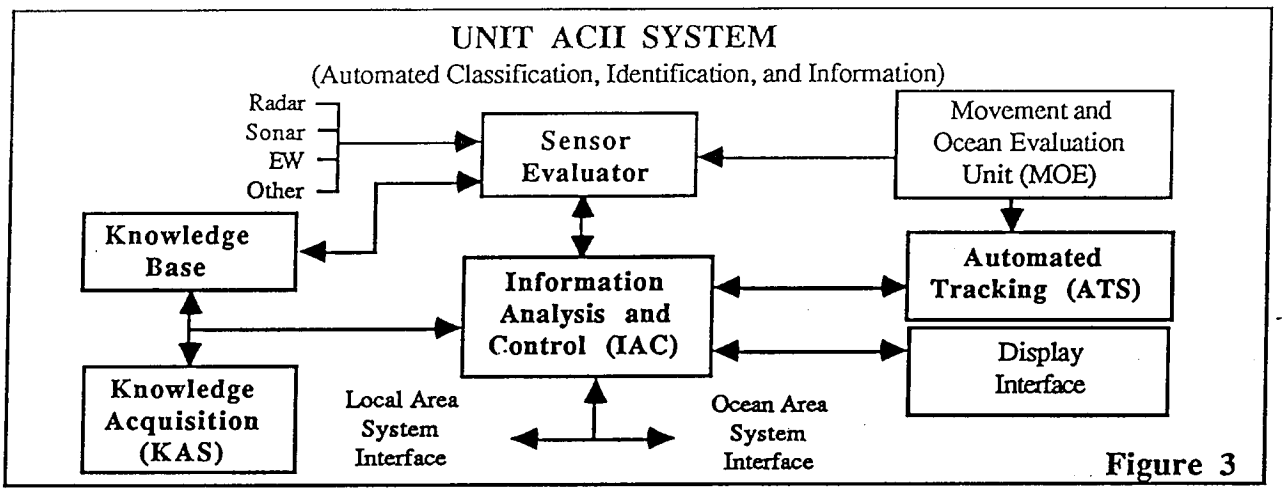

Figure 3

The major advantages of the ACII system are security of information, speed of evaluation, automatic report generation, coordinated flow of internal and external information, and knowledge of contacts before their detection. The plan is to develop a secure system with minimal hardware requirements. Interfaces to presently existing display, communications, navigation, radar, sonar, and electronic warfare systems would eliminate redundant systems. Examples are using information generated by the Naval Tactical Data System (NTDS) for the Radar Evaluator and the NTDS communications system for local area of operations exchange of information. The only additional hardware requirement is a high speed, medium size, TEMPEST approved multiprocessor computer for the modules and their interfaces. Bulk encryption units required for the Local Area and Ocean Area communication networks are already in existence. As the hardware will be small, lightweight, and inexpensive, redundant systems could be installed on the larger units (like ships and submarines) to prevent loss of the system during hostile operations. For loss of the unit's power source, a secondary power source like batteries and a continuous backup

secondary memory system are needed.

INFORMATION ANALYSIS AND CONTROL UNIT

The Information Analysis and Control unit (IAC) is the heart of the Unit ACII system. It has several functions as shown in Figure 4. The primary function of the IAC is to take a classification (if possible) from the Sensor Evaluator, compare it to contacts in the Automated Tracking unit (Track Coordination Module), determine the identification (Identification Module), and report to the unit's display facilities and the Inter-area and Ocean Area systems (Report Generation Module). It also interfaces with the Ocean Area ACII System via a communications link to obtain contact information for Automated Tracking. The system also interfaces with the unit's display system to handle queries from the unit's information collection center (CIC) such as listing active surface tracks with probable locations inside a hundred mile radius and providing evaluated information based on the parameters set by the user. The IAC interfaces with the Knowledge Acquisition unit to generate new information on contacts like changes in tactics, new sensors, counter-detection activities, etc. The Information Coordination Module controls information flow in the IAC as well as queries of the Knowledge Base. The Mathematical Module is used by all the modules for combinatoric evaluations.

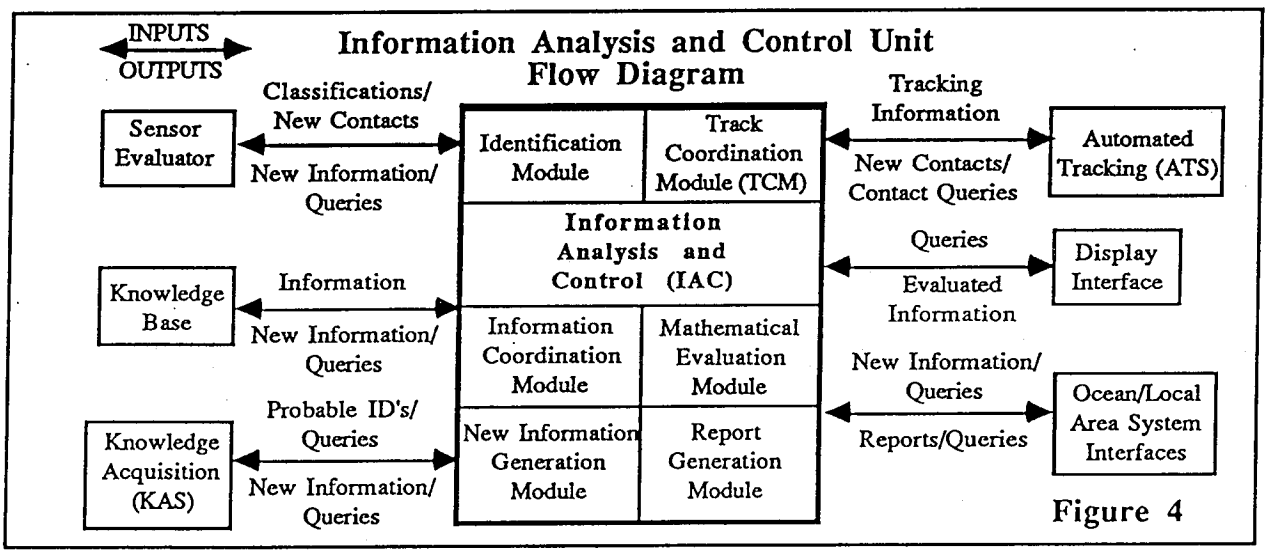

Figure 4

SENSOR EVALUATOR

The Sensor Evaluator is the information gathering and evaluation system. It is broken into four modules (Radar Evaluator, Electronic Warfare Evaluator, Sonar Evaluator, and Other Signals Evaluator) and the Sensor Coordination, Classification, and

Evaluation (SCCE) unit. (See Figure 5.) The purpose of the Sensor Evaluator is to provide classification information to the Information Analysis and Control unit (IAC). Each module's functions are described separately.

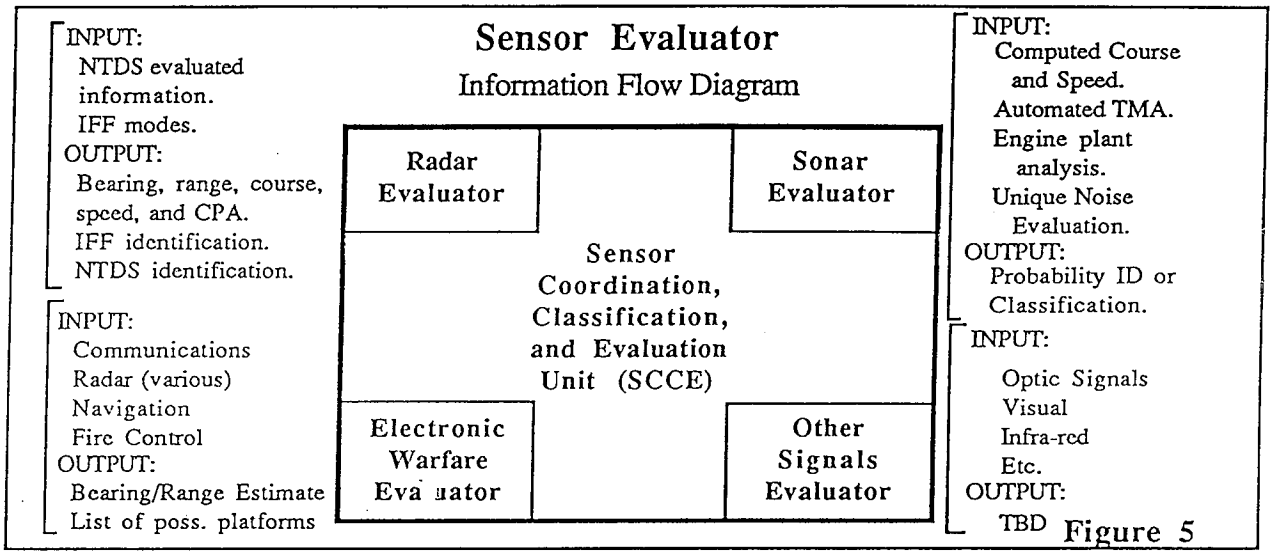

Figure 5

The Radar Evaluator functions similar to the existing Naval Tactical Data System (NTDS). The Radar Evaluator receives digitized radar signals and sends information to the unit's display consoles throughout the vessel and the SCCE for classification. It provides bearing, range, course and speed of the contact, and the closest point where the contact will pass based on present course and speed (i.e. the Closest Point of Approach (CPA)). The Radar Evaluator also provides recommended course and speed changes to increase or decrease the CPA. The standard NTDS representations are enhanced to include identification information like 0410/F-14 or 0413/DDG-53. Separate track identification information like 0410/F-14/101/CV-65/VF-84/CAP 3 or 0413/DDG-53/TG 70.2/STA 5, etc. can be included on another screen.

The Electronic Warfare Evaluator is the most important source of identification and classification information for surface and air units. Electronic Warfare equipment should identify communications signals and various types of radars (air search, surface search, altimeters, fire control, navigation, and satellite radars). As the equipment is also a computer system, the output of bearing and range, frequency, emission type, list of possible platforms for the intercepted signals is used by the SCCE for classification. The Electronic Warfare Evaluator could be an expert system to generate evaluated information to the SCCE reducing the complexity of that unit.

The Sonar Evaluator is limited to submarines and anti-submarine warfare vessels. The variety of sonar equipment on the various types of vessels and aircraft make its generic

expert system a significant challenge. Most of the sonar systems are automated and a large amount of information generated, like course and speed, engine plant and propeller, unique noise information, and approximated range and bearing from automated Target Motion Analysis, etc., are similar. Many of the sonar systems perform classifications themselves which would be incorporated into the Sonar Evaluator. For less sophisticated systems, the Sonar Evaluator's expert system will perform the classification to standardize input into the SCCE.

The Other Signals Evaluator refers to direct visual input and the development of other systems like optic and infra-red systems. You could easily refer to this section, other than visual identification, as future developments.

The Sensor Coordination, Classification, and Evaluation unit will collect the above information, perform evaluation as required, and provide a classification or likely candidate for classification to the IAC. The SCCE will also coordinate access to the Knowledge Base for information on classification required by the other modules.

KNOWLEDGE BASE

The Knowledge Base is another unique system. It is not a standard artificial intelligence list of facts. The Knowledge Base will store detailed information on all types of vessels. The information includes:

1. Profile information for visual identification.

2. Unique engine plant and propeller system information.

3. Unique noise information on a specific class of vessel or on a specific vessel by name.

4. Signal emitters like radars, active sonars, altimeters, etc. The Knowledge Base may have specific signature information on units by name or class for matching.

5. Detection equipment information on the vessel and methods to prevent counter-detection.

6. Standard tactics employed by the vessel or group of vessels. (e.g. aircraft raid procedures like laying chaff in a corridor or using long range targeting aircraft in another direction from the attack. Another example is submarines that attack as a group using a

torpedo shooter to get close to provide targeting information to a medium range missile shooter.)

7. Standard classification methodology for responding to queries. Other information such as recommendations for actions in specific instances based on the "Rules of Engagement" for the area.

8. Other information as required by the local commanders.

The method of access to the information is a unique system in itself. It will be related to the artificial intelligence support systems, JOBLIST and SOLID. It is a network similar to a telephone call system except the nodes are in the program. The nodes define the area of inquiry, type, and priority of the user. (An access by the IAC or SE have higher priority.) The nodes are paths to the information, more like a graph data structure than a binary tree. Information can be accessed in more than one way, so if a path is busy, the system will re route the inquiry like a phone call being routed to another city or system. Nodes are enabled/disabled based on whether the information relates to the present situation. An example would be when all vessels of a class (like a certain type of submarine) are known to be in port, their path is disabled.

The storage of information is also broken into subunits. Information for rapid access will be stored in a facts list or in specific modules. Rarely used information would be on a secondary storage device.

AUTOMATED TRACKING UNIT

The Automated Tracking Unit provides the ACII system with prior knowledge about other units in an area of operations. The Automated Tracker receives contact information from the Ocean Area ACII System, other combatant vessels, and the unit's Sensor Evaluator. It automatically tracks the contact based on the last location and last known course and speed. The Automated Tracker also has provisions for special functions like vessels operating in a submarine patrol area. The Automated Tracker will also compute the probability of a contact from the Ocean Area ACII System or the NTDS network, being the same contact received by the Sensor Evaluator. Each of the capabilities will be detailed separately.

The Automated Tracking Unit is broken into modules as displayed in Figure 6. Each module has a specific type of vessel to track. The reason for the different modules is that tracking requirements vary based on type of vessel and threat. The commercial

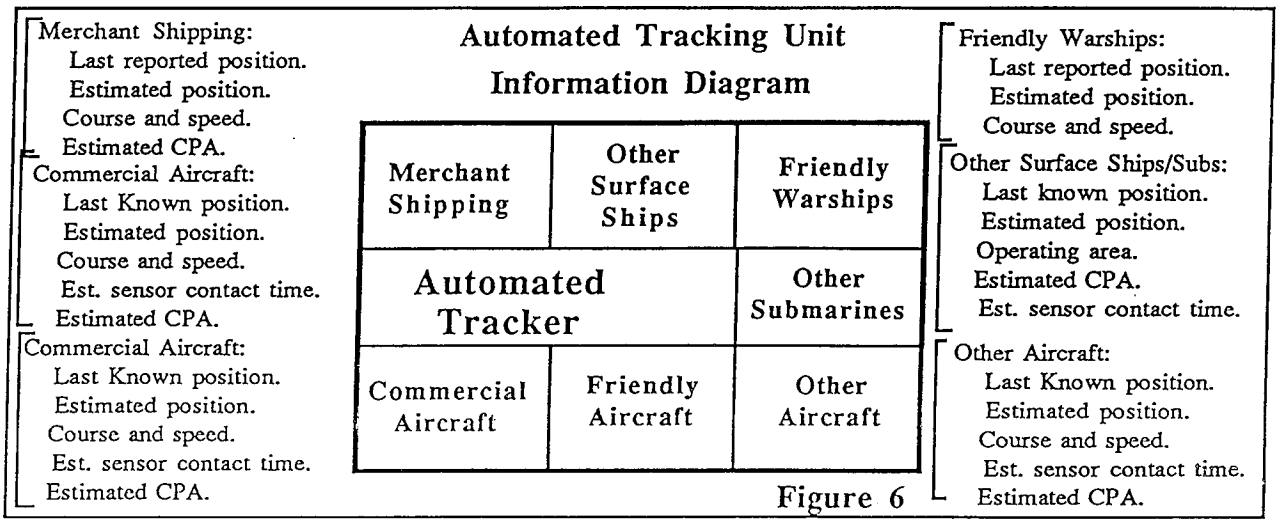

Figure 6

aircraft has certain profiles, IFF modes, etc. to distinguish it from combatant aircraft. Their tracking requirements are minimal as are those for friendly merchant vessels. The requirements for combatant aircraft and warships are significantly increased and require full use of the features mentioned above. Commercial vessels rarely change course or speed and do not maintain on-station activities. The ATU receives unit movement information from the navigation system called the Movement and Ocean Environmental Unit. The unit's movement information is used to determine the range and bearing to a contact.

In order for the Automated Tracker to function in a global environment, it must track contacts based on global coordinates. The progress of a contact is measured by its change in longitude and latitude. The basic tracking scheme periodically computes the new latitude and longitude using a standard mathematical computation. By maintaining the system in global coordinates, information in and out of the system does not require computations and synchronization. (If location information is defined by range and bearing from the host unit, the Ocean Area ACII System would have to compute the latitude and longitude based on the unit's latitude and longitude at the exact instant the range and bearing were taken. For NTDS units, a global coordinate system would eliminate the need to establish a reference location that all units on the system use for sending contact information.)

MOVEMENT AND OCEAN EVALUATION UNIT

The Movement and Ocean Environment unit is an interface to an automatic navigation system like SATNAV or SINS. Ocean sampling for temperature gradients, salinity, and related information are computed and stored for use by the sensor module requiring the information (i.e. Sonar Evaluator). For units without the capability of

obtaining the information, it could be passed via communications links. If the capability does not exists, it could be developed along with this system.

DISPLAY INTERFACE

The display interface will utilize the existing automatic information display system.

SECURITY

A primary concern with any defense software system is security of the information. The solution to the internal problem involves developing a closed, limited access system with only TEMPEST approved computers exchanging information. Bulk encryption devices are used for the transfer of information over communications networks. A sophisticated software security package can be developed or an installed package can be interfaced. The backup software can be stored with other materials of equal security classification. The ACII software should be protected based on its abilities to interface with other equipment. Only the Knowledge Base will have any intelligence information that would require high security classification.

INFORMATION FLOW

The following section provides a description of information flow through the system. It is not detailed, but illustrates how some decisions are made. Specific vessels may have different requirements.

1. Information Analysis and Control Unit.

a. Identification - an AUTOREC system that takes a classification from the Sensor Evaluator and compares it to known contacts from the Automated Tracking unit to find a match. It uses information stored in the Knowledge Base to match contacts. Figure 7 is an example of the decision flow methodology. (Note (1): The values in these examples are created for the example only.) The Sensor Evaluator sends a report to the IAC identification module. The report has identified the contact as a surface vessel of subtype 43 based on the emitters 798 and 896. It also reports no radar, sonar, or other confirmation. The identification module cannot generate a positive identification and generates a query of the Automatic Tracking unit. The ATU responds with three contacts along bearing 350 degrees with other information including system identification number,

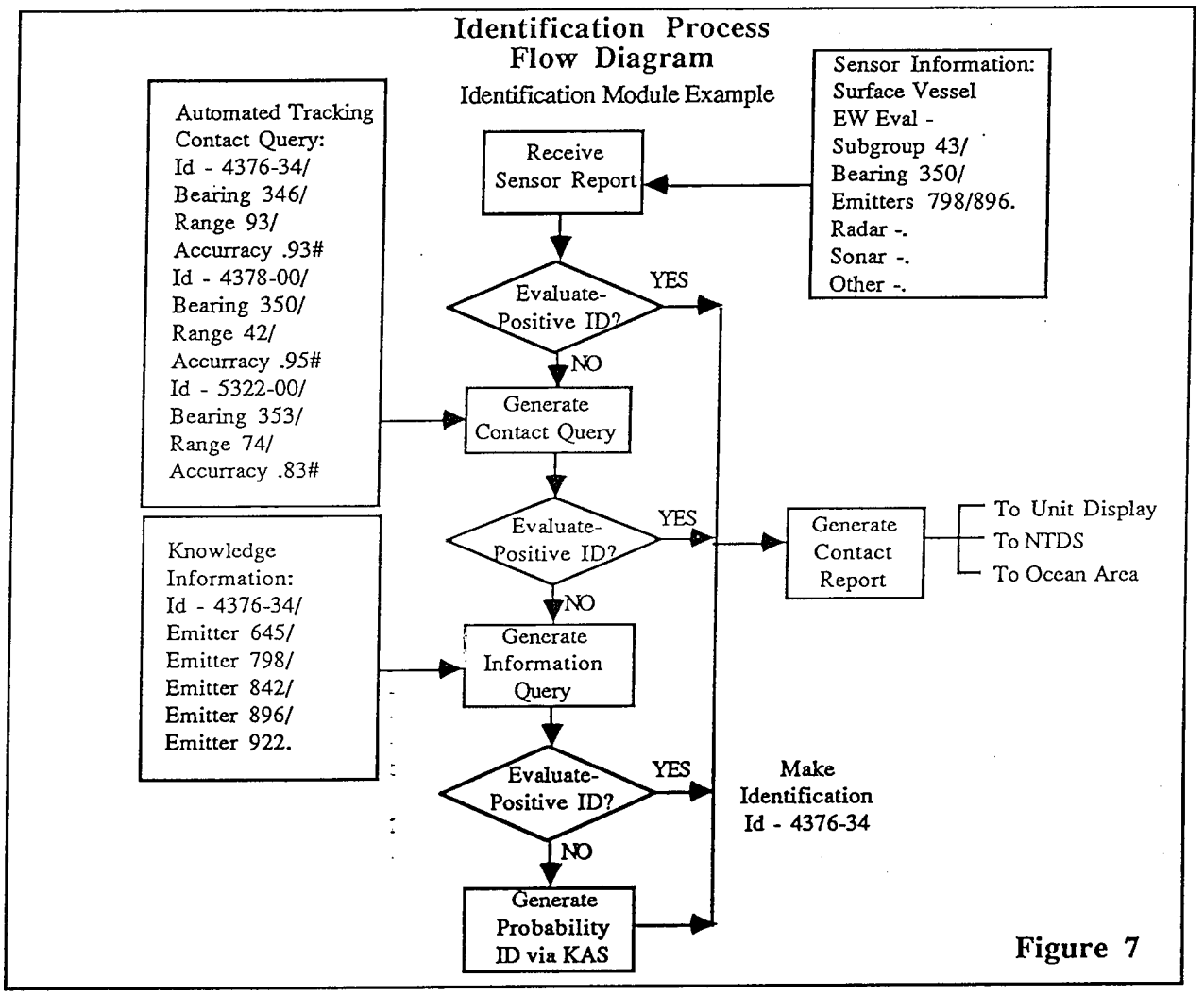

Figure 7

range, and accuracy. Since there are two possible contacts, the identification module generates a query to the Knowledge Base with the sensor report information. The Knowledge Base identified the contact and provided other emitters from that type of unit. If the Knowledge Base did not provide an identification match, the Identification Module would have queried the Knowledge Acquisition System for the best probability of identification. Once the identification has been made, a report is automatically generated for the unit display, the Inter-Area ACII system, and the Ocean Area ACII system.

b. Other decision making systems with similar flow diagrams are the Track Coordination Module and the New Information Module. The TCM decides when to drop a contact from automated tracking and whether new contacts should be sent to automated tracking or stored in the Knowledge Base for further reference. It also generates a call (head's up) to the Sensor Evaluator that a certain contact should be near the outer range limit of a certain sensor. The New Information Module works with the Knowledge

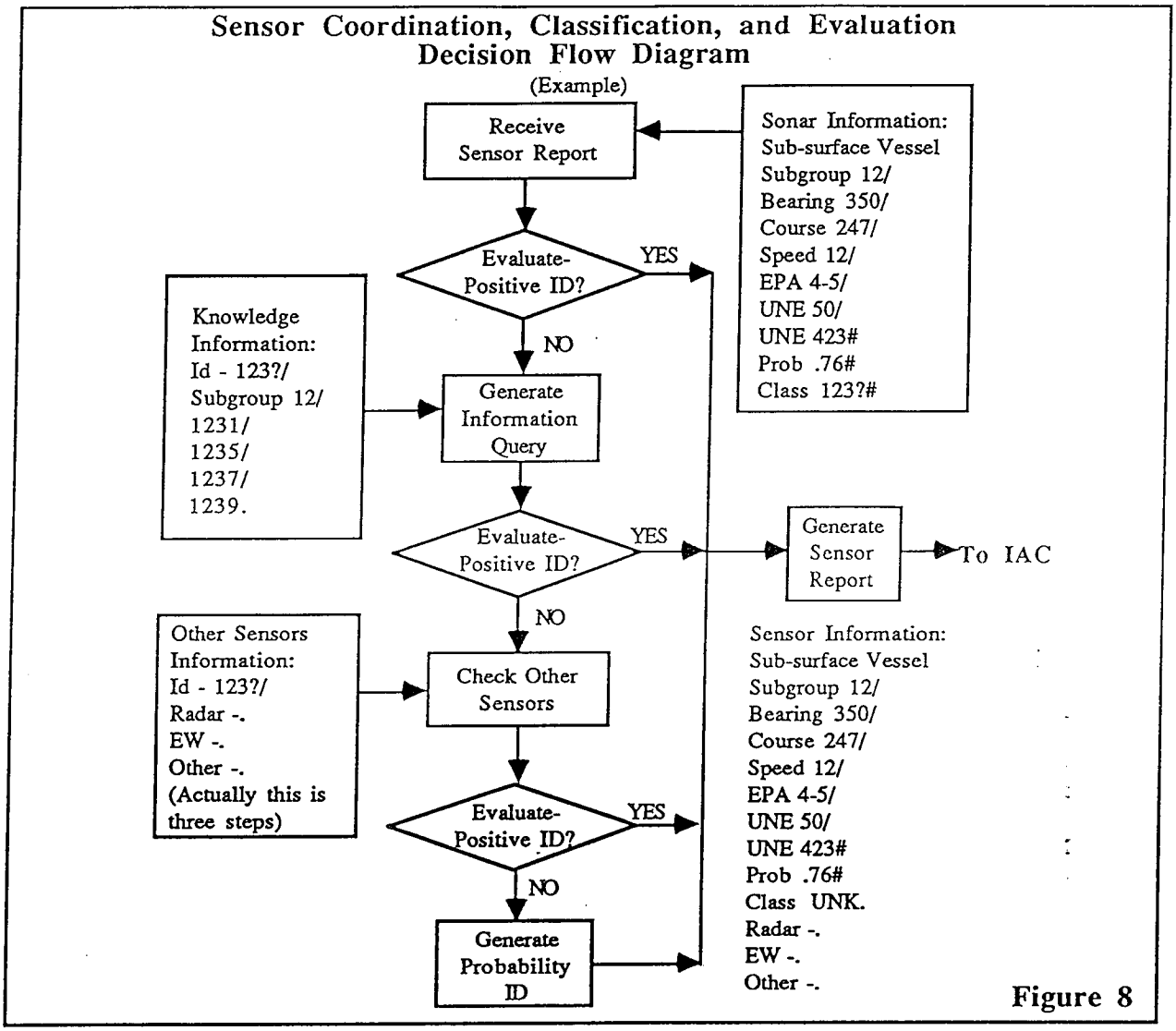

Figure 8

Acquisition System when an identification is not made to determine if the contact has changed its profile, is a new vessel type, a new tactic is employed, etc.

2. Sensor Evaluator.

a. The Sensor Coordination, Classification, and Evaluation (SCCE) Unit functions similar to Figure 8. (See Note (1) above on information.) The Sonar Evaluator generates a sensor report having identified the vessel as a submarine of subgroup 12. The vessel has not been classified. The Knowledge Base is queried for further information. Four submarines meet the criteria set forth in the query. The other sensors are checked for contacts with Radar checked with bearing, course, and speed, and Electronic Warfare for signals from the bearing that match the four possible submarines. No further classification can be made so the senor report is submitted to the Information Analysis and

Control unit.

b. The Sonar and Electronic Warfare Evaluator Automatic Deductive System's function similar to the SCCE. The Radar Evaluator is not an ADS system.

3. Automated Tracking Unit.

a. The Automated Tracker determines the cell or module of a new contact based on identification or classification. It has a mathematical module that polls the contact cells and updates the positions of all the contacts. (Of course, aircraft are polled more often than slower moving contacts. Priorities can also be given to certain contacts for almost continuous polling.) The Automated Tracker can also generate the probability that a contact has changed course and could be in a specified (by the IAC) area.

4. Knowledge Acquisition Unit.

a. This Automatic Adaptive Learning System will generate new information about contacts like new tactics and counter-detection devices. It will also generate a probability matrix on unidentified contacts to generate the best possible candidates based on information and greatest threat. The full function package of the KAU is still in the development phase.

OTHER APPLICATIONS

The expert systems developed for the ACII system will have applications in numerous areas other than Combat Systems. The major area would be Weapons Control. A unit like the Sensor Evaluator could be added for Weapons Control. It would have engagement areas defined for independent or battle group operations. The same communications networks would be available. During Battle Group operations, engagements could be conducted by the Warfare Commander even though he is not physically located on the shooting platform. (Of course, the "Command by Negation" option would still be available to the unit's Commanding Officer.) Incorporation of a weapons unit or set of modules is not part of the initial ACII system development.

On ships expert systems could be applied to control of a main propulsion system whether it be an Automatic Boiler System, Gas Turbine, or Diesel. They can be applied to engineering auxiliaries like evaporators, fueling systems, and other sensor monitored systems. In damage control, they could be applied to automatic sprinkler systems, used to monitor pressurized spaces to detect hull damage, etc. In the supply department, they

could be used to monitor use patterns to detect overuse or misuse of items, or as an ordering system based on use patterns rather than limits. In an actual radar system, they could be used to remove noise, sea return, etc. from the signal before sending it to the display unit without sacrificing significant sensitivity or resolution. For navigation the expert system could be used to detect collision situations and provide recommended actions, to evaluate "Rules of the Road" violations, or to evaluate changes to the "Rules" based on location.

CONCLUSION

The Automated Classification, Identification, and Information System is designed to be a building block for the next generation of combatant vessel while interfacing with the present combat environment. The system will reduce present manning requirements on most vessels, primarily enlisted personnel. Future combat vessels, especially ships and submarines, will be manned by warfare specialists, pilots (or ship drivers), and engineers with enlisted personnel being support types only. Ships will have automated engineering and damage control systems. Systems will be distributed so that if one is damaged, another takes its place. The ACII can be the major system for the Navy of the late 1990's and used well into the twenty-first century.

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IV.3 SCANMAT System

The procurement policy for SCANMAT will be similar to that for CURFIT and FRANS. The complete documentation will consists of:

1. Copies of the source, object and tests.

2. Reprints of key papers.

3. Copies of manuals.

4. Other services contact reporting and information generation (Air Force AWACS and KC-130 / Coast Guard ships and aircraft).

5. Commercial ships and aircraft movement reporting.

6. Other intelligence sources.

External information could be consolidated, continuously updated and evaluated, tailo: to specific operating area need, and exchanged for use in decision making. Internal information could be evaluated using rules developed by the most experienced Navy experts available.

Besides the improved information flow, the automatic system solves other problems. If a fleet unit detects a sub-surface contact, the ACII automatically knows whether to identify it as friendly or unknown. If the contact is friendly, prosecution is not attempted preventing hostile fo :es from detection by elimination (They know where their sub-surface units are.) If the contact is unknown, a report is automatically generated and submitted, eliminating the need for a manual contact reporting system. Additionally, movement reporting would also be eliminated as a vessels position is periodically updated to the central information center. Numerous other manual reports (OPREP / RAINFORM / CASREP / etc.) are eliminated, changed, or enhanced by this system.

EXPERT SYSTEMS

The goal of this project is to build a family of expert systems that can easily be adapted to solve any shipboard or aircraft information evaluation problem. The major emphasis will be on solving combat information problems. Expert systems are conventionally defined as computer programs that solve classes of problems. They can be used to acquire new knowledge by a person familiar with the subject area. In this paper, an expert system is used to discover non-obvious knowledge, thereby eliminating database systems with obvious inference schema. R. K. Belev, in "Knowledge Representation for Decision Support Systems," North-Holland, Amsterdam, 1985, identified the five components of an expert system as a user friendly interface, model base, rule base, text base, and data base. This contrasts with the traditional user interface, inference engine, knowledge base, and database. In the Belev scheme, the model base defines the method for deducing new knowledge from the rule base and data base. The text base contains instructions for communicating with the user interface in an easily understood, familiar language. In the traditional identification scheme, the inference engine would be a combination of the model base and part of the knowledge base, while the text base is part

manages information and processes both retrieval and update requests received from the JOBLIST system. It is fully described in references 4 and 5. Its mathematical basis is the JOBLIST data structure. SOLID has three interdependent files (REGFILE, AFILE, and MFILE) that can be accessed independently. MFILE contains the referenced information in compressed form. AFILE is a keyed-entry file that yields the machine address of the compressed items in the MFILE. REGFILE is a simulated communications network whose information paths are described by the queries, i.e. there is no directory. The file structure and performance data are discussed in references 4 and 6. A prototype of the SOLID system was used as part of the highly successful PENNRAMS system, reference 6, for processing patient health-care information.

OVERALL ACII SYSTEM OPERATION

The overall ACII system operation involves creating a central information storage and evaluation unit, the Ocean Area Automatic Classification, Identification, and Information (ACII) System, to feed specific information to fleet units in their area of operations based on their need to know. If a Battle Group is operating in the Sea of Japan, it has access to all information on friendly and possible non-friendly contacts (not previously identified or known hostile) in that area and adjacent operating areas. The information would be transferred via a secure communications link to the unit's ACII Knowledge Base and Automated Tracking unit for access by the fleet unit and fleet commanders with access based on the individual need to know.

Figure 1 is a block diagram of the Ocean Area ACII System. It communicates with fleet units, fleet commanders (via the flagship's ACII), and headquarters commands. The Navy Communications System's network is used to transfer information to and from the

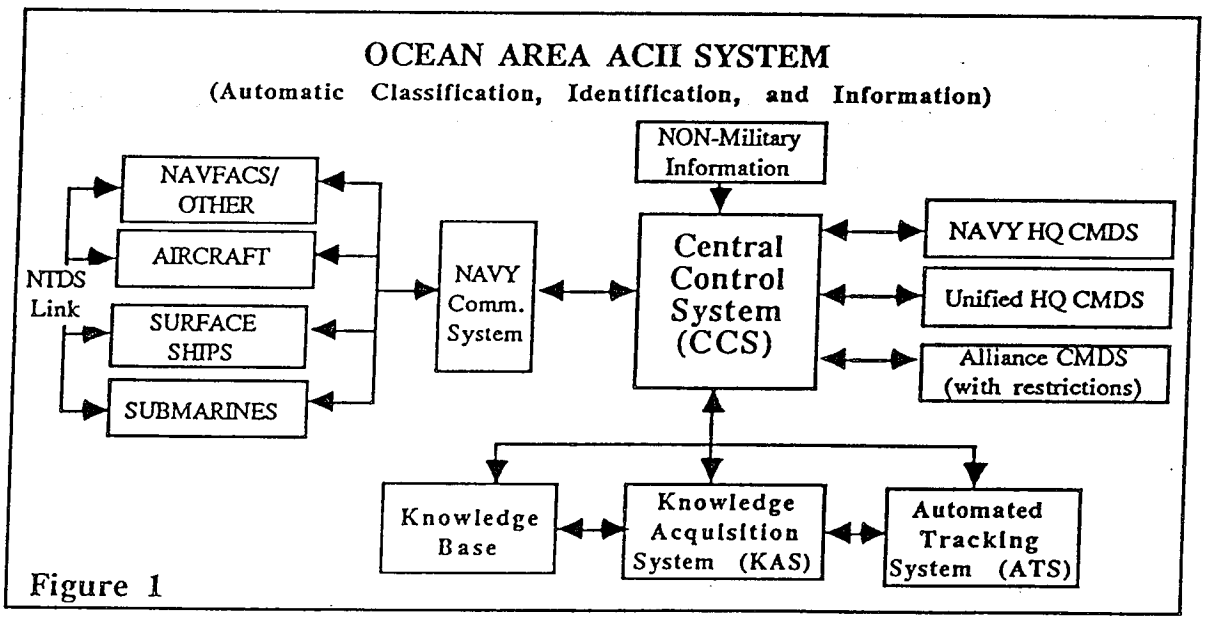

Figure 1

Pacific Ocean) already has a major computer system and the Navy's Communications System has adequate satellite networks, specific hardware requirements are not provided. The software for the Ocean Area ACII System would use algorithms similar to those developed for the unit ACII system.

UNIT ACII SYSTEM

The Unit ACII System, Figure 3, is a block diagram of the primary system for ships, submarines, and aircraft. It is similar to the Ocean Area ACII System. There are several significant differences like the Sensor Evaluator and the interface with the Movement and Ocean Evaluation Unit (MOE). The details of the individual blocks will be presented separately.

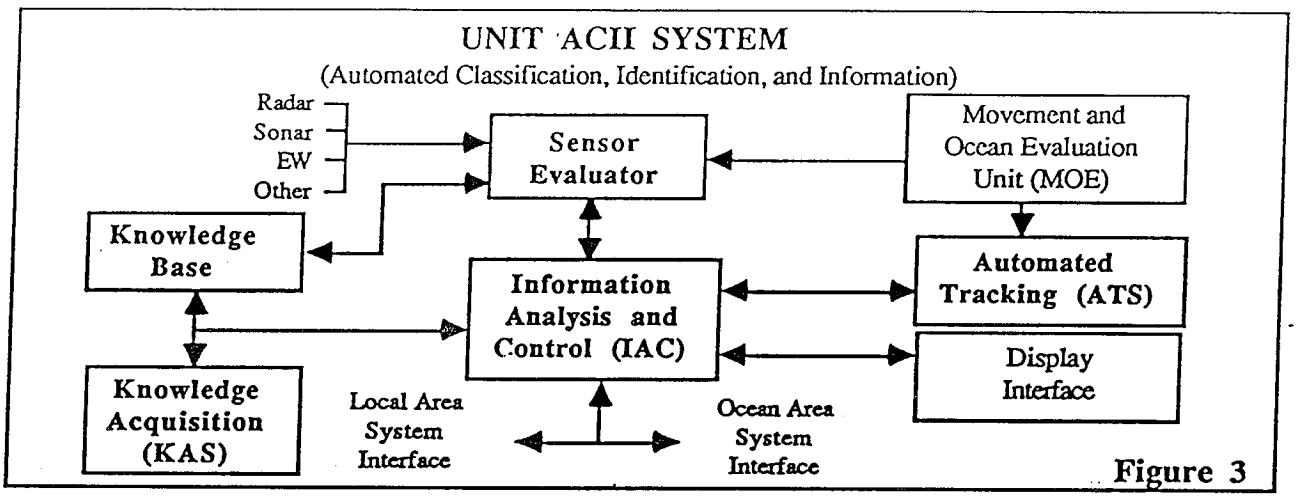

Figure 3

The major advantages of the ACII system are security of information, speed of evaluation, automatic report generation, coordinated flow of internal and external information, and knowledge of contacts before their detection. The plan is to develop a secure system with minimal hardware requirements. Interfaces to presently existing display, communications, navigation, radar, sonar, and electronic warfare systems would eliminate redundant systems. Examples are using information generated by the Naval Tactical Data System (NTDS) for the Radar Evaluator and the NTDS communications system for local area of operations exchange of information. The only additional hardware requirement is a high speed, medium size, TEMPEST approved multiprocessor computer for the modules and their interfaces. Bulk encryption units required for the Local Area and Ocean Area communication networks are already in existence. As the hardware will be small, lightweight, and inexpensive, redundant systems could be installed on the larger units (like ships and submarines) to prevent loss of the system during hostile operations. For loss of the unit's power source, a secondary power source like batteries and a continuous backup

Evaluation (SCCE) unit. (See Figure 5.) The purpose of the Sensor Evaluator is to provide classification information to the Information Analysis and Control unit (IAC). Each module's functions are described separately.

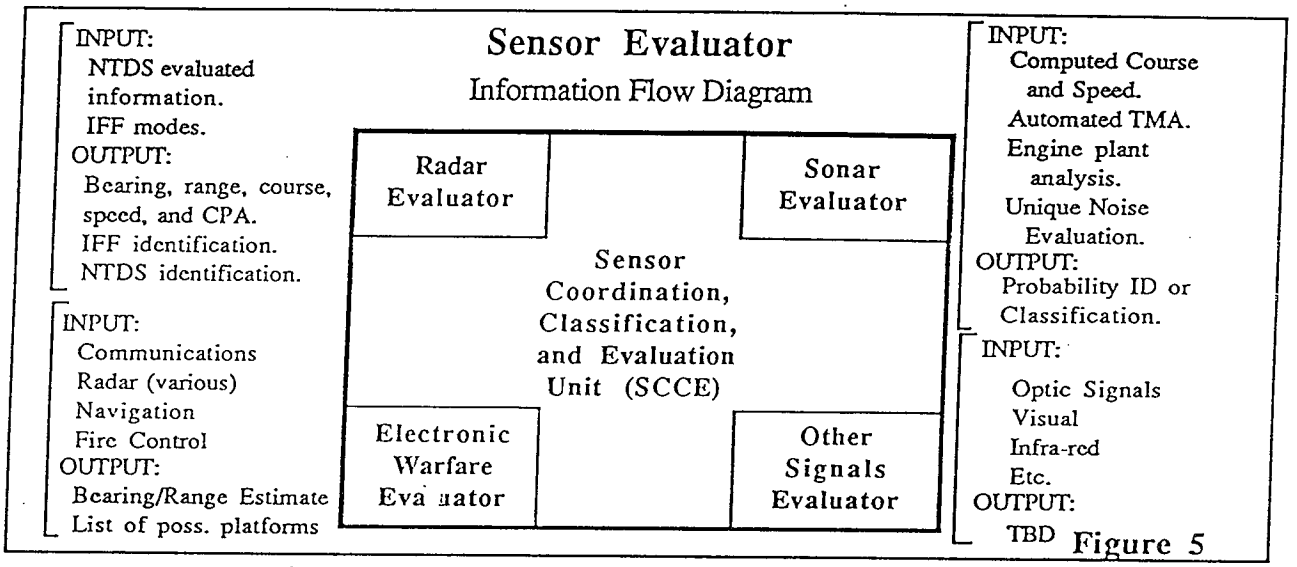

Figure 5

The Radar Evaluator functions similar to the existing Naval Tactical Data System (NTDS). The Radar Evaluator receives digitized radar signals and sends information to the unit's display consoles throughout the vessel and the SCCE for classification. It provides bearing, range, course and speed of the contact, and the closest point where the contact will pass based on present course and speed (i.e. the Closest Point of Approach (CPA)). The Radar Evaluator also provides recommended course and speed changes to increase or decrease the CPA. The standard NTDS representations are enhanced to include identification information like 0410/F-14 or 0413/DDG-53. Separate track identification information like 0410/F-14/101/CV-65/VF-84/CAP 3 or 0413/DDG-53/TG 70.2/STA 5, etc. can be included on another screen.

The Electronic Warfare Evaluator is the most important source of identification and classification information for surface and air units. Electronic Warfare equipment should identify communications signals and various types of radars (air search, surface search, altimeters, fire control, navigation, and satellite radars). As the equipment is also a computer system, the output of bearing and range, frequency, emission type, list of possible platforms for the intercepted signals is used by the SCCE for classification. The Electronic Warfare Evaluator could be an expert system to generate evaluated information to the SCCE reducing the complexity of that unit.

The Sonar Evaluator is limited to submarines and anti-submarine warfare vessels. The variety of sonar equipment on the various types of vessels and aircraft make its generic

torpedo shooter to get close to provide targeting information to a medium range missile shooter.)

7. Standard classification methodology for responding to queries. Other information such as recommendations for actions in specific instances based on the "Rules of Engagement" for the area.

8. Other information as required by the local commanders.

The method of access to the information is a unique system in itself. It will be related to the artificial intelligence support systems, JOBLIST and SOLID. It is a network similar to a telephone call system except the nodes are in the program. The nodes define the area of inquiry, type, and priority of the user. (An access by the IAC or SE have higher priority.) The nodes are paths to the information, more like a graph data structure than a binary tree. Information can be accessed in more than one way, so if a path is busy, the system will re route the inquiry like a phone call being routed to another city or system. Nodes are enabled/disabled based on whether the information relates to the present situation. An example would be when all vessels of a class (like a certain type of submarine) are known to be in port, their path is disabled.

The storage of information is also broken into subunits. Information for rapid access will be stored in a facts list or in specific modules. Rarely used information would be on a secondary storage device.

AUTOMATED TRACKING UNIT

The Automated Tracking Unit provides the ACII system with prior knowledge about other units in an area of operations. The Automated Tracker receives contact information from the Ocean Area ACII System, other combatant vessels, and the unit's Sensor Evaluator. It automatically tracks the contact based on the last location and last known course and speed. The Automated Tracker also has provisions for special functions like vessels operating in a submarine patrol area. The Automated Tracker will also compute the probability of a contact from the Ocean Area ACII System or the NTDS network, being the same contact received by the Sensor Evaluator. Each of the capabilities will be detailed separately.

The Automated Tracking Unit is broken into modules as displayed in Figure 6. Each module has a specific type of vessel to track. The reason for the different modules is that tracking requirements vary based on type of vessel and threat. The commercial

obtaining the information, it could be passed via communications links. If the capability does not exists, it could be developed along with this system.

DISPLAY INTERFACE

The display interface will utilize the existing automatic information display system.

SECURITY

A primary concern with any defense software system is security of the information. The solution to the internal problem involves developing a closed, limited access system with only TEMPEST approved computers exchanging information. Bulk encryption devices are used for the transfer of information over communications networks. A sophisticated software security package can be developed or an installed package can be interfaced. The backup software can be stored with other materials of equal security classification. The ACII software should be protected based on its abilities to interface with other equipment. Only the Knowledge Base will have any intelligence information that would require high security classification.

INFORMATION FLOW

The following section provides a description of information flow through the system. It is not detailed, but illustrates how some decisions are made. Specific vessels may have different requirements.

1. Information Analysis and Control Unit.

a. Identification - an AUTOREC system that takes a classification from the Sensor Evaluator and compares it to known contacts from the Automated Tracking unit to find a match. It uses information stored in the Knowledge Base to match contacts. Figure 7 is an example of the decision flow methodology. (Note (1): The values in these examples are created for the example only.) The Sensor Evaluator sends a report to the IAC identification module. The report has identified the contact as a surface vessel of subtype 43 based on the emitters 798 and 896. It also reports no radar, sonar, or other confirmation. The identification module cannot generate a positive identification and generates a query of the Automatic Tracking unit. The ATU responds with three contacts along bearing 350 degrees with other information including system identification number,

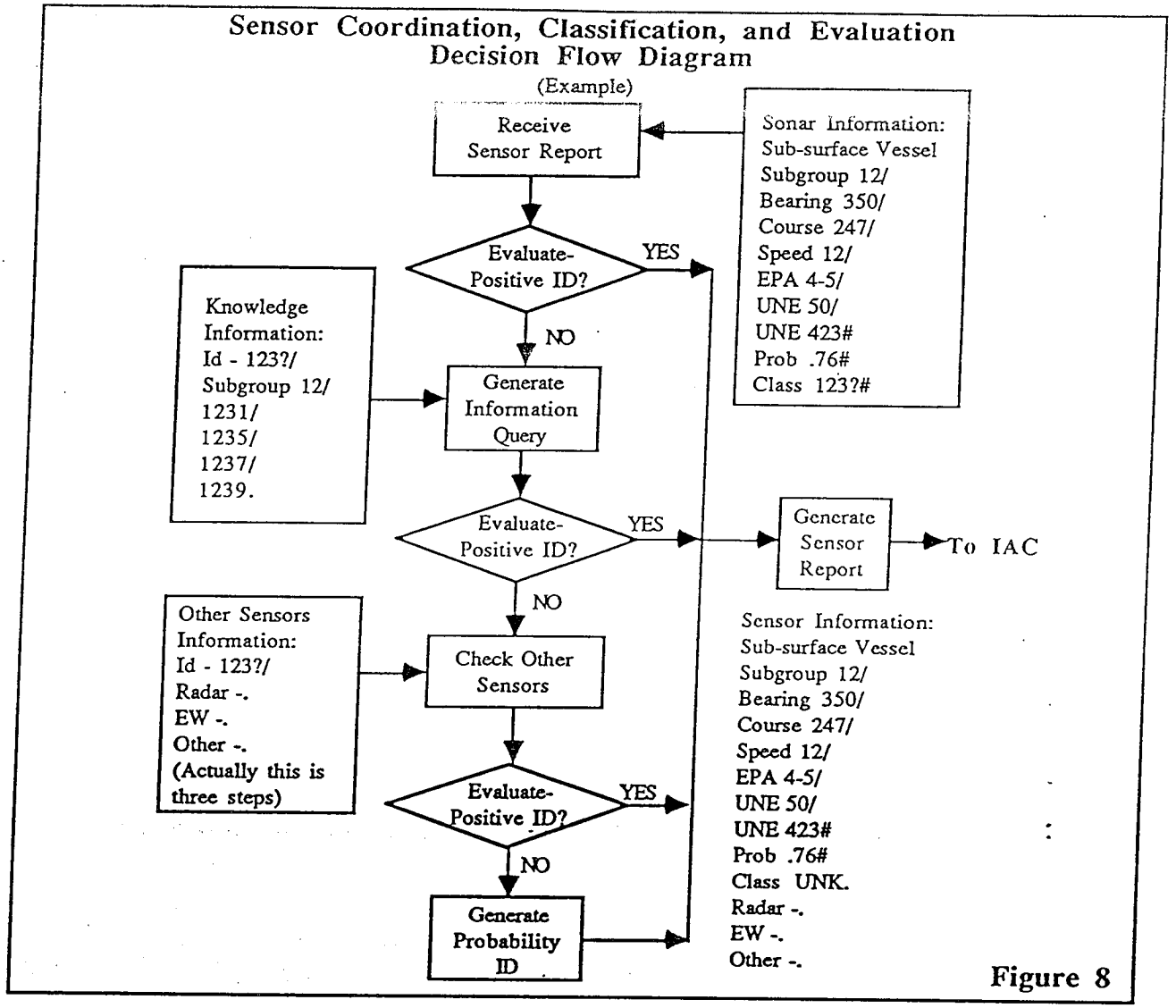

Figure 8

Acquisition System when an identification is not made to determine if the contact has changed its profile, is a new vessel type, a new tactic is employed, etc.

2. Sensor Evaluator.

a. The Sensor Coordination, Classification, and Evaluation (SCCE) Unit functions similar to Figure 8. (See Note (1) above on information.) The Sonar Evaluator generates a sensor report having identified the vessel as a submarine of subgroup 12. The vessel has not been classified. The Knowledge Base is queried for further information. Four submarines meet the criteria set forth in the query. The other sensors are checked for contacts with Radar checked with bearing, course, and speed, and Electronic Warfare for signals from the bearing that match the four possible submarines. No further classification can be made so the senor report is submitted to the Information Analysis and

could be used to monitor use patterns to detect overuse or misuse of items, or as an ordering system based on use patterns rather than limits. In an actual radar system, they could be used to remove noise, sea return, etc. from the signal before sending it to the display unit without sacrificing significant sensitivity or resolution. For navigation the expert system could be used to detect collision situations and provide recommended actions, to evaluate "Rules of the Road" violations, or to evaluate changes to the "Rules" based on location.

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