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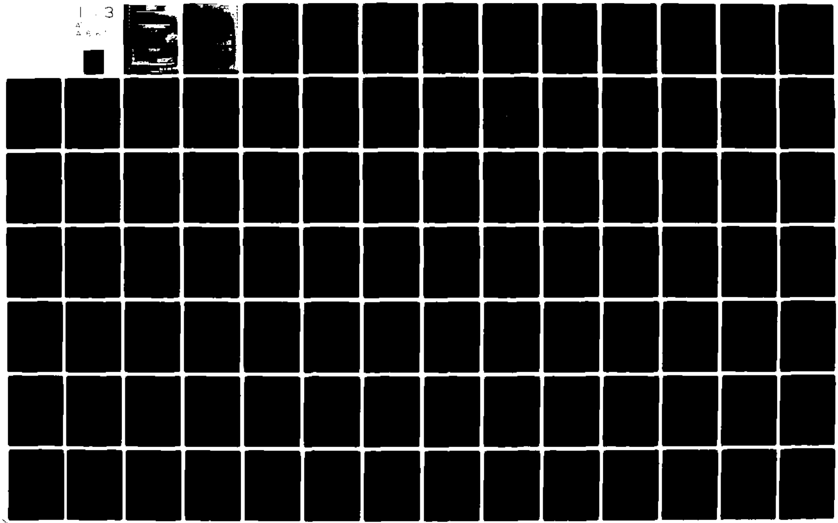

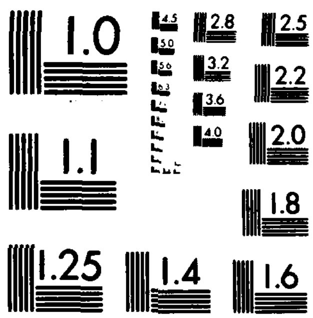

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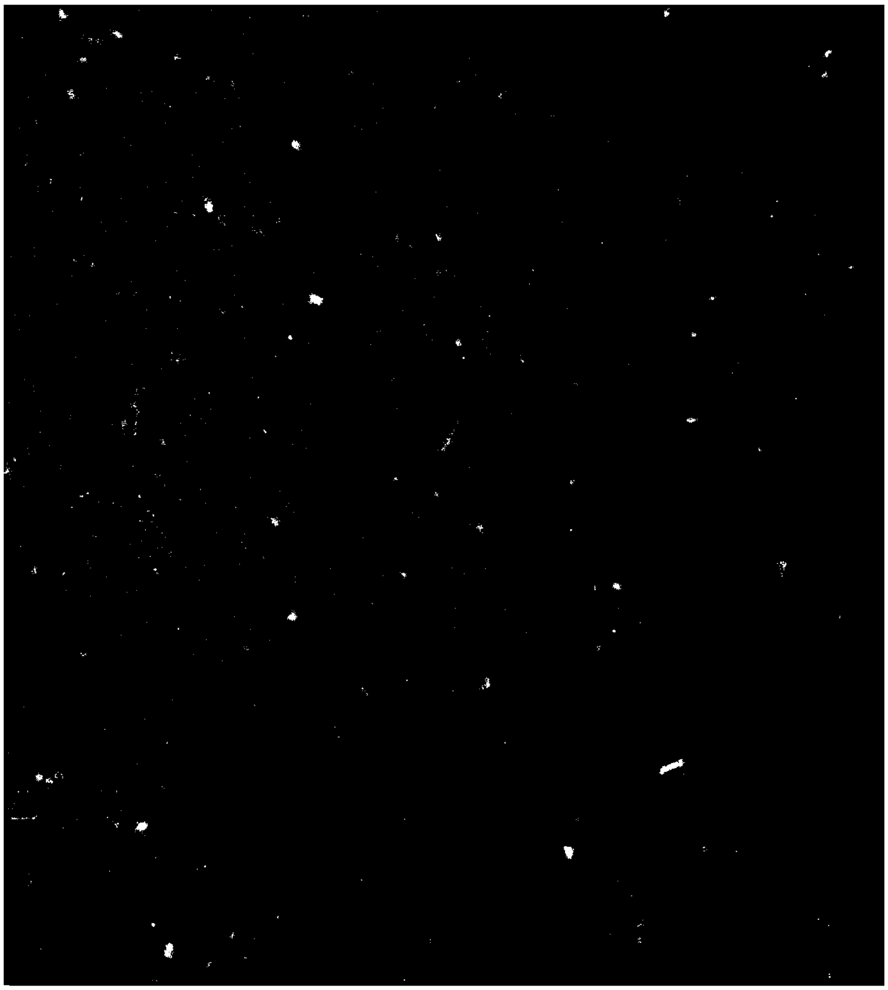

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Annual Technical Report PATR-1069-80-8
Contract No. N00014-78-C-0495
August 1980

INFORMATION COLLECTION AND CORRELATION SUPPORT SYSTEM FOR THE MARINE CORPS TCO ENVIRONMENT

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER PATR-1069-80-8	2. GOVT ACCESSION NO. AD-A089617	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) An Information Collection and Correlation Decision Support System for the Marine Corps TCO Environment		5. TYPE OF REPORT & PERIOD COVERED Final Technical Report 1 July 1979 — 30 June 1980
		6. PERFORMING ORG. REPORT NUMBER PATR-1069-80-8
7. AUTHOR(s) Alain Crolotte Joseph Saleh		8. CONTRACT OR GRANT NUMBER(s) N00014-78-C-0495
9. PERFORMING ORGANIZATION NAME AND ADDRESS Perceptronics, Incorporated 6271 Variel Avenue Woodland Hills, CA 91367		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS PE 62721N RF 244-001 NR 199-002
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research 800 North Quincy Street, Arlington, VA 22217		12. REPORT DATE 15 August 1980
		13. NUMBER OF PAGES 199
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Unlimited

18. SUPPLEMENTARY NOTES

the Marine Amphibious Force (MAF)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Tactical Combat Operations (TCO)
Decision Making
Decision Aiding
Multisensor Correlation
Combat Information
Information Correlation
Bayesian Classification
Information Selection
Information-Measure

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes an information collection and correlation (ICC) decision support system designed to aid the process of combat information production in Marine amphibious operations. Three operators perform information correlation: one at the reconnaissance and surveillance (R&S) station of the division Intelligence Center, another at wing level and a third one at MAF level. They correlate new information with existing information in order to maintain a file which contains the most current picture of the enemy situation in the form of ground tracks. In addition, the MAF operator performs combat information

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coordination. The present unaided information correlation system is likely to create information overload resulting in processing delays and failure to make combat information available in a timely manner. The ICC support system was designed to reduce this overload by automating or aiding of some of the functions involved in combat information production. The system covers the following processes: (1) reliability assessment, (2) identity identification, (3) conflict identification, (4) conflict resolution, and (5) information selection. The support system has been designed for implementation in the Marine Tactical Combat Operations (TCO) System.

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EXECUTIVE SUMMARY

Analysis of the Marine Corps decision-making environment identified information acquisition and transfer as the problem area with the greatest need for improvement. Due to the stringent requirements of [illegible] the need for timely and accurate information to support effective decision making is increased. At the same time the amount of information received from various sources (sensors, automated systems, etc.) is overwhelming, literally burying commanders in a flood of raw data. In parallel the Intelligence analysts provide aggregated information, e.g., in the form of estimates. Although useful for commanders out in the field, this aggregated information does not fulfill their need for real-time information on enemy units, positions and movements. In order to fulfill the requirement for providing this type of information to Marine ground commanders, the Marine Corps Tactical Support Systems Activity (MCTSSA) has defined a system concept aimed at producing combat information. Definition of combat information is included in the framework of the Tactical Combat Operations (TCO) system as *that information about the location of enemy weapons, personnel and equipment on the ground made available immediately, only after some technical processing.*

The main problem in producing combat information is that of correlation due to the existence of a multitude of sensors which may simultaneously provide information about the same enemy position. As defined in the TCO Preliminary System Description Document (PSDD) information correlation is an operator function. Three operators perform information correlation: one at the reconnaissance and surveillance (R&S) station of the Division Intelligence Center, another at wing level and a third one at [illegible] level. They correlate new information with existing information in order to maintain a TCO file which contains the most current picture of the enemy situation in the form of ground tracks. In addition to correlation the [illegible] [illegible] performs combat information coordination, i.e., assigns track management responsibilities and resolves possible conflicts between division and wing operators with regard to proposed updates of the track record file.

Operators are aided in their functions by some TCO capabilities of a supportive nature such as a display with map background, alerts and some computational procedures. Due to the high number of expected sensor sightings and the large number of required interactions between operators at different levels, the information correlation system defined in the PSDD is likely to create an enormous information overload which would result in long processing delays and failure to make combat information available in a timely manner.

In order to speed up the process of combat information production and decrease communication requirements between various levels, an information collection and correlation (ICC) decision support system was conceived and a specific design was selected for implementation. First the process of information correlation was decomposed into subprocesses. Then modules were designed which automate or aid the defined subprocesses. Finally a framework was provided around which the modules were organized. From the standpoint of operator performance in correlating information there is only one correlation process. From an organizational standpoint, however, two correlation processes were distinguished. These are (1) local correlation, performed on sensor reports by division, wing and MAF operators separately and resulting in proposed track file modifications and (2) global correlation performed by a MAF operator on the proposed track file modifications and resulting in implementation or deletion of these proposed modifications. This distinction has the advantage of separating various operators functions and thus reducing communications requirements.

Information collection and correlation is composed of the following processes: (1) reliability assessment, (2) identity identification, (3) conflict identification, (4) conflict resolution and (5) information selection. Reliability assessment is necessary to attach a value of merit to the incoming information. This step is particularly important when comparing two conflicting pieces of information. Identity and conflict identifications are fundamental in determining whether two information elements refer to the same entity. Proper techniques have been provided to aid these two processes by handling of the uncertainty which is attached to information sources. Finally when conflicts are identified, attempts are made to resolve them. If a conflict cannot be resolved using the available information, e.g., by disregarding the less reliable information, more information must be sought thus requiring selection of the most informative source of information as the collection means.

Automating and aiding these processes are expected to help operators to overcome the overload problem by decreasing the average processing time per sighting. Also, by providing a structure which limits the need for various level operator interactions, it is expected to decrease even further the processing time.

A specific design for implementation of the ICC concept was also provided. It shows the feasibility of the concept from an implementation standpoint since the selected design does not require extra information nor does it require operators to perform functions not already required without the support system. The system draws on a number of mathematical techniques. Although representation of some of these techniques requires complicated mathematical notations, they do not present any further complexity to the information correlation process. The purpose of these mathematical techniques is solely to provide a proper framework for automation or aiding to the functions which are required for information correlation with or without a decision support system.

1. INTRODUCTION

1.1 Overview

The present report documents the results of the second-year effort of the decision support program. During the first program year a methodology for decision-aid selection was established based on a taxonomy of the Marine Amphibious Brigade (MAB) decisions. During the second program year, this methodology was used to select a decision aid for the MAB decision-making environment. The selected decision aid is in fact composed of a family of decision aids conceptually organized in an Information Collection and Correlation (ICC) decision support system for production of combat information. Within the framework of this second year effort a specific design was also provided. Although designed for an amphibious operation of Marine Amphibious Force (MAF) size, the decision support system is transferable to MAB level with only minor modifications.

1.2 Scope of the Effort

The second-year effort is planned within the framework of a program directed toward production of a working taxonomy of tactical decisions for the Command, Control and Communications (C^3) environment of Marine Corps commanders. The program focusses on the Marine Amphibious Brigade (MAB) decision environment, and will provide a base-line for a systematic approach to design and/or selection of effective decision aids for the tactical C^3 environment. The specific objectives of the program are as follows:

(1) Analyze the MAB command and control environment in terms of its tactical commanders' decisions, information needs and operational objectives.

(2) Develop a taxonomy of decision tasks encountered in the MAB decision-making environment, and identify classes of decision tasks requiring similar decision-making skills and cognitive behaviors.

(3) Develop a taxonomy of potential decision makers among MAB commanders at different levels and develop a taxonomy of available, as well as plausible, decision aids.

(4) Identify the range of decision aids suitable for the MAB environment.

(5) Recommend, using the taxonomy, high-payoff decision aids and select among them a decision aid well accepted by the users.

(6) Design a software system for the simulation and demonstration of the selected decision aid.

(7) Implement the decision aid in-house and demonstrate its operation.

(8) Transfer the decision aid to the MTACCS Test Facility (MTF) and investigate the suitability of possible model generalizations.

(9) Design a test plan to evaluate the effectiveness of the decision aid.

During the first year of the program a methodology for decision-aid selection was established fulfilling objectives (1) to (4). During the second year of the program, objectives (5) and (6) were addressed.

1.3 Method of Approach

Of particular salience in this program is that its time span coincides with Tactical Combat Operations (TCO) concept validation testing. TCO is envisioned as an information system in which microcomputers control interactive display devices, manage a distributed data base, perform computational tasks and generate hard copy records. TCO, which consists of

92 capabilities supporting the functions of planning, operations and intelligence, is currently undergoing thorough concept validation testing at the Marine Corps Tactical System Support Activity (MCTSSA), Camp Pendleton, on the Interim Test Facility (ITF) and is scheduled for extensive testing on the Marine Corps Tactical Command and Control Systems (MTACCS) Test Facility (MTF). Treating the individual decision aids which make up the decision support system as TCO capabilities provides an excellent opportunity for "benchmark" evaluation of these decision aids in an operational context.

In order to accommodate the specific requirement of the decision-aid inclusion into the TCO system, the decision-aid selection methodology developed during the first year was refined. (Details are presented in Appendices A, B and C.) The refined methodology facilitates decision-aid selection when inclusion of the aid into a system is desired by providing an overall degree of merit for the decision aid with regard to all the decision tasks already supported by the system. For instance Bayesian classification techniques were found to have a high degree of suitability for inclusion into TCO. Although Bayesian classification techniques were included into the ICC, i.e., developed as an aid for information correlation and collection, they could be developed for other decision areas as well. This point is illustrated in Appendix F which describes a decision aid concept utilizing Bayesian classification for situation assessment.

Due to the specific needs of Marine Corps commanders for timely and accurate information, the decision area "information correlation" takes on special importance. At the present stage of TCO concept development, this function is an operator function. The operators who perform correlation functions are subject to extreme task overload. The decision support system described in this report is expected to reduce this overload substantially while increasing the accuracy of the processes involved.

The correlation process was analyzed in terms of the decision subprocesses it involves. Modules were then conceived to support these subprocesses by providing either automation or aiding. A framework was also provided around which the modules were organized. The framework and its various modules constitute the ICC decision support system. The system was specified and an implementation design was provided. Requirement analysis results have shown that this design is feasible and can be implemented in the TCO simulated environment.

1.4 Program Continuation

During the third program year, the ICC decision support system will be transferred and implemented into the MTF. Also, an evaluation plan, in the lines of TCO concept validation testing, will be designed.

1.5 Organization of the Report

The report is organized in four chapters and six appendices. Chapter 2 introduces the problem of combat information correlation. Chapter 3 describes the system concept while Chapter 4 describes the design selected for implementation. Chapter 5 concludes the report. Appendices A, B and C altogether document the required refinement to the decision-aid selection methodology. Appendices D and E respectively describe the computation of the surface of the α-level confidence ellipse for a 2-dimensional normal variable and a queueing model for ICC system behavior analysis. Finally, Appendix F describes a decision aid concept for situation assessment which also utilizes one of the techniques included in the ICC support system.

2. PROBLEM ANALYSIS

2.1 Introduction

Amphibious operations in the 1980's will be characterized by a combination of sophisticated weaponry, a high concentration of fire power, high speed of maneuver enhanced by the use of armored/motorized/mechanized forces, and enemy's capabilities to disrupt and deceive friendly forces.

> *"The term 'fog of battle' aptly describes the situation which will face the ground combat commander in this environment. Enemy electronic warfare and a rapidly changing situation will combine to give him scanty or erroneous information in some areas. In other areas the sophisticated communications and data collection capabilities available to him will tend to bury him in a flood of electronically generated raw data. If he is to prevail, he must be able to rapidly adjust his plans and execute changes to his scheme of maneuver to react to changes in the battlefield situation."* (TCO Maneuver Control Paper.)

The combination of time pressure and information overload cannot be effectively coped with using the present tactical command and control system. This system works and has worked effectively for many years, but it is too slow to accommodate the requirements of the post 1980 battlefield. This operational deficiency was identified in the Required Operational Capability (ROC) document which states:

> *Technological progress has resulted in vastly improved sensor, communications, and automated processing capabilities. Automation is being introduced into virtually every functional area of command and control: fire support, air control, intelligence, logistics and manpower. After 1986, the unprecedented volume of information from these systems that is pertinent to tactical decisions cannot be received and processed at operation centers without the aid of automation. Current manual methods of message processing, data filing, retrieval, and posting to plotting boards are slow and*

susceptible to inaccuracies and omission of relevant information and are, therefore, inadequate to support the timeliness and accuracy requirements of Marine Corps commanders in the post 1980's

As a result, the Marine Corps defined the requirement for a Tactical Combat Operations (TCO) System to overcome the identified operational deficiency of the present system. The ROC document briefly summarizes TCO as "An on-line, interactive, secure tactical command and control system designed to enhance the capability of the commander and his operational staff to conduct combat operations and planning."

A detailed description of TCO is included in the TCO Preliminary System Description Document (PSDD). Basically, the system consists of 92 capabilities which support a number of military functions. Again quoting the ROC: "As a minimum, TCO would provide additional support of the following functions:

(a) Planning, coordinating and supervising the tactical employment of units.
(b) Controlling the current ground combat situation.
(c) Evaluating the tactical situation and preparing operations estimates.
(d) Integrating fire with maneuver.
(e) Receiving, transmitting, and displaying data/information.
(f) Determining priorities for allocations of personnel, weapons, equipment and ammunition.
(g) Preparing and distributing operations plans and orders.
(h) Developing, preparing, and supervising the execution of training programs and field exercises.
(i) Preparing and submitting reports."

TCO is envisioned as an information system in which microcomputers control interactive display devices, manage a distributed data base, perform computational tasks and generate hard copy records in order to provide automated assistance to the tactical commander and his staff in the areas of planning, intelligence and operations.

TCO is the focal point of the Marine Tactical Command and Control Systems (MTACCS) family, a conceptual association of eight command and control systems, interacting, functionally oriented and using the same design philosophy. The MTACCS Test Facility (MTF) at the Marine Corps Tactical Systems Support Activity (MCTSSA) (Camp Pendleton) provides a test bed for these systems by allowing simulation of real-life combat situations. System capabilities are simulated and their relative contribution to performance enhancement can be assessed (Kemple, Stephens and Crolotte, 1980).

Similarly, decision aids can be designed and implemented as system capabilities. The MTF offers an excellent opportunity for benchmark testing of decision aids. Once the effectiveness of the decision aids has been evaluated, a good basis exists for decision with regard to their actual inclusion into the system.

2.2 Aiding Requirement for TCO

In order to allow selection of a decision aid for inclusion in the TCO system, the decision aid selection methodology needed to be refined. The results of this methodology refinement are presented in Appendix A. As a preliminary step in defining this refined methodology, an assessment of the relative importance of TCO-supported decision task areas for mission effectiveness was carried out. This assessment was performed through a structured interview of Marine Corps personnel using a decomposition of TCO-supported Marine Corps functions. The most striking result in this assessment is the overwhelming importance of operations (67%) and intelligence (25%) over planning (8% only). Rated very high in operations was ground maneuver control (23%).

The particular emphasis of ground maneuver control in Amphibious Operations is well-known and had been previously singled out by MCTSSA (TCO Maneuver Control Concept Paper). Ground maneuver takes its significance for units in contact with the enemy, i.e., at battalion level. *"The Marine infantry battalion is the basic tactical unit of the ground combat power in the Marine Corps. It provides the nucleus of the battalion landing team for amphibious and Marine amphibious unit air-ground task force operations."* (FMFM 6-3.) For these units mobility is the crucial issue and consequently any change in equipment apparatus, etc. should enhance their mobility--not hamper them.

As stated in the TCO Maneuver Control Concept Paper:

> *Commanders influence the conduct of maneuver by modifying the concept of operations, reallocating available assets or changing the missions of subordinate units. The decision to do one or a combination of these things is based on the information available to the commander; the quality of his decision will be directly related to the quality of the information available at the time it must be made.*

Thus, timely and accurate information must be available to commanders in order to enhance decision making.

Decision making at battalion level is characterized by (1) time pressure and (2) information overload. To cope with these problems and be able to accommodate the needs of commanders out in the field for timely and accurate information, a number of TCO capabilities were designed. These capabilities are geared toward presentation of *near real-time graphic and* *textual display of tactical information on demand. It would provide the commander with the capability to develop, store, edit and disseminate, over standard communication links, information associated with the command, control, and coordination efforts.* (Infantry Battalion Concept Paper for TCO.)

The actual production of real-time information gathered from various sources, in particular sophisticated sensors and automated data systems, poses the specific problem of information correlation. Information correlation was also identified as an important decision task area within intelligence (see Appendix A). At the present time, i.e., as described in the PSDD, information correlation is a TCO operator function. Consequently, aiding would be particularly suitable in this important area in order to speed-up the production of usable information and at the same time ensure accuracy.

2.3 Combat Information

As demonstrated earlier, commanders in the field require timely and accurate information. The type of information they require, however, must be clearly defined. From raw data to intelligence, information passes through various stages of processing. Raw data would certainty be timely, but it would be detrimental if non-accurate. In addition, raw data would probably be too voluminous to be meaningful. Buried in overwhelming amounts of raw data, the decision maker could easily overlook the important facts.

On the other hand, the intelligence process is often very long so that waiting for its completion to transmit information to commanders would not be acceptable. Consequently, somewhere between raw data and intelligence, an amount of data processing exists which realizes the best tradeoff between timeliness and meaningfulness.

Raw information is currently available to commanders through the use of the hot line. The drawback is that this information goes directly from the source (e.g., the BASS van) to the user and is not correlated with information coming from other sources.

Considerations of this sort led MCTSSA to define the notion of combat information (McDonough and Lawson, 1979) as: *that information about the location of enemy weapons, personnel and equipment on the ground which is made available immediately, after only technical processing. It differs from intelligence in that intelligence is the result of the analysis of many diverse elements of information and provides identification of enemy units as well as predictions and estimates of enemy intentions and capabilities. Combat information is the ground equivalent of the track information on enemy aircraft provided by the TAOC. It is utilized by intelligence analysts as one input in the production of intelligence. It is also used simultaneously by aviation and fire support agencies to select targets for immediate engagement and by maneuver control agencies to determine the objectives of maneuver and immediate threats to friendly forces.*

Although the term "combat information" is for many people a synonym of "unconfirmed intelligence," we have retained the definition of McDonough and Lawson (1979). This definition should, however, be refined since it is very hard to determine where correlation ends and analysis begins. A specific definition of what correlation consists of, i.e., the process it involves, therefore naturally yields a working definition of combat information. To illustrate the difference between combat information and intelligence, consider Figure 2-1 which depicts the interaction between G2 and commander during ground maneuver control. Under the scrutiny of a number of sensors, the environment provides information to the Reconnaissance and Surveillance station of the Intelligence Center. The sensors

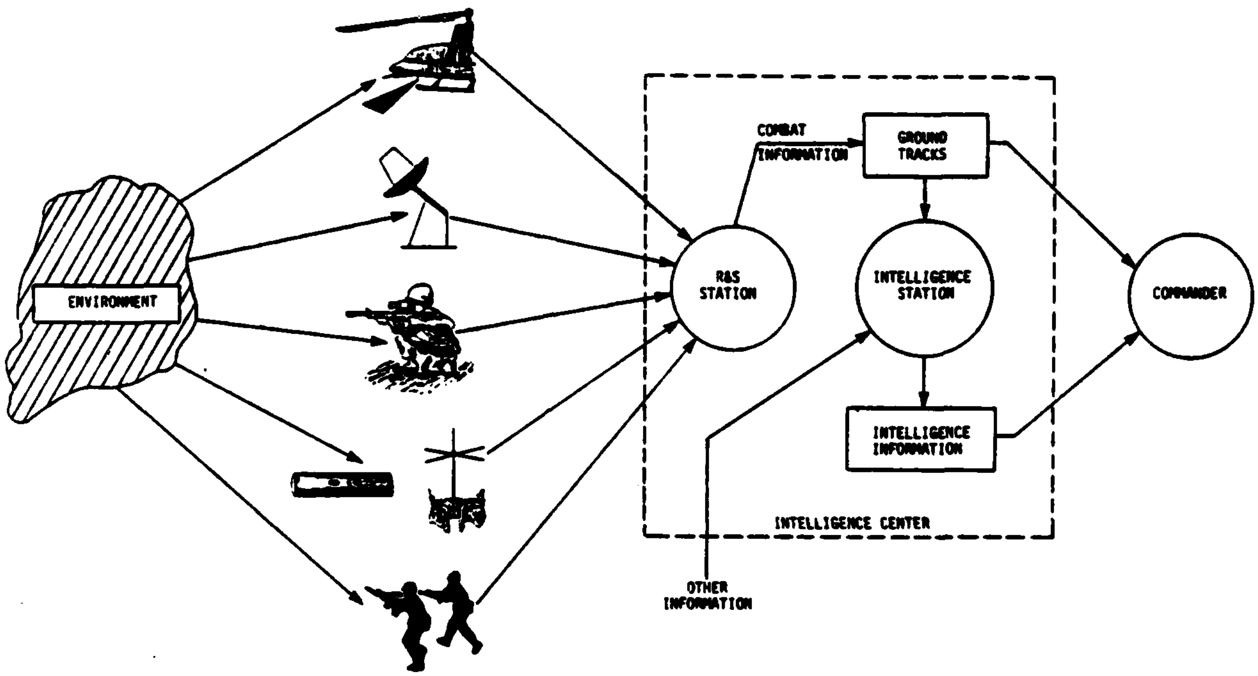


FIGURE 2-1.
G2/COMMANDER INTERACTION DURING GROUND MANEUVER CONTROL

portrayed in this figure are a helicopterborne infrared seeker, a ground surveillance radar, an individual served weapon sight, a hand-placed and an artillery delivered unattended ground sensor of the REMBASS generation and infantrymen in direct contact with the enemy. The Reconnaissance and Surveillance station creates ground tracks which represent the current picture of the battlefield together with its history. These tracks are available without delay to the commander and yet the information has been correlated.

The ground tracks are also available to the intelligence station within the Intelligence Center. Together with other information, these tracks allow the intelligence analyst to perform required analyses, estimates and inferences which are also very useful to the commander. The following example, extracted from the PSDD illustrates this point:

> *"The Battalion is operating at the Forward Edge of the Battle Area (FEBA). The Intelligence Officer receives a combat report from 'A' Company, who sighted an enemy tank forward of their position. The Intelligence Officer fills in an Enemy Sighting Report. Next, by a single action, he causes the report to be simultaneously automatically forwarded, to update his files, and to be graphically displayed on his enemy situation display. Reviewing the situation on his DSD, the Intelligence Officer notes an enemy track, received in response to a previous SRI, within 1000 meters of the sighting. He "hooks" the symbol and reviews the text display of the correlated combat information. The amplifying information indicates that five tanks suspected to belong to the 2d Bn 205th were sighted moving southwest two hours earlier. Noting the Unit ID, the Intelligence Officer recalls that recent intelligence summaries and responses to his previously submitted Ad Hoc queries had mentioned the 205th. Querying his intelligence files about the 2d Bn 205th the Intelligence Officer is provided known Unit Order of Battle information, which includes the enemy unit's strength and weapons. Equipped with all this information the Intelligence Officer makes his assessment. Contacting the Commander he warns that Company A's sighting is probably one of five tanks previously tracked and that four others are no doubt in the immediate vicinity. He Passes the same information to the CO of Company A, and he further alerts the Battalion and Company Commander to the combat power capabilities of the 2d Bn 205th."*

2.4 Present Information Correlation Concept

This section summarizes the present concept of employment of TCO to support information correlation within the MAGTF as described at length by McDonough & Lawson (1979) and the PSDD. For additional details the reader should refer to these documents. For an amphibious operation of MAF size there are three intelligence centers each managing its collection assets as depicted in Figure 2-2. For an operation of MAB size only one intelligence center exists managing all collection assets. Although defined at MAF level, the concept is immediately transferable to the MAB level. Raw data coming from a variety of sensors is received by division, wing, and MAF intelligence centers, correlated and included in the TCO data base. Combat information sources are portrayed and described in Tables 2-1 and 2-2. A Combat Information Track record consists of the following data elements:

(1) Track Identifier number.
(2) Source(s) of the information.
(3) Location (UTM coordinates).
(4) Time of detection.
(5) Classification.

- (a) Troops.
- (b) Vehicles.
  - 1 Tracked.
  - 2 Wheeled.
- (c) Weapons (type).
- (d) Emitters (Comm or Radar).

(6) Number (of troops, vehicles and/or weapons).
(7) Activity.

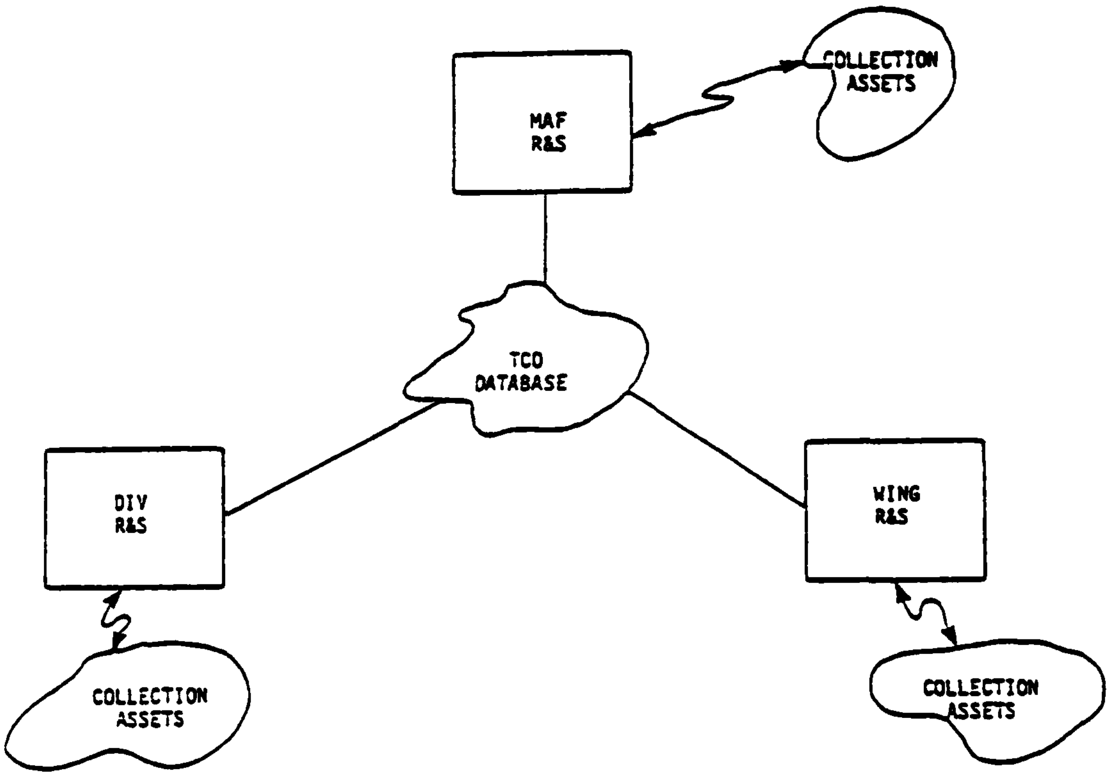


FIGURE 2-2.
COMBAT INFORMATION FLOW

TABLE 2-1

COMBAT INFORMATION COLLECTION ASSETS

UNIT / SENSOR TYPE	DIVISION					WING					MAF		
	INF. BAT.	RECON BAT.	ART. REG.	SCAMP PLA.	ITT	WHO	VMA-(AW)	VMFA F/18	VMFP	VMAQ	ELEMENTS RADIO BATTALION	TEAMS FORCE RECON	EXTERNAL SOURCES
UNATTENDED GROUND SENSORS	(1)			(7)									
GROUND SURVEILLANCE RADAR	(2)												
OPTICAL SIGHTS/ SCOPES	(3)	(4)				(10)		(15)				(25)	
SIDE-LOOKING AIRBORNE RADAR									(18)				
INFRARED LINE SCANNER									(19)				
FORWARD LOOKING INFRARED						(11)	(13)	(16)					
MOVING TARGET INDICATOR							(14)						
PHOTOMETRIC		(5)			(8)	(12)		(17)	(20)			(26)	
DIRECTION FINDING											(22)		
COMMUNICATIONS COLLECTORS											(23)		
ELECTRONICS COLLECTORS										(21)	(24)		
COUNTER MORTAR RADAR			(6)										
TAPE RECORDER REPRODUCTION					(9)								
NATIONAL ASSETS													(27)
OTHER SERVICES SYSTEMS													(28)
ALLIED COLLECTORS													(29)

The numbers in circles refer to Table 2-2

TABLE 2-2

COLLECTORS OF COMBAT INFORMATION

AGENCY	NUMBER KEY	COMMON NAME	NOMENCLATURE	DESCRIPTION
INFANTRY BATTALION	(1)	MINI-PSID	Tactical Intrusion Detector (TID)	Miniature patrol seismic intrusion device lightweight, self powered, portable, seismic sensor.
	(2)		AN/PPS-15	Portable ground radar designed to acquire moving targets. Visual/audio signal. Personnel/vehicles.
		FOLPEN-BSD		Folliage penetration, Battlefield Surveillance Device. All weather, all terrain, day/night observation, surveillance and target acquisition ground radar.
	(3)	Individual served weapon sight	AN/PVS-11	Small, lightweight all weather night observation telescope.
		Night Vision Goggles	AN/PVS-5	Infrared night observation head goggles used for close up work.
		Night Observation Device (NOD)	AN/TVS-4	Night observation device which utilizes starlight and moonlight for panoramic passive viewing.
		Starlight Scope	AN/PVS-2	Portable, battery powered, electro-optical instrument handheld or mounted on individual weapons.
DIVISION RECONNAISSANCE BATTALION	(4)	Starlight Scope	AN/PVS-2	Described in (3) above.
		Individual served weapon sight	AN/PVS-4	Described in (3) above.
		Night Vision Goggles	AN/PVS-5	Described in (3) above.
		NOD	AN/TVS-4	Described in (3) above.
		Crew served weapon sight	AN/TVS-5	Night vision sight utilizing starlight/moonlight and provides panoramic passive viewing.
	(5)	Camera	35mm NIKONOS II	Snapshot photographs.
ARTILLERY REGIMENT	(6)		AN/TPQ-36	Counter mortar radar.
SCAMP	(7)	REMBASS		Remote Battlefield Sensor System family of unattended ground sensors.
			DT 561	Magnetic
			DT 562	Seismic, acoustic
			DT 565	Infrared
			DT 567	Seismic, acoustic
			DT 570	Seismic, acoustic
INTERROGATION TRANSLATION TEAM	(8)	Camera	Polaroid	Snapshots of POW, captured documents, enemy equipment.
	(9)	Tape recorder reproduction set	AN/UNF-3	Utility type portable tape recorder.
VMO	(10)	STEADY-EYE	SVD	Hand-held stabilized optical viewing device.
	(11)	NOS	Night Observation System	A forward looking infrared device used for night observation.
	(12)	Cameras	70mm panoramic Polaroid	Can be mounted to A/C hand-held snapshots.
VMA(AW)	(13)	FLIR	Forward Looking Infrared	Feature of the TRAM weapons system.
	(14)	MTI	Moving Target Indicator	Locates and tracks moving enemy ground targets in the target area.
VMFA (F-18)	(15)	Optics		Optical/electro-optical sights support the A/F-18 pilot.
	(16)	FLIR	Forward Looking Infrared	
	(17)	Cameras		The aircraft is capable of being equipped with photographic equipment.
VMFA	(18)	SLAR	AN/APD-10	Produces radar imagery on film (can be down linked).
	(19)	IR	AN/AAD-5	Produces infra red photography.
	(20)	Cameras	Photo	Panoramic and vertical imagery, B&W, color, camouflage.

TABLE 2-2. (CONT'D)

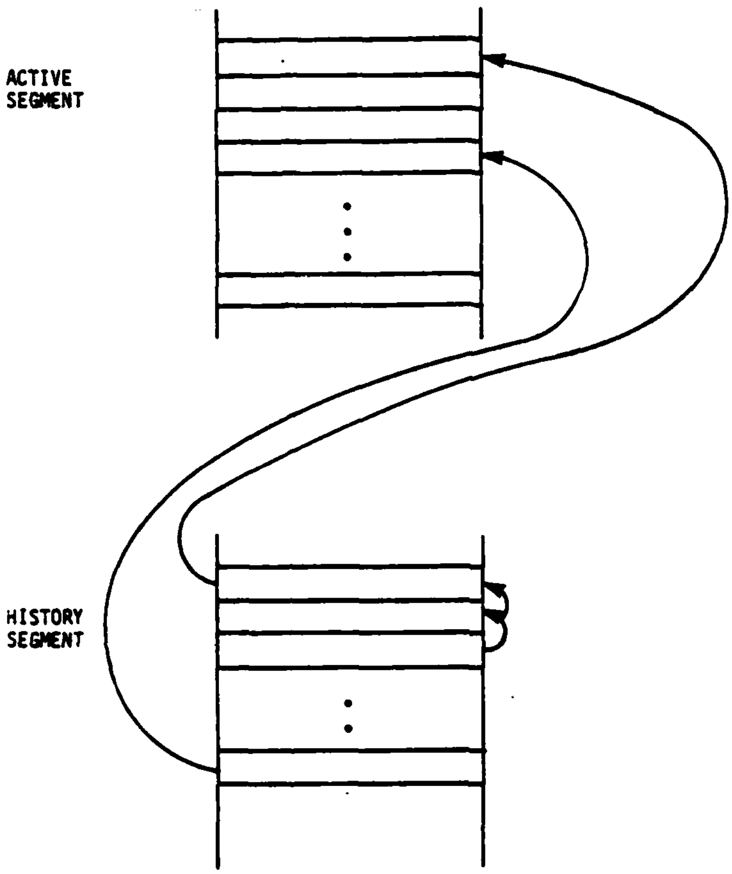
AGENCY	NUMBER KEY	COMMON NAME	NOMENCLATURE	DESCRIPTION
VMAQ	21	ELINT		Electronics intelligence collectors.
RADIO BAT.	22	D.F.	AN/MRD-16	Mobile radio direction finding (D.F.) set.
			AN/GRA-94	D.F. radio.
			ARDF	Team portable, omni directional airborne radio direction finding system. Mounted to UH-IN helicopter type.
	23	COMINT		Communications intelligence collectors.
			AN/TSQ-54	Heavy mobile intercept facility, voice, Morse and teletype.
			AN/TSQ-88	Multichannel communications collection van.
			AN/TSQ-103	Mobile, light intercept facility.
			AN/PRR-640	Man-packed radio receiver set.
			AN/TRQ-30	Single channel man-packed intercept receiver set.
	24	ELINT		Electronics intelligence collectors.
FORCE RECONNAISSANCE TEAMS	25	Starlight Scope	AN/PVS-2	Force Reconnaissance is equipped with devices identical with those identified for Recon B 4 above.
		Individual served weapon sight	AN/PVS-4	Described in (4) above.
	26	Camera	35mm NIKONOS	Snapshot photographs.
EXTERNAL SOURCES	27	National Assets		CLASSIFIED
	28	The following systems identify sources providing combat information from other artillery services operating adjacent to or in conjunction with the MAGTF.		
		ASAS		All Source Analysis System (U.S. Army).
		AGTELIS		Automated Ground Transportable Emitter Location-Identification System (U.S. Army).
		SOTAS		Staff Off Target Acquisition System (U.S. Army).
		TACELIS		Tactical Emitter Location and Identification System (U.S. Army).
		QUICKLOOK II	AN/ALQ-133	CLASSIFIED (U.S. Army).
		TRAILBLAZER	AN/TSQ-144	CLASSIFIED (U.S. Army).
		GUARDRAIL V		CLASSIFIED (U.S. Army).
		MULTEWS		Multiple Target Electronic Warfare System (U.S. Army).
		QUICK FIX	AN/ALQ-151	(U.S. Army).
		BSTAR		Battlefield Surveillance and Target Acquisition Radar (U.S. Army).
		ALR	AN/TPQ-37	Artillery Locating Radar (U.S. Army).
		RPV		Remotely Piloted Vehicle System (U.S. Army).
		NBDS		Nuclear Burst Detection System (U.S. Army).
		TSSLS	ROLM 1602	Tactical Single Station Locator System (U.S. Army).
		RTASS		Remote Tactical Airborne SIGINT System (USAF).
		COMPASS EARS	AN/ASQ-114(V)	(USAF)
		RIVET JOINT		CLASSIFIED (USAF)
	29	The following allied systems typify automated systems which might provide combat information to the MAGTF.		
		BATES		United Kingdom. Battlefield Artillery Target Engagement System.
		WAVELL		United Kingdom. Provides G-2/G-3 support similiar to TCO.
		BEROS		German.
		GEADGE		German Air Defense Ground Environment
		ATILA		French.
		ODIN		Norwegian.
		SAGAT		Italian.
		CCDS		Canadian.

(a) Moving (direction/speed).
(b) Deployed.
(c) Assembling.
(d) Emitting.
(e) Firing.

(8) Unit I.D.

The Combat Information available is summarized in the track record file which is divided into two segments as depicted in Figure 2-3: (1) the active segment which contains the most current track data and (2) the history segment which summarizes past track behavior.

When a sensor report is received at the center, the corresponding information is correlated with existing tracks to determine if it corresponds to (1) a new track, (2) an update of an existing track, or (3) redundant or less reliable data about an existing track. This correlation is performed by an operator aided by displays on the Dynamic Situation Display (DSD). If a new track is created the operator assigns to it an identifier from an authorized set of numbers and the track is entered in the track record file with a prefix referring to the track manager (e.g., D for division). A center which creates a track automatically becomes the manager of this track. Upon updating by an R & S station of a track which is under management of another R & S station, both stations must agree on the proposed update. Conflicts are referred to the track coordinator located in the MAF intelligence center. In the present concept MAF track correlator and track coordinator are the same person. In addition to resolving conflicts the track coordinator may reassign track management responsibility from one center to another.



The arrows are pointers identifying all
the data elements which constitute a track.

FIGURE 2-3.
COMBAT INFORMATION TRACK RECORD FILE

2.5 Areas of Improvement

In the present concept of employment of TCO support of combat information production and management, the operator correlates information manually with the aid of certain TCO capabilities of a general supportive nature only, such as time computations, displays of ranges and line-of-sight calculations. These capabilities probably make the operator's job easier and enhance accuracy and timeliness. They do not, however, provide any direct aid to the decision processes which are involved in information correlation, thus do not significantly reduce processing time. At the estimated rate of 600 sightings per hour shared between division, wing, and MAF operators, i.e., on the average one sighting every 20 seconds, it is very likely that a task overload would occur. In the decision support system concept presented in Chapter 3, the information correlation decision process is decomposed into elementary decision sub-processes which are automated or aided. It is expected that, by employment of the support system, the average processing time per sighting will be much shorter so that those sightings which require operator intervention can be allocated more time.

The process of information correlation involves comparing pieces of information to decide if they refer to (1) the same entity or (2) two distinct entities. When referring to the same entity the pieces of information can either be in accord or create a conflict. If a conflict between two pieces of information occurs, one must be able to compare these information in terms of the credibility or reliability which can be attached to them. Even if there is no conflict, it is essential to be able to decide if a piece of information is unreliable in order to disregard it. If a conflict cannot be resolved by discarding the less reliable information, more information needs to be collected. A decomposition of the decision functions involved in the process of information correlation is presented in Figure 2-4. In the following chapter the proper aiding techniques to support these functions are described.

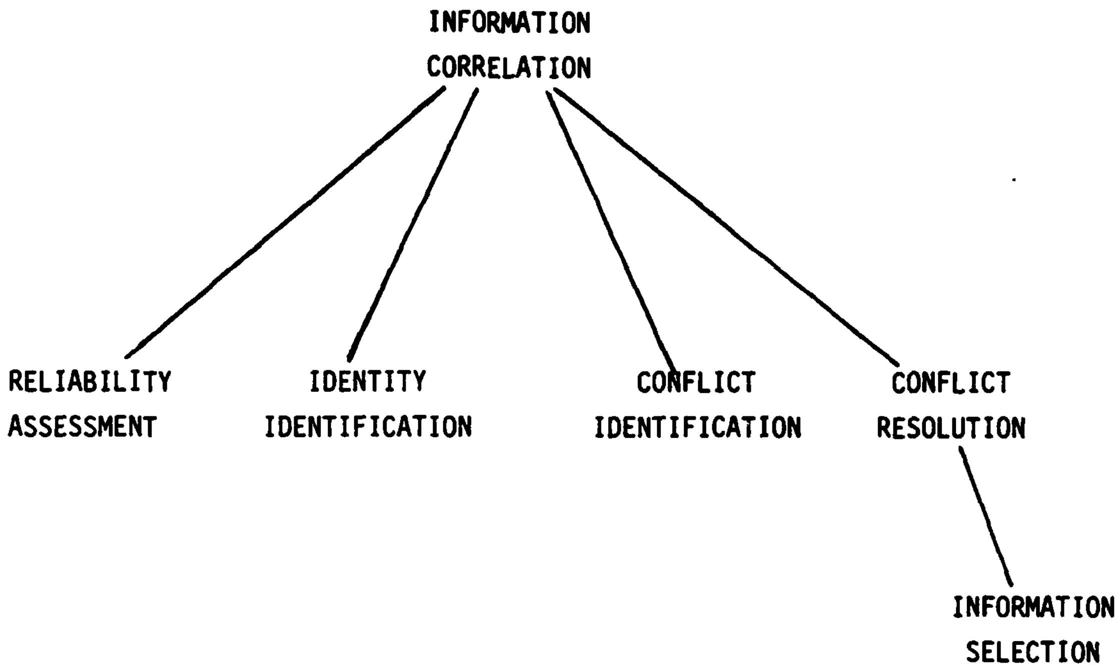


FIGURE 2-4.
DECISION PROCESSES INVOLVED IN
INFORMATION CORRELATION

An improvement in overall concept framework can also be brought about. Note that conflicts in proposed track file modifications could occur not only between division and wing, but also between division and MAF, and wing and MAF. The last two types of conflict differ from the first one only in the sense that the MAF G2 can resolve conflicts acting as the ultimate decision maker. All conflicts, however, involve the same processes and could consequently be treated alike. Thus, a file of proposed track record modifications could be created whose elements would be subjected to analysis to identify and resolve possible conflicts. This would be, of course, a MAF function. The creation of such a file would, in turn, imply centralization of track management functions at MAF level. This would avoid extra communications between MAF, wing, and division with regard to the assignment of track identifiers. This modification which is of an organizational nature would simplify the situation and decrease communication requirements. It should permit an improvement in decision quality and a decrease in processing time.

3. DECISION SUPPORT SYSTEM CONCEPT

3.1 Overview

The decision support system described in this section has been conceived to provide two elements: (1) an organizational structure and (2) a set of decision-aiding modules connected to each other within the defined structure. The decision-aiding modules support the decision-making functions which were identified previously and are portrayed in Figure 2-4. From an organizational viewpoint, correlation functions fall into two categories:

(1) Local correlation, performed on sensor reports by Division, Wing, and MAF operators separately, and resulting in proposed track file modifications.

(2) Global correlation, performed by an MAF operator on the proposed track file modifications, and resulting in a decision on proposed modifications with regard to their implementation.

In the concept depicted in Figure 3-1 local and global correlations interact as follows: Upon receipt of a sensor report the local correlation operator (Div., Wing, or MAF) correlates this new sensor information with existing information contained in the track record file. When the local correlation process is completed, a proposed track file update is issued and sent to the track modifications file. The specific functions and mode of operation of the system for local and global correlation are described in Section 3.2.

The decision-aiding modules support both local and global correlations which actually involve the same decision processes. Since only the implementation of these techniques is different, from local correlation

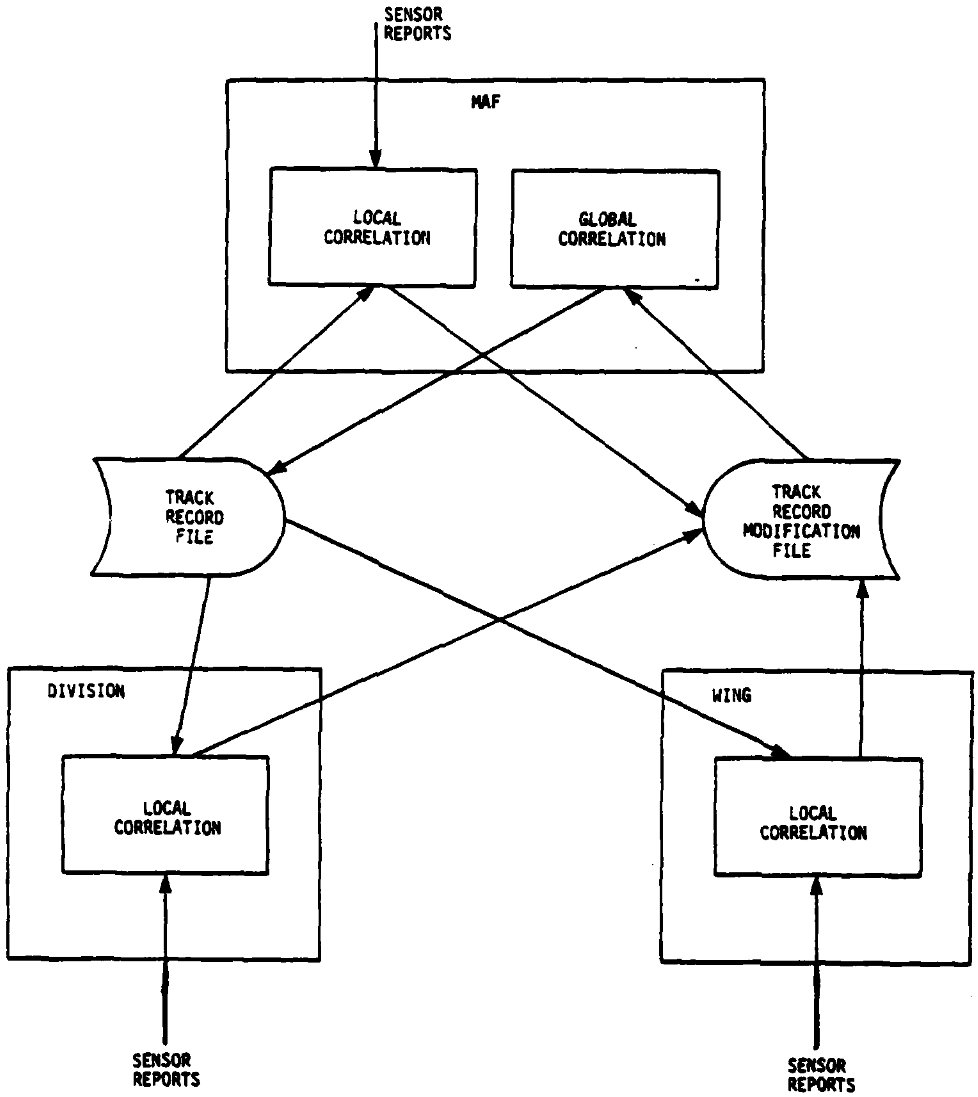


FIGURE 3-1.
DECISION SUPPORT SYSTEM CONCEPT OVERVIEW

to global correlation, these differences will appear in the design description only (Chapter 4). From a functional standpoint, the aiding techniques fall into two categories: (1) information correlation and (2) information collection. While information correlation is based on comparing pieces of information, information collection consists of comparing sources of information. The various techniques which can be used to aid the processes involved in information correlation and collection, together with their concept of employment, are described in Sections 3.3 and 3.4.

3.2 Correlation Concepts

3.2.1 Local Correlation. As depicted in Figure 3-2, there are five decision-making functions involved in local correlation: (1) reliability assessment, (2) conflict identification, (3) conflict resolution, (4) information selection, and (5) track record file modification identification. These functions are articulated as follows: upon receipt of a sensor report its reliability score is computed; simultaneously possible conflicts between the information contained in the sensor report and the track record file are identified. When a conflict is identified, the reliability scores are used to reject tracks with very low reliability and possibly resolve the conflict. When it is not possible to resolve a conflict this way, more information is required. Thus, the most informative way to gather information is determined. The gathering of this information yields a sensor report which is again input to the system. When no conflict is identified or when the conflict is resolved, the proper track record file modification is determined and sent to the track record modification file.

3.2.2 Global Correlation. Global correlation consists of comparing one element of the track record modification file to all others in order to determine whether to implement this proposed modification. The global correlation module should, therefore, enable comparison between any two proposed modifications to the track record file.

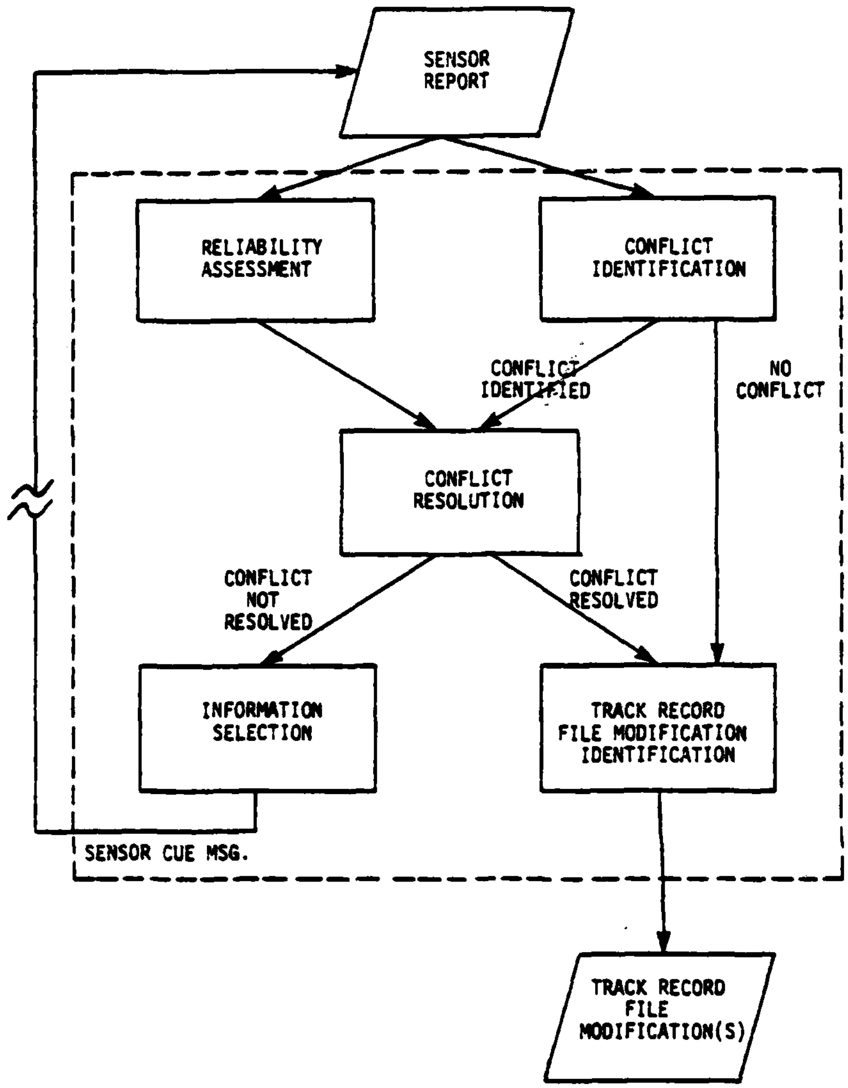


FIGURE 3-2.
LOCAL CORRELATION OVERVIEW

The functional similarity between local and global correlations is now apparent since they both involve the same functions except reliability assessment (see Figure 3-3). Since a modification to the track record file is proposed on the basis of a sensor report, the reliability score attached to this sensor report will be carried along with the proposed modification.

Two proposed modifications to the track record file are compared for the purpose of identifying a possible conflict. When a conflict is indeed identified, the reliability scores are used to disqualify the sufficiently low-reliability modification, if such a case exists. In the case where the conflict cannot be resolved by the virtue of reliability scores, the most effective information for conflict resolution is identified and sought. Upon inspection of this requested information, the proper modification is selected. However, if a moving entity is involved and too much time has already elapsed, the operator performs the conflict resolution manually (with the option of requesting more information to enable him to consider the displacement of the entity). At the end of the execution of this module, the decision is made as to whether create a new track or update an existing one.

3.3 Information Correlation Aiding

3.3.1 Reliability Score. In order to assess the confidence on a sensor report, a reliability score can be computed. It will be a monotonic function of the confidence which can be attached to a sensor report in each specific situation. Each situation can be defined in terms of two parameters: (1) the characteristics of the sensor and (2) the environmental conditions under which the sensor operates. Sensor characteristics dictate the confidence on (1) the location of the entity reported and (2) the accuracy of the classification provided.

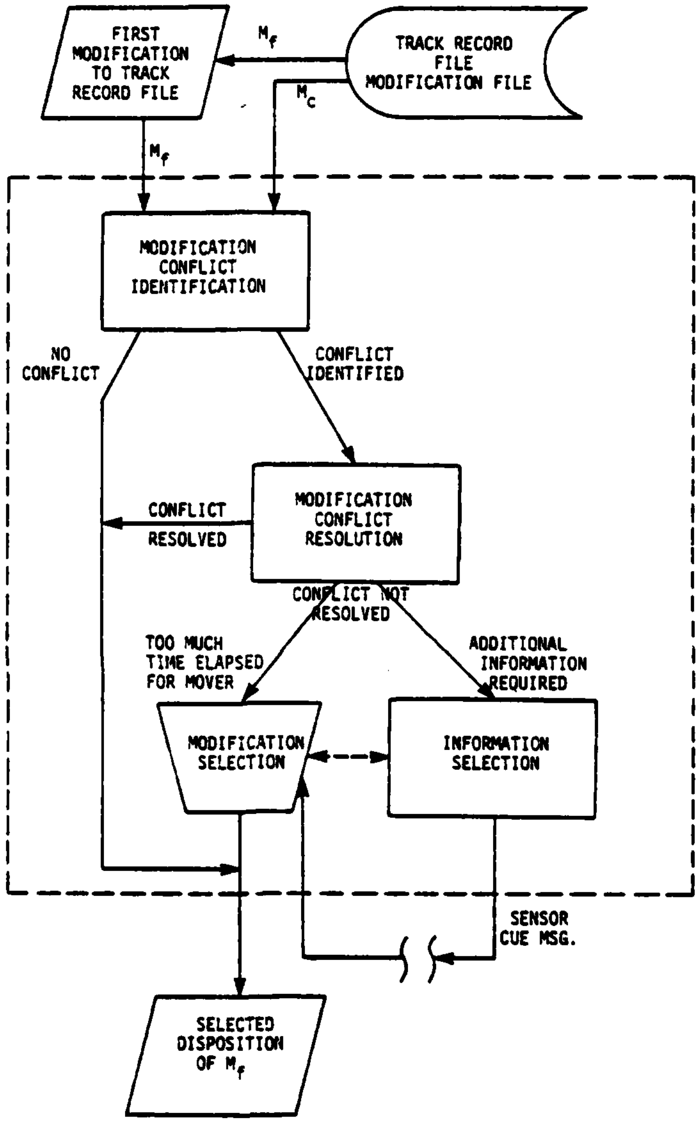


FIGURE 3-3.
GLOBAL CORRELATION OVERVIEW

Generally, the uncertainty about a location can be summarized by a dispersion matrix Σ. If the report provides 2-dimensional location $\underline{m}$, it is generally assumed that the actual location of the entity is $\underline{m} + \underline{x}$, where $\underline{x}$ is distributed as $N(\underline{0}, \Sigma)$*. Define E_α as the ellipse such that there is a probability α that the actual location of the entity is in E_α. For a given value of α (say 90%), the surface S_α of this ellipse is a good indicator of the sensor's credibility since the bigger S_α, the less precise the sensor. It can be shown (see Appendix D) that S_α is proportional to $|\Sigma|$ (the determinant of Σ). Consequently, a good indicator of the sensor's reliability with regard to its localization function is the localization reliability score defined as $\sigma_L = \frac{1}{1+|\Sigma|}$. For a very unreliable sensor, $|\Sigma|$ is large and, therefore, σ_L is close to zero, while, for a reliable sensor, $|\Sigma|$ is small and thus, σ_L is close to 1.

The accuracy of the classification provided can be measured by the misclassification rate or probability of error P_e. Thus, the classification reliability score can be defined by $\sigma_C = 1 - P_e$. In addition, the performance of certain sensors can be hampered by the environmental conditions which are related to the terrain (such as foliage, which restricts line-of-sight) or enemy activity (such as jamming). These conditions reduce the above scores by factors ρ_L and ρ_C, respectively. The general reliability score is a combination of these individual scores: $r = w_L\rho_L\sigma_L + w_C\rho_C\sigma_C$, where $w_L + w_C = 1$ and w_L and w_C are weights specified in advance and independent from the particular sensor (e.g., $w_L = \frac{1}{2} = w_C$). The reliability score thus defined permits discrimination among pieces of information. Its computation is automatic requiring certain human judgments to be stored ahead of time. Other required human judgments are incorporated on-line and are available immediately to the system.

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*$\underline{x}$ is distributed normally around the origin with dispersion matrix Σ, i.e., its p.d.f. is given by $f(\underline{x}) = \frac{1}{2\pi|\Sigma|^{1/2}} e^{-\frac{1}{2}\underline{x}'\Sigma^{-1}\underline{x}}$

3.3.2 Identity Testing. When comparing the information contained in two sensor reports regarding locations very close to each other, it is legitimate to ask whether the two sensors might sense the same entity. An apparently similar problem is encountered in the naval environment where several ships can sense the same entity but each gets "shifted" pictures due to the uncertainty about the actual location of the ship itself. The problem of locating the target in these conditions is known as the "grid-lock problem" for which only a manual system exists. References on this topic were communicated to us late in this project (McCall, 1980) and include Tirnan (1970) and Cantrell, Grindlay and Dodge (1976). The problem faced here is slightly different from the grid-lock problem however, since, in our case, the sensor location is known and the uncertainty about target location is due to sensor limitations. Should the uncertainty about ship location be somehow translated into target location uncertainty and modeled in a manner similar to the one presented here, the method presented next would also apply to the grid-lock problem.

Assume, for example, that sensor 1, characterized by a dispersion matrix Σ_1 reports on an entity of class C at location $\underline{x}_1$ and that simultaneously sensor 2, characterized by a dispersion matrix Σ_2, also reports an entity of class C at $\underline{x}_2$ in the vicinity of $\underline{x}_1$. Let $\underline{m}_1$ (respectively $\underline{m}_2$) be the true location of the entity reported by sensor 1 (respectively sensor 2). It is desired to devise a statistical procedure allowing one to test hypothesis H_0: $\underline{m}_1 = \underline{m}_2$ (i.e., the two sensors are actually sensing the same entity) versus H_1: $\underline{m}_1 \neq \underline{m}_2$ (i.e., the two sensors are sensing different entities).

In other words, consider two independent 2-dimensional non-degenerated normal variables X_1 and X_2, i.e., with the same notations as above, $X_1 \sim N(\underline{m}_1, \Sigma_1)$ and $X_2 \sim N(\underline{m}_2, \Sigma_2)$ for which samples $\underline{x}_1$ and $\underline{x}_2$, respectively, are available and try to devise a statistical procedure to test H_0 against H_1 defined above.

Note that since X_1 and X_2 are stochastically independent, their difference is also normally distributed. More specifically, $X_1 - X_2 \sim N(\underline{m}_1 - \underline{m}_2, \Sigma_1 + \Sigma_2)$. The problem is thus reduced to the following: given a 2-dimensional normal variable $X \sim N(\underline{m}, \Sigma)$ for which sample $\underline{x}$ is available, devise a procedure to test:

$$H_0: \underline{m} = 0 \quad \text{against} \quad H_1: \underline{m} \neq 0$$

It is assumed that Σ is definite positive since both Σ_1 and Σ_2 are. It is well-known that, if H_0 is true, the quantity $\underline{x}'\Sigma^{-1}\underline{x}$ is distributed as chi-square with two degrees of freedom. To perform the test the quantity $\underline{x}'\Sigma^{-1}\underline{x} = \chi^2_{obs}(2)$ is computed, and its value compared to $\chi^2_{\alpha_0}(2)$, where α_0 is an acceptable error threshold (e.g., $\alpha_0 = 10\%$).

The concept of employment for this technique is as follows: when comparing an incoming sensor report with an existing track record about locations $\underline{x}_1$ and $\underline{x}_2$, which are close to each other, the quantity $K = (\underline{x}_1 - \underline{x}_2)' (\Sigma_1 + \Sigma_2)^{-1} (\underline{x}_1 - \underline{x}_2)$ is computed. Simultaneously, for the a priori level of confidence $1-\alpha_0$ the quantity $\chi^2_{\alpha_0}(2)$ is looked-up (typically $\alpha_0 = 10\%$ or 5% for which $\chi^2_{\alpha_0}(2)$ is equal to 4.61 and 5.99, respectively). The system will then either accept or reject hypothesis H_0 is the following manner:

accept H_0 if $K < \chi^2_{\alpha_0}(2)$

reject H_0 if $K \geq \chi^2_{\alpha_0}(2)$

3.3.3 Track Similarity. Track similarity, i.e., closeness between two tracks, can be defined in a multitude of ways. First, the classes must correlate, i.e., if one report says 'radar' and the other says 'personnel', the entities cannot possibly be the same. A contrario, if one says 'three tanks' and the other says 'five tanks' the sensed entities can conceivably be the same. Along the same lines, if one report says 'three tracked vehicles' and the other says 'five tanks', the corresponding reports can also refer to the same entity. More specifically, if the classes are defined in a hierarchical way, i.e., via a tree, we will say that there is a class discrepancy between two classes if the nodes which represent these classes in the tree do not belong to the same path from the root node. Figure 3-4 portrays examples of class discrepancies. Track proximity must be defined along two dimensions:

(1) The class the entity belongs to.
(2) The number of elements in the track.

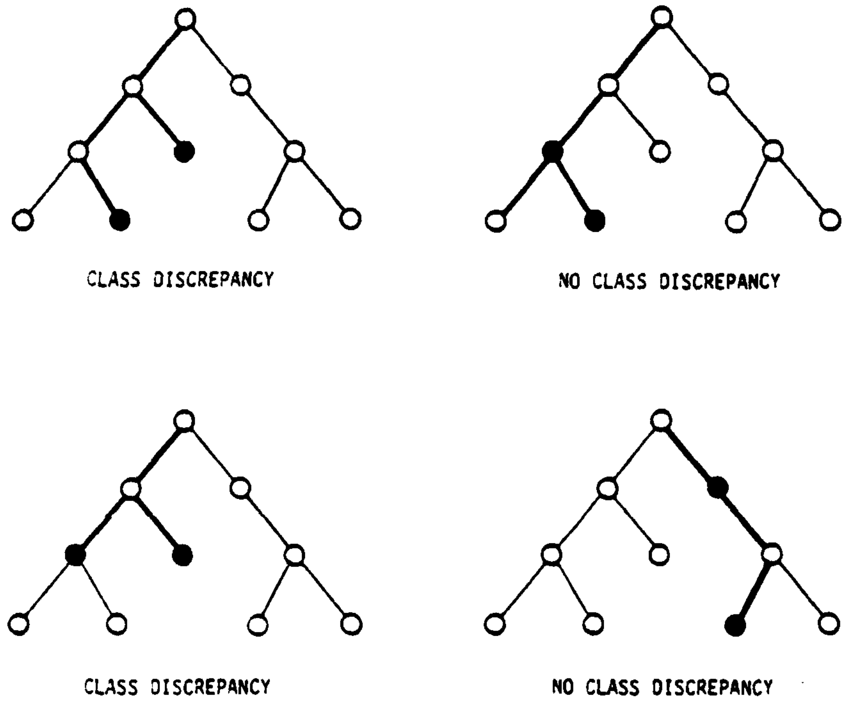
Since the number of elements is often the by-product of another process such as counting occurrences while watching a classifying unattended ground sensor, figures should be taken only as indicative in many cases. In addition, when a time span is involved, attritions can occur. The retained solution is the following: Define track record T_i which contains n_i entities of class $C_i = a_i b_i c_i$ (Dewey notation for 3-level hierarchy). We then define the distance between T_1 and T_2 by $d(T_1, T_2) = W_1\Delta_1(n_1, n_2) + W_2\Delta_2(C_1, C_2)$, where W_1 and W_2 are positive weights and Δ_1 and Δ_2 are distances in $\mathbb{R}$ defined as follows:

$$\Delta_1(n_1,n_2) = |n_1 - n_2|$$

$$\Delta_2(C_1,C_2) = 100\delta(a_1,a_2) + 10\delta(b_1,b_2) + \delta(c_2,c_2)$$

where δ is Kronecker's delta function.

$$\delta(\alpha,\beta) = \begin{cases} 0 \text{ if } \alpha = \beta \\ 1 \text{ otherwise} \end{cases}$$



FIGURES 3-4.
EXAMPLES OF CLASS DISCREPANCIES

The concept of employment of these notions is as follows: After it was determined that two entities are indeed at the same location, thus implying that they are very likely to be the same, the classes are checked for a possible discrepancy. If such a discrepancy is identified and the numbers of entities in the tracks are the same, then a class conflict exists.

The notion of track distance is used for track filtering. When the operator wants to determine whether it is possible that a moving entity just sensed is actually an already tracked entity which has moved, he can filter out from further consideration those tracked entities which are very dissimilar from the entity under scrutiny. This reduces the number of candidates to be considered and thus permits an improvement in processing time.

3.3.4 Time Computation Algorithm. TCO capability number 92, designated "Calculate time/distance ratio," is described as "the capability to predict the time needed to travel a given distance over a given terrain by a given means." A path is decomposed in n segments and the time to traverse the path is given by:

$$T = \sum_{i=1}^{n} (d_i/s_i r_i + l_i)$$

where i refers to the i^{th} leg of the path, d_i the leg length, s_i the maximum speed of the entity, r_i the reduction factor due to road condition and l_i the loiter time. Road conditions are defined as excellent, good, poor, and very poor, and the corresponding reduction factors are 1.0, .75, .50, .25. d_i is defined by the formula:

$$d_i = \sqrt{(x_{i1} - x_{i2})^2 + (y_{i1} - y_{i2})^2}$$

where (x_{i1}, y_{i1}) and (x_{i2}, y_{i2}) are the UTM coordinates of the extremities of the leg.

The concept of employment of this capability is as follows: Upon receipt of a sensor report regarding a moving entity in a location where no enemy activity was previously reported, the operator desires to check whether it is possible that the entity sensed is actually already in the active track file. To check out the possibility whether the entity sensed at location (x,y) can come from elsewhere requires that the operator:

(1) Displays similar entities located in the vicinity of (x,y).
(2) Ascertains whether (x,y) can be accessed by any of the displayed entities from a geographical standpoint.
(3) Computes the time required for the displayed units to move to location (x,y).
(4) Compares the computed travel time to the observation time differences.

Retrieval of entities located in the vicinity of (x,y) will be performed on the basis of similarity as described in 3.3.4 above.

3.3.5 <u>Bayesian Classification</u>. The Bayesian classification model provides a framework to make the following classification decision: given m-classes specified in advance and an observed entity, which of these classes does the entity belong to? Probabilities $\pi_1, \ldots, \pi_m$ that the entity belongs to $C_1, \ldots, C_m$, respectively are available. Bayes' strategy consists of selecting the class which minimizes the expected loss. When a 0-1 loss function is used, i.e., if the subject incurrs a loss equal to 1 in case of a erroneous decision and a loss equal to 0 in case of a right decision, this strategy is equivalent to minimizing the probability of error, i.e., to select i_0 such that:

$$\pi_{i_0} = \max_i \pi_i$$

Then the probability of error is $P_e = 1-\pi_{i_0}$.

In the statistical pattern recognition approach (Duda & Hart, 1973), the situation is such that new evidence comes which modifies the current a priori probability estimate $\underline{\pi}^0$. One random variable can be observed which is related to the classes via conditional probabilities. Namely, X, also called a feature, which can take the values 1, ..., K, can be observed and the probabilities $P(X = k|C_i)$ are known. Upon observation of X which yields a specific value for X (e.g., X = k), the probabilities are updated according to Bayes' formula:

$$\pi_i^1 = \frac{P(X = k|C_i)\ \pi_i^0}{\sum_{i=1}^{m} P(X = k|C_i)\ \pi_i^0}$$

A classification decision can then be made using π_i^1. If the probability of error is higher than a certain specified threshold, the actual decision is postponed and more information is sought.

Sensor reports are presented in the form of classification decisions. Thus, in the case of sensor reports, the feature observed is itself a classification decision, thus requiring the knowledge of conditional probabilities of the type $P(C_i|C_j)$, i.e., probability that the sensor declares C_i when the actual class is C_j. Certain sensors provide high-level classification only, such as personnel, tracked vehicle, wheeled vehicle. In this case the features are these higher-level classification decisions. Then the required numbers are $P(C_{high\text{-}level}|C_i)$. For instance, $P(C_{tracked\ vehicle}|C_{tank})$ falls in this category. To require these numbers is a realistic assumption as demonstrated through interviews of experts. Such numbers can be obtained through simulation or elicited from experts having field experience. When the elicitation mode is selected, assumptions must be made on the type of combat which is expected and subjects selected whose background includes as many as possible of these expected conditions.

The concept of employment of Bayesian classification is as follows: Consider the case where it is determined that two entities reported by different sensors are close enough to assume that they are actually one entity. If the classes reported are distinct, a classification conflict exists which can be resolved via the Bayesian Classification approach. The priors are elicited from the operator who is prompted by the system when such a classification conflict is identified. Then the system uses the conflicting classification decisions provided by the sensors to modify the priors, identify Bayes' decision, and compute the probability of error. If the probability of error is higher than a certain prespecified threshold, more information will be sought and Bayesian classification applied again.

3.4 Information Collection Aiding

3.4.1 Sensor Coverage and Line-of-Sight Calculations. When information must be collected on enemy suspected presence at a given location, it must be certain that the information can indeed be acquired by the available sensors. This requires that the location under scrutiny be within sensor coverage and that no line-of-sight limitations preclude sensor employment. Thus, TCO capabilities number 67, designated as "Calculate/Display Sensor Placement and Coverage" and number 91, "Calculate Line-of-Sight" play an important role in the process of selecting a sensor to gather information about a specific location.

TCO capability number 67, which is described as "the capability to display the coverage which would be provided (e.g., circles/fans) by a proposed placement of sensors," was viewed by TCO designers as a planning aid. It can obviously be utilized after sensors have been implanted, as well.

The concept of employment of these TCO capabilities for sensor selection is straightforward. Once the location under scrutiny is input to the system, the coverages of available sensors are computed using TCO capability number 67 to determine which sensors can acquire the target at that particular location. For those sensors which are subject to line-of-sight limitations (such as ground surveillance radars), TCO capability 91 is called upon to determine if a line-of-sight exists between the sensor and the target.

3.4.2 Information and Discrimination Measures. When available information has been exhausted and uncertainty still prevails, decision makers generally perform a cost-benefit analysis to determine whether new information should be acquired. In a case where more than one information source can be utilized, decision makers who desire to acquire information must, in addition, determine which information source should be utilized. The problems of whether to acquire information and which information source to use are linked together via the notion of informativeness. Informativeness can be defined as the ability to discriminate among hypotheses. If $P_1, \ldots, P_m$ are the respective probabilities attached by the decision maker to m exhaustive exclusive events, the following measures of informativeness are available (Mathai & Rathie, 1975):

- Shannon's Entropy: $-\sum_i P_i \operatorname{Log} P_i$
- Renyi's Entropy of order α: $\frac{1}{1-\alpha} \operatorname{Log} \sum_i P_i^\alpha \quad \alpha \neq 1$
- Havrda and Charvat's Entropy of order α: $\frac{1}{2^{1-\alpha}-1}(\sum_i P_i^\alpha - 1) \quad \alpha \neq 1$
- Rathie's Entropy: $-\sum_i P_i^{\beta+1} \operatorname{Log} P_i$
- Belis and Guiasu's Entropy: $-k \sum_i u_i P_i \operatorname{Log} P_i$
- Gini's diversity index: $1 - \sum_i P_i^2$

In a Bayesian context with a 0-1 loss function, Shannon's entropy possesses some optimality properties (Patrick, 1972) and its use is therefore recommended.

When two sources of information can be consulted, it is natural for the decision maker to select the one which will most increase their informativeness. Let us define I_j as the net expected information gain obtained through consultation with information source j which is equal to the difference between the current measure of uncertainty and the expected posterior measure of uncertainty after consultation with information source j.

This definition expresses I_j an an expectation, and therefore, takes into account the uncertainty attached to the actual information provided by the source. In a Bayesian context, let $C_1, \ldots, C_m$ be exhaustive mutually exclusive events whose a priori probabilities are $\pi_1^0, \ldots, \pi_m^0$. Consultation with information source j will yield the actual value of a random variable

X_j. The class probabilities $P(X_j = x_j | C_i)$ are supposed to be known, either elicited from people or obtained via simulation ahead of time. Assume that x_j can take values 1, 2, ..., k. Then,

$$I_j = f(\underline{\pi}^0) - \sum_{k=1}^{K} f(\underline{\pi}^1(k))\, P(X_j = k)$$

where $f(\underline{\pi})$ is the information measure utilized, $\underline{\pi}^1(k)$ the uncertainty vector after the observation of $x_j = k$, and $P(X_j = k)$ the probability that information source j will yield observation $x_j = k$. $\underline{\pi}^1(k)$ is obtained via Bayes' formula:

$$\pi_i^1(k) = \frac{\pi_1^0\, P(X_j{=}k | C_i)}{\sum_{\ell=1}^{m} \pi_\ell^0\, P(X_j{=}k | C_\ell)}$$

and

$P(X_j{=}k)$ via

$$P(X_j{=}k) = \sum_{i=1}^{m} P(X_j{=}k | C_i) P(C_i)$$

Prior to consultation with any information source, the operator's estimate of the class probabilities are $\hat{P}(C_i) = \pi_i^0$. I_j can therefore be calculated using this estimate since the class conditional probabilities $P(X_j = k | C_i)$ are known.

The concept of employment of this information source selection aid is the following. When information is required for classification of a given entity and several sensors can be deployed to acquire the information, the expected informativeness increase is computed for each sensor. This computation is performed using the model described above based on a priori probabilities elicited from the operator and prestored class conditional probabilities. The sensor which maximizes this expected increase is then selected.

4. INFORMATION COLLECTION AND CORRELATION SYSTEM DESIGN

4.1 Overview

4.1.1 Local and Global Correlation Interface. There are two basic system functions: (1) local correlation and (2) global correlation. Incoming sensor reports are the input to local correlation. The output of local correlation is a proposed track record modification which is sent to a file referred to as the track record modification file. The inputs to global correlation are the proposed track record modifications and the output is the proper modification to the track record file. Local correlation integrates the information available at either Division, Wing or MAF level independently and proposes changes to the existing track records. The basic function of global correlation is to compare a proposed track record modification (e.g., M_f) to all other proposed track record modifications and identify the resulting track file modifications based on the information provided by all three levels. As depicted in Figure 4-1, the track record modification file is organized as a queue so that M_f will be the element in front of the queue. Such an organization ensures completeness since during the local correlation the incoming information contained in sensor reports is compared to the information received earlier. During global correlation, however, it is compared to the information received later while it was in the queue. In addition, modelling and thus analysis of the system's behavior can be performed using the framework of queueing theory. Such an analysis is provided in Appendix E.

An overview of the local and global correlation subsystems is presented in the next two sections.

Although some of the modules in both local correlation and global correlation systems involve the same decision subprocesses, due to input/output

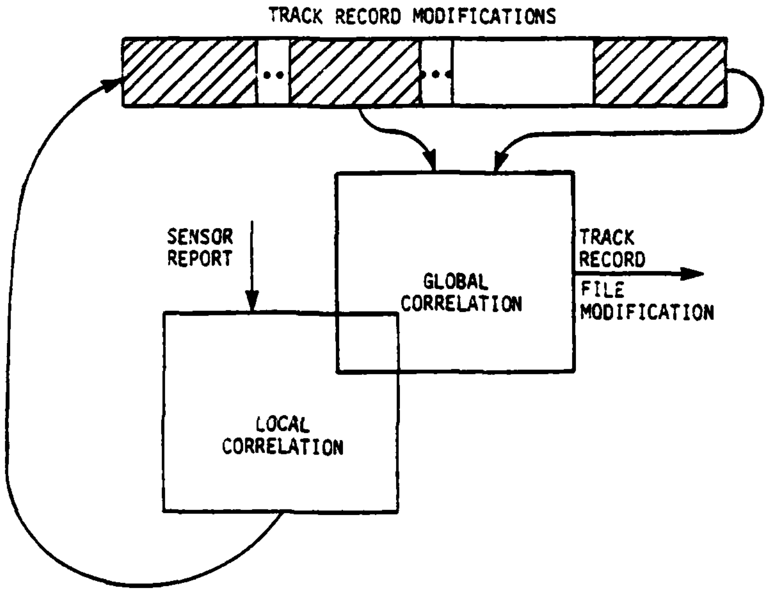
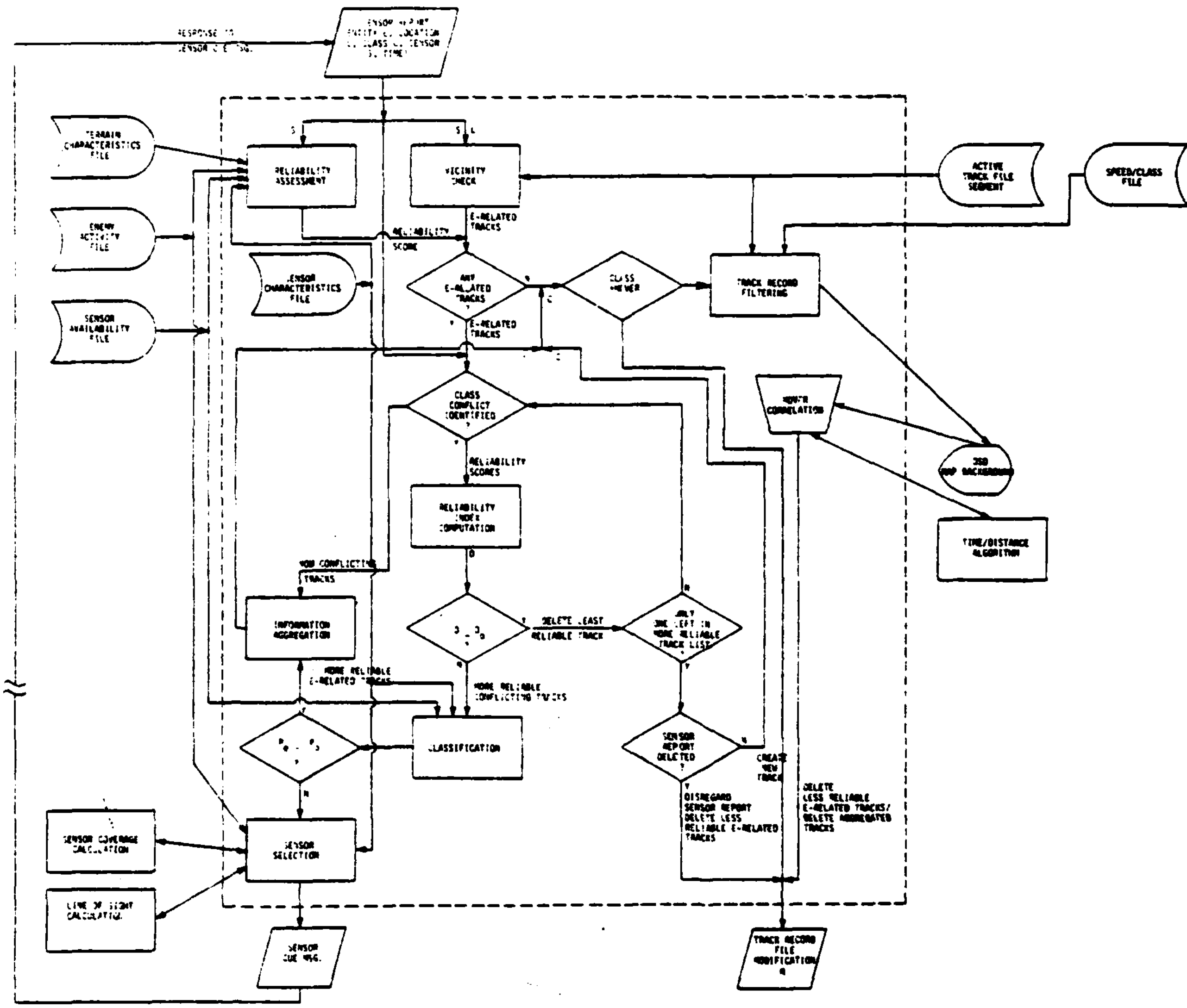


FIGURE 4-1.
LOCAL AND GLOBAL CORRELATION INTERFACE

requirements, there are basic differences in the design of most of the modules. However, there are some identical modules used in both systems for which only one description is given.

4.1.2 Local Correlation. In this section an overview of the local correlation system function is presented. The selected design is portrayed in Figure 4-2. It makes explicit the concept shown previously in Figure 3-2 by showing the modules which are within the system boundaries, the files used, the external resources on which the system draws, the internal connections and the interactions with the environment.

The local correlation module is activated upon receipt of a sensor report which contains such information as the location and class of the entity sensed (E), the sensor (specifically sensor type and location), the time of the sighting and the number of elements identified. First the reliability score for this report is computed using the sensor type and the sensor location. The sensor location is retrieved from the sensor availability file and is used in conjunction with the terrain characteristics file and the enemy activity file to determine the environmental conditions which surround the sensor. Concurrently, the vicinity check module is activated with the entity location and the sensor type as inputs. This module checks for entities which are in the active segment of the track record file and which could be the same as the entity involved in the sensor report just received. The output of this vicinity check module is the list (possibly empty) of E-related tracks. If there are any E-related tracks in the active segment of the track record file, an action can be taken with regard to the received sensor report. If the entity belongs to a non-moving class, a new track is created. If the entity is a mover it must be determined whether to create a new track or update an existing track, i.e., determine whether or not this move is actually an already tracked entity which moved. In support of this human function the system



Functions and files outside dotted
lines provided for in the TCO concept.

FIGURE 4-2.
LOCAL CORRELATION DESIGN OVERVIEW

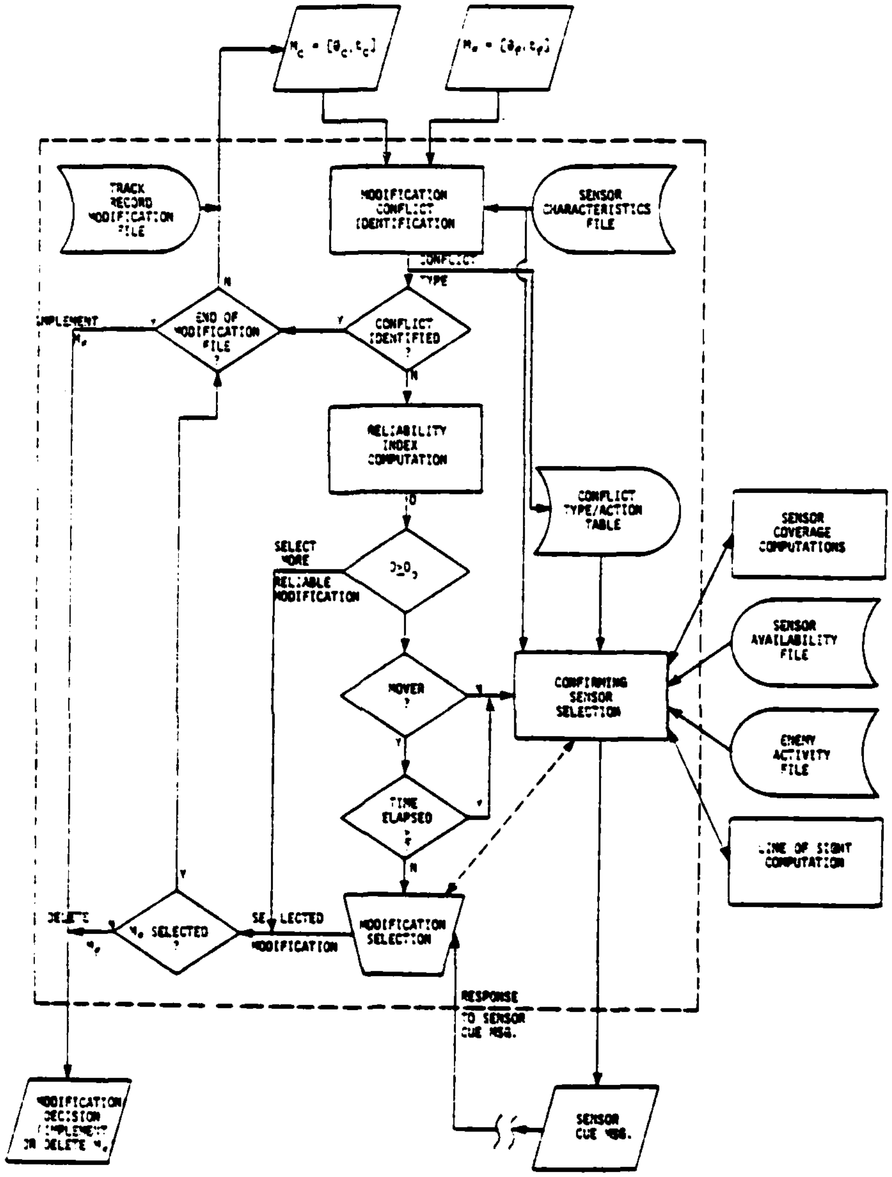
executes the track record filtering module which filters out irrelevant tracks. It also displays on the DSD terminal the entities which are similar (in the sense defined in 3.3.3) to the entity just reported. During the execution of the mover correlation module the operator then interacts with TCO capabilities such as DSD with map background showing natural routes of penetration and time/distance algorithm which computes the time it takes for an entity to traverse a distance. Upon completion of the mover correlation module a decision is made with regard to the track modification action(s) to be taken.

When the E-related track list is not empty the case is a little more complicated. In this case, the E-related tracks together with the sensor report are checked for a class discrepancy. If no class discrepancy is found the information contained in these E-related tracks must be aggregated with the information contained in the sensor report to define an aggregated location and to compute a reliability score. Also the E-related tracks must be removed. The situation is now the same as if the E-related track list was empty. The aggregated information is used to identify the proper action, i.e., creation of a new track or activation of the mover correlation module. If a class conflict is identified among members of the E-related track list (including the sensor report itself) the conflict must be resolved. First the various reliability scores are computed and if a large discrepancy between these scores exists the less reliable E-related tracks (or the sensor report itself) are deleted. If a conflict still exists, or if data do not permit this deletion, the classification module is activated. This module aggregates the conflicting classification decisions by determining Bayes classification decision and computing the corresponding probability of error. For these computations inputs from the sensor characteristics file are used. If the probability of error is below a prespecified threshold, the information aggregation module is activated and the system proceeds as when the E-related track record list is empty.

If the probability of error is unacceptably high, more information must be gathered. For this purpose a sensor must be deployed thus requiring the selection of the most informative among available sensors. For this selection the system uses inputs from the sensor characteristics file, the enemy activity file and the sensor availability file, and draws on TCO capabilities sensor coverage calculations and line-of-sight calculations. After the proper sensor has been selected, a cue message is sent to the manager of this sensor. The result is the receipt of a response to the request which is input as a new sensor report. New information will eventually permit resolution of the class conflict and upon this resolution the situation will be the same as when the E-related track list is found empty, i.e., the system proceeds toward creating a new non-mover track or activating the mover correlation module.

The output of the local correlation module is a proposed modification or set of modifications to the track record file. These modifications fall into two general categories: creation of a new track and updating or deletion of an existing track. Proposed modifications to the track record file are formatted in a manner which facilitates the identification of conflicts between proposed track modifications.

4.1.3 Global Correlation. This section presents an overview of the global correlation system function. The selected design, portrayed in Figure 4-3, makes explicit the concept shown previously in Figure 3-3. The proposed track file modification, which is in front of the track record modification queue, will be compared to all other proposed modifications in the queue. As a result of this comparison, one of the two actions will be taken: implement or delete M_f. Hence, M_f is compared to the current M_c in the queue. If M_f is superseded by one M_c, the decision is then made to delete M_f and global correlation will proceed with the proposed track record modification which is now in front of the queue. If M_f



Functions and files outside dotted lines provided for in the TCO concept.

FIGURE 4-3.
GLOBAL CORRELATION

supersedes or does not conflict with any of the other elements of the queue then the decision is made to implement M_f. It is assumed that the elements of the track record modification queue are formatted in a standard way suitable for automatic handling.

Upon inspection of M_f and M_c the modification conflict identification module automatically identifies any conflict together with the conflict type. This can be done by consultation with the conflict type/action table which contains an exhaustive list of all possible conflicts. The processes which are involved in modification conflict identification are basically the same as in class conflict identification since the following questions must be answered in the present case as well: (1) can the two entities under scrutiny actually be the same? and (2) is there a class discrepancy? If no conflict is identified, the next M_c in the queue is taken and compared to M_f. If a conflict is identified, it must be resolved. First the reliability index computation module is activated to determine if a reliability discrepancy exists. If a significant difference in reliability scores does exist, the less reliable modification is deleted and proper action is taken, i.e., either delete M_f or take next M_c in the queue. If no reliability discrepancy can be identified, more information must be gathered to resolve the conflict. However, if the entity is a mover and a substantial amount of time has already elapsed due to the local correlation process and the subsequent waiting in the queue, the entity has possibly moved elsewhere and therefore indiscriminately requesting more sensor information is not meaningful due to the uncertainty about the present entity location. Thus, if the time elapsed is longer than a specified threshold the operator is called upon. He then executes the modification selection module, i.e., makes a decision with regard to the next action. As the next action, he has the option of requesting more information, i.e., to call the confirming sensor selection module. This module draws its label from its function which is to select the best sensor to confirm the presence of an entity of a certain class at a certain location. With regard to which location(s) to focus on, the conflict type/action table provides, for each conflict type, the proper information gathering action. The locations in which the entities were last seen are also used. The available sensors which can acquire the entity are matched against the sensor characteristics file which contains the list of sensor types prioritized on the basis of appropriateness for confirmation. Once the best sensor has been selected, a sensor cue message is sent. Upon receipt of the requested information the operator selects the proper action. This results in an implementation decision on M_f.

4.2 Local Correlation

4.2.1 Reliability Assessment.

Purpose: This module, portrayed in Figure 4-4, automatically computes the reliability score of a sensor report.

Input: A sensor report (the required information are (1) sensor type and (2) sensor location).

Output: The reliability score which will be attached to the sensor report.

Files:
- Sensor Characteristics File (internal)
- Sensor Availability File (external)
- Enemy Activity File (external)
- Terrain Characteristics File (external)

Functions: Using the sensor type as input, the system retrieves from the sensor characteristics file the maximum localization and classification scores σ_L^{max} and σ_C^{max}. Concurrently, using the sensor report which contains the information source the system retrieves the sensor location from the sensor availability file (the sensor availability file contains the list of all available sensors including their type and location and the collection agency which manages them). The sensor location together with the enemy activity file and the terrain characteristics file, are used to define the environmental conditions at sensor location. Using the defined environmental characteristics as input, the score reduction factors ρ_L and ρ_C are retrieved from the sensor characteristics file. The localization and classification scores are then computed using the formulas:

$$r_L = \rho_L \sigma_L^{max} \quad \text{and} \quad r_C = \rho_C \sigma_C^{max}$$

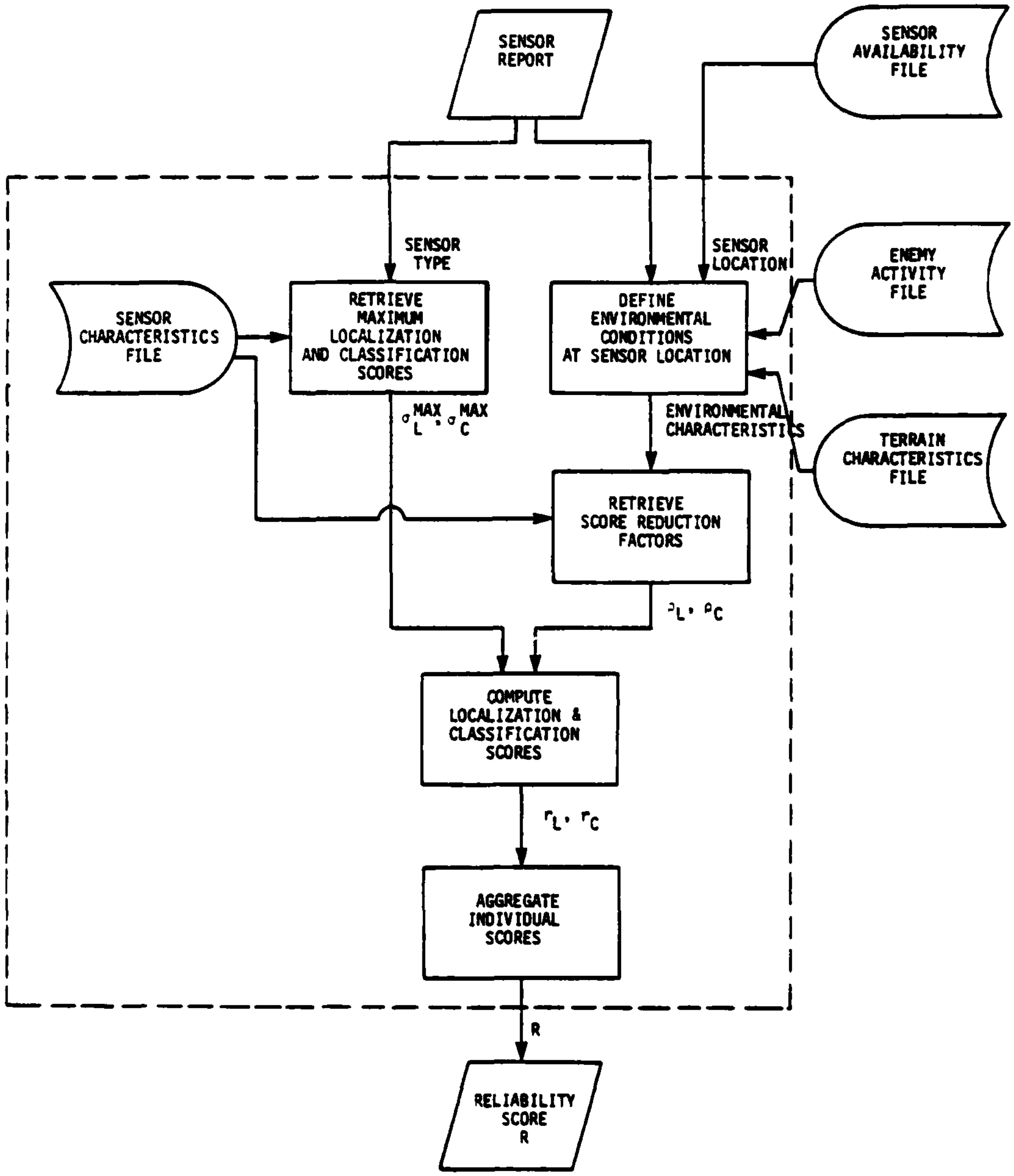
The individual scores are then aggregated into a single number using the formula $R = (r_L + r_C)/2$.

4.2.2 Vicinity Check.

4.2.2.1 Overview.

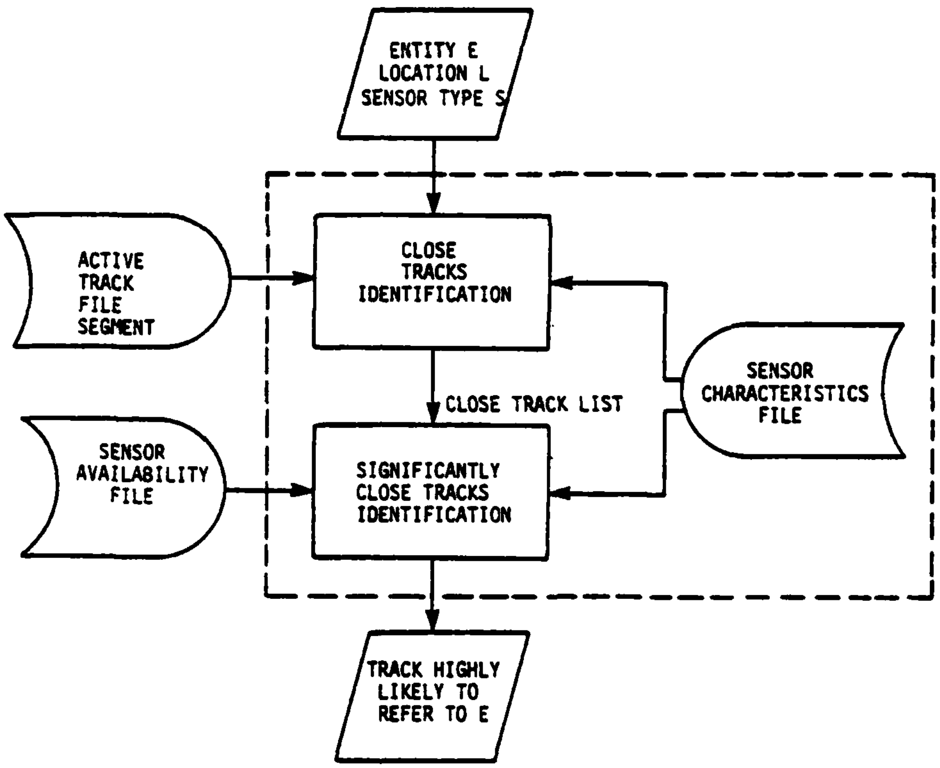
Purpose: This module, portrayed in Figure 4-5, identifies the list (possibly empty) of tracks which are very likely to be the same as a given entity E.

Input: An entity E just sensed. The specific inputs are:
Entity location
Sensor type



Functions and files outside dotted
lines provided for in the TCO concept.

FIGURE 4-4.
RELIABILITY ASSESSMENT



Functions and files outside dotted lines provided for in the TCO concept.

FIGURE 4-5.
VICINITY CHECK

Output: The list of E-related tracks.

Files: Active Track File Segment (external)
Sensor Characteristics File (internal)
Sensor Availability File (external)

Functions: This module is made of two modules: (1) close track identification and (2) significantly close tracks identification. These two modules operate in sequence.

4.2.2.2 Close Tracks Identification

Purpose: This module defines the active tracks which are in the vicinity of an entity E sensed by a sensor of a given type (Figure 4-6).

Input: Sensor type
Entity location

Output: The list of tracks in the vicinity of E.

Functions: A vicinity area is defined as a circle of radius R_0 centered at L. R_0 is a threshold function of the uncertainty associated with the sensor type. It is retrieved from the sensor characteristics file. The track records in the active track record file which are at a distance less than R_0 from E are then identified thus yielding the list (possibly emply) of the tracks close to E.

4.2.2.3 Significantly Close Tracks Identification

Purpose: This module which is portrayed in Figure 4-7 identifies, among the tracks close to E, those which are significantly close, i.e., which refer to the same entity with a probability higher than an operator-specified threshold.

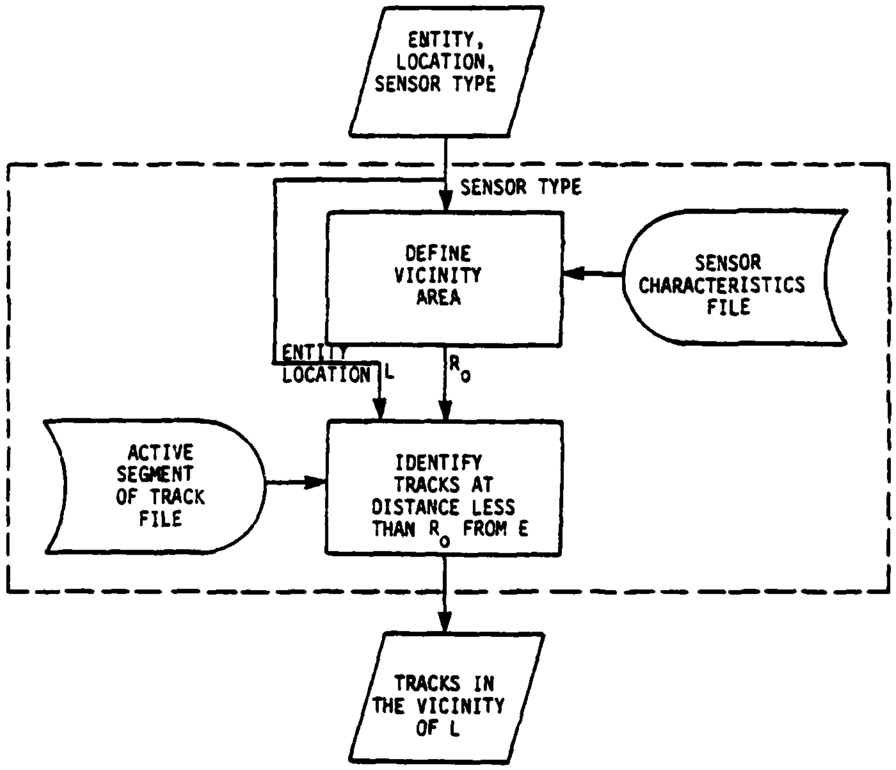
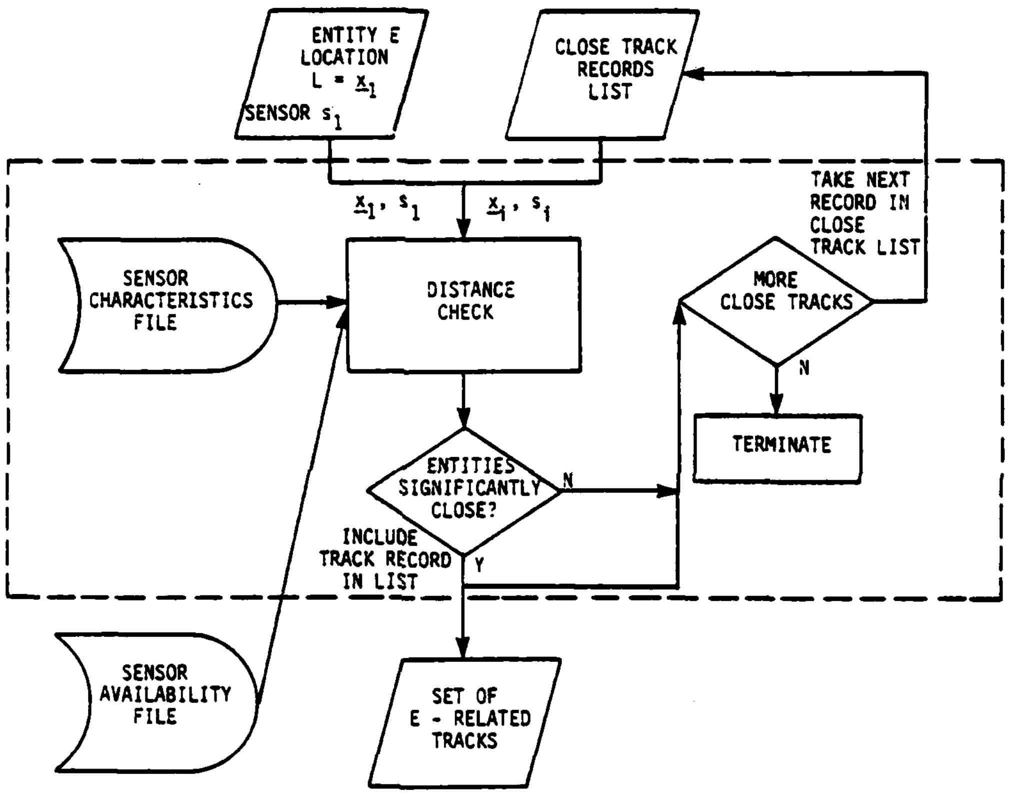


FIGURE 4-6.
CLOSE TRACKS IDENTIFICATION



Functions and files outside dotted lines provided for in the TCO concept.

FIGURE 4-7.
SIGNIFICANTLY CLOSE TRACKS IDENTIFICATION

Input: $\underline{x}_1$ location of E and s_1 the sensor which acquired E; $\underline{x}_i$ location reported by sensor s_i for track record i in the vicinity of E.

Output: The set of E-related tracks.

Files: Sensor Characteristics File (internal)
Sensor Availability File (external)

Functions: The distance check module is applied to all combinations $(\underline{x}_1, s_1) | (\underline{x}_i, s_i)$ for i in the close track record list. If track record i passes the distance check, i.e., if track record i is significantly close to E, it is put in the set of E-related tracks.

4.2.2.4 Distance Check

Purpose: This module, depicted in Figure 4-8, checks if two sensors could have sensed the same entity.

Input: Two observed locations $\underline{x}_1$ and $\underline{x}_i$, and
The respective sensors s_1 and s_i which acquired the corresponding entities.

Output: A decision whether the entities are at the same or distinct locations.

Files: Sensor Characteristics File (internal)
Sensor Availability File (external)

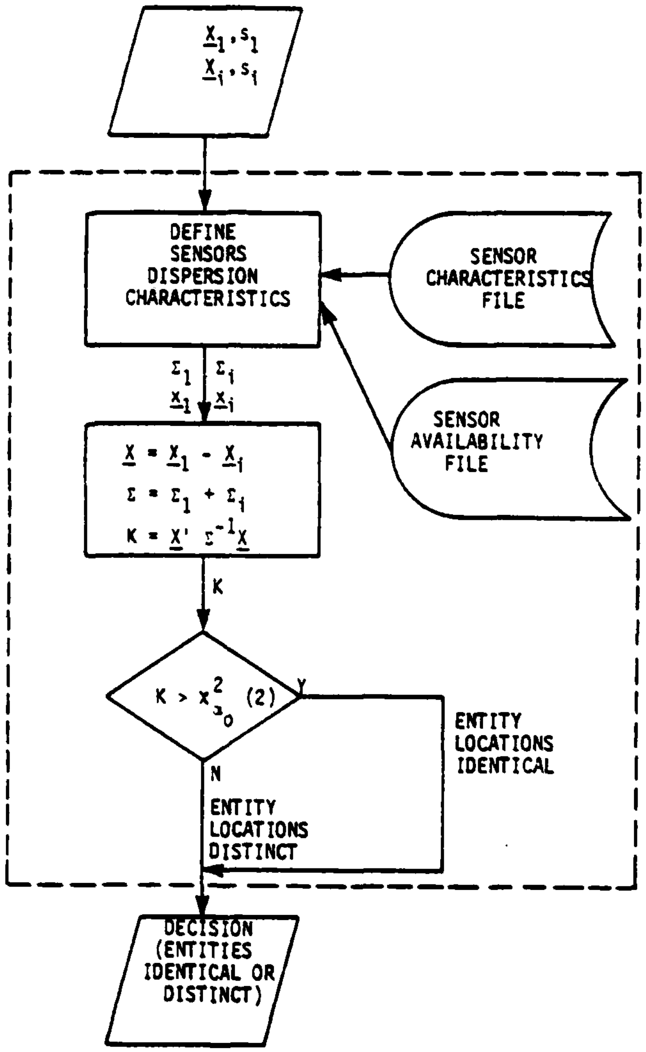


FIGURE 4-8.
DISTANCE CHECK

Functions: The sensor dispersion characteristics Σ_1 & Σ_2 are defined from the sensor characteristics file and the sensor availability file. If Σ_0 is the dispersion matrix of a given sensor and θ is the sensor orientation we have:

$$\Sigma = \Sigma_0 \times \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

The quantity $K = (\underline{x}_1 - \underline{x}_2)' (\Sigma_1 + \Sigma_2)^{-1}(\underline{x}_1 - \underline{x}_2)$ is then computed and compared to $\chi^2_{\alpha_0}(2)$, where α_0 is a predicted maximum acceptable percentage of error. The decision immediately follows.

4.2.3 Reliability Index Computation

Purpose: The purpose of this module, portrayed in Figure 4-19, is to compute an index which reflects discrepancies between reliability scores.

Input: A set of numbers $R_1, \ldots, R_n$ between 0 and 1 which represent reliability indices.

Output: A number which reflects discrepancies between n numbers.

Files: None.

Functions: The maximum and minimum among the R_i's are computed thus allowing computation of the range. The simple average of the scores is also computed. The dispersion characteristic D = range/average is then computed as the discrepancy indicator.

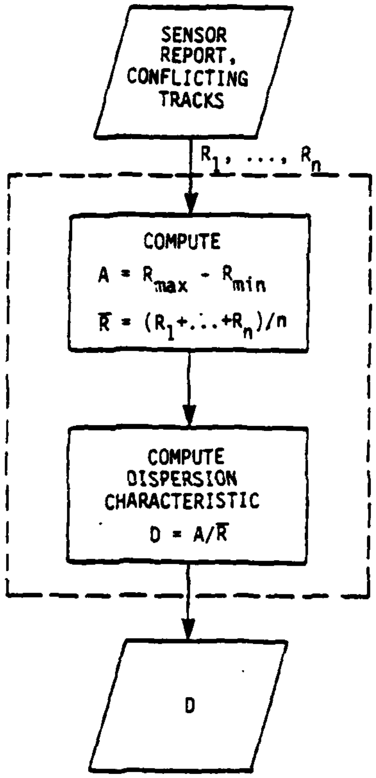


FIGURE 4-9.
RELIABILITY INDEX COMPUTATION

4.2.4 Classification

4.2.4.1 Overview

Purpose: This module, which is portrayed in Figure 4-10, implements Bayes' strategy and computes the probability of error corresponding to Bayes' decision.

Input: A set of conflicting classification decisions and the corresponding sensor types.

Output: Bayes' classification decision and the corresponding probability of error.

Files: Sensor Characteristics File (internal)

Functions: The operator is first prompted to assign prior probabilities to the possible classification decisions which can be made concerning the entity under scrutiny. These elicited priors may be equal. Using these prior probabilities the system applies the Bayesian updating module and uses all the classification decisions and input from the sensor characteristics file to determine the a posteriori class probabilities. The Bayesian classification module is then activated thus resulting in a classification decision γ and a probability of error P_e.

4.2.4.2 Bayesian Updating

Purpose: This module, which is portrayed in Figure 4-11, updates a priori probabilities to take into account new information using Bayes' formula.

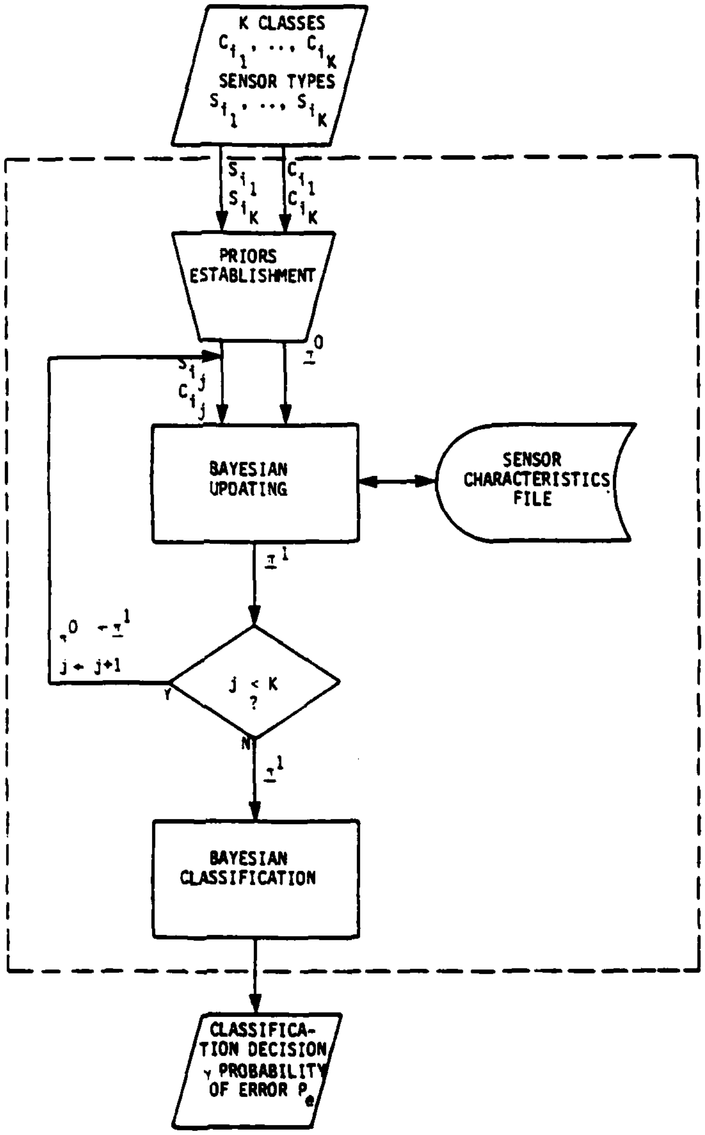


FIGURE 4-10.
CLASSIFICATION

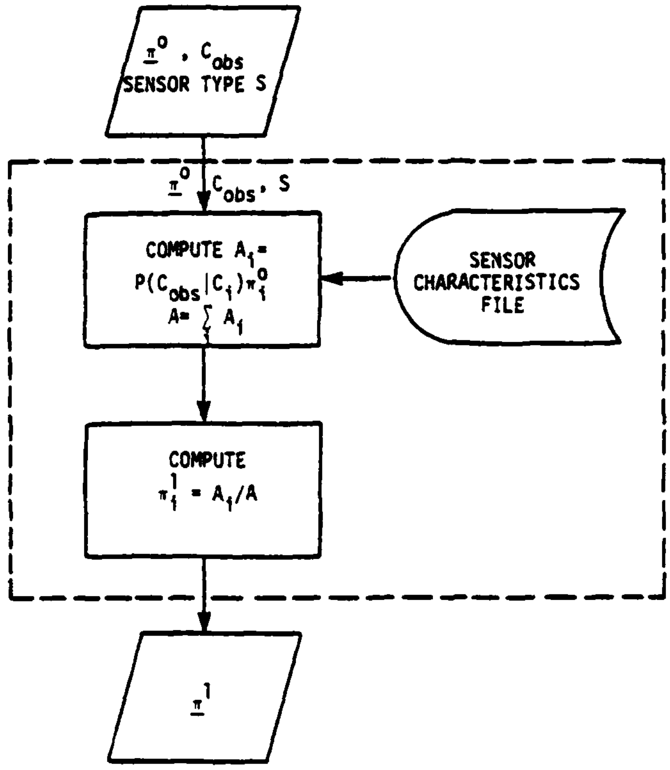


FIGURE 4-11.
BAYESIAN UPDATING

Input: A priori probabilities
Classification decision C_{obs} and the corresponding sensor type.

Output: A posteriori probabilities.

Files: Sensor Characteristics File (internal).

Functions: Using the sensor type as an input, the class conditional probabilities $P(C_{obs}|C_i)$ are retrieved from the sensor characteristics file and Bayes' formula applied thus yielding the a posteriori probabilities.

4.2.4.3 Bayesian Classification

Purpose: This module which is portrayed in Figure 4-12 determines Bayes' decision and computes the corresponding probability of error.

Input: The possible decisions $C_1, \ldots, C_k$ and the corresponding probabilities $\pi_1, \ldots, \pi_k$.

Output: Bayes' classification decision
Probability of error

Files: None.

Functions: Bayes' decision which minimizes the probability of error is determined by maximizing π_i (since if i is selected the probability of error is $P_e = 1-\pi_i$).

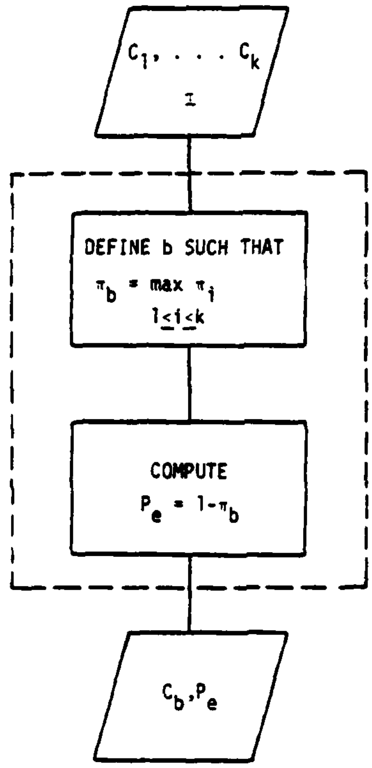


FIGURE 4-12.
BAYESIAN CLASSIFICATION

4.2.5 Sensor Selection

4.2.5.1 Overview

Purpose: The purpose of this module which is portrayed in Figure 4-13 is to define the best (i.e., the most informative) available sensor.

Input: K possible classification decisions and the corresponding probabilities.
The entity Location L.

Output: The best available sensor

Files: Sensor Characteristics File (internal)
Sensor Availability File (external)
Enemy Activity File

Functions: First the list of applicable sensors, i.e., the list of the sensors which can indeed acquire the entity located at L is defined. These sensors are then prioritized by order of informativeness according to their type during the execution of the sensor prioritization module thus resulting in the determination of the best available sensor.

4.2.5.2 Applicable Sensors Definition

Purpose: The purpose of this module, which is portrayed in Figure 4-14, is to determine the sensors which can acquire information at a given location.

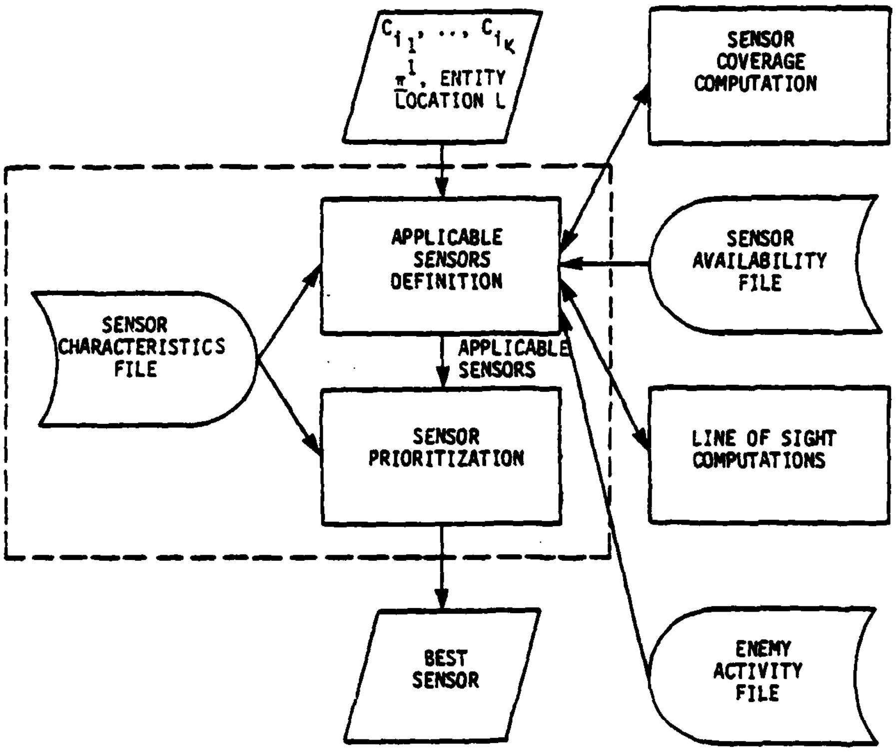


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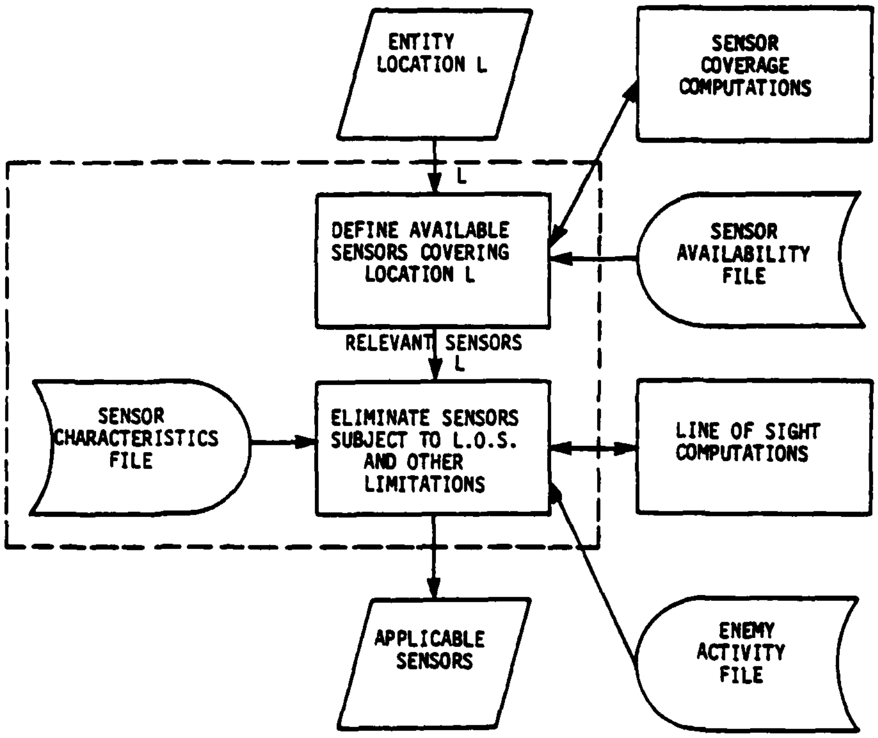
FIGURE 4-13.
SENSOR SELECTION



Functions and files outside dotted lines provided for in the TCO concept.

FIGURE 4-14.
APPLICABLE SENSORS DEFINITION

Input: A location L

Output: The list of sensors which can acquire information at location L.

Files: Sensor Characteristics File (internal)
Sensor Availability File (external)
Enemy Activity File (external)

Functions: Using location L as an input the system first defines the relevant sensors by checking out all available sensors to determine whether they can cover location L. To perform this function the system draws on the TCO capability to compute sensor coverages. From the list of available sensors those which are subject to line-of-sight and other limitations are deleted. This is performed by application of the TCO capability to compute the line-of-sight between two points and on the enemy activity file to determine if the enemy can prevent acceptable sensor operation.

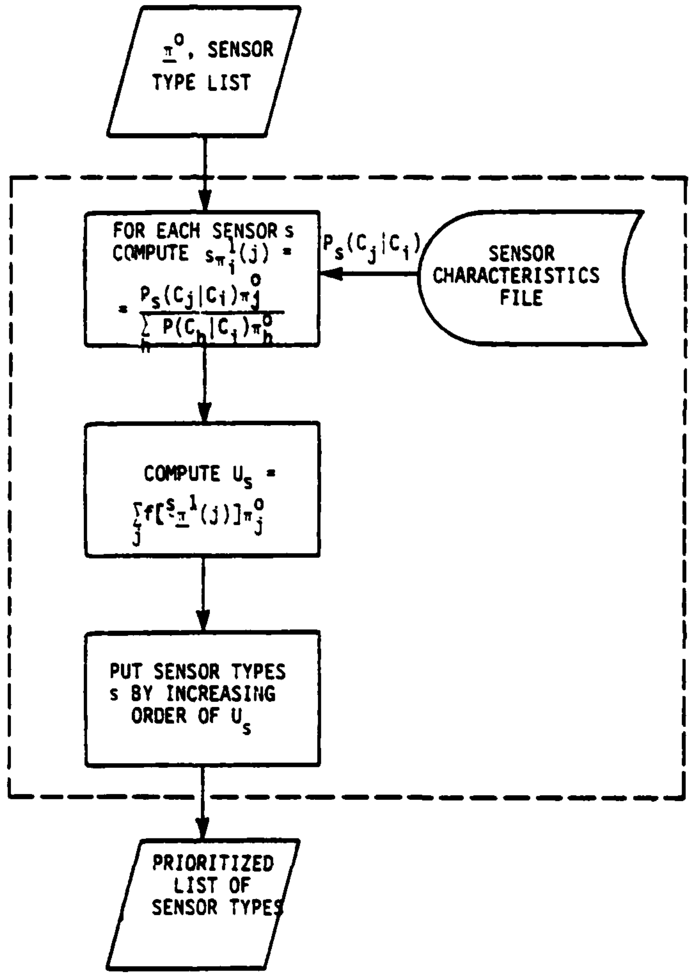
4.2.5.3 Sensor Prioritization

Purpose: This module which is described in Figure 4-15, prioritizes sensors by decreasing order of informativeness.

Input: A prior class probabilities $\underline{\pi}^0$
Sensor type list

Output: Prioritized list of sensor types

Files: Sensor Characteristics File (internal)



f = information measure (e.g., $f(\underline{\pi}) = - \sum_i \pi_i \operatorname{Log} \pi_i$)

FIGURE 4- 15.
SENSOR PRIORITIZATION

Functions: Using sensor type S the class conditional probabilities $P_S(C_j|C_i)$ are retrieved from the sensor characteristics file. This permits the computation of the updated class probabilities if a sensor of type S is used and C_j is observed. The information increase expected from usage of a type S sensor is then computed. This permits prioritization of the sensor types by decreasing order of informativeness.

4.2.6 Information Aggregation

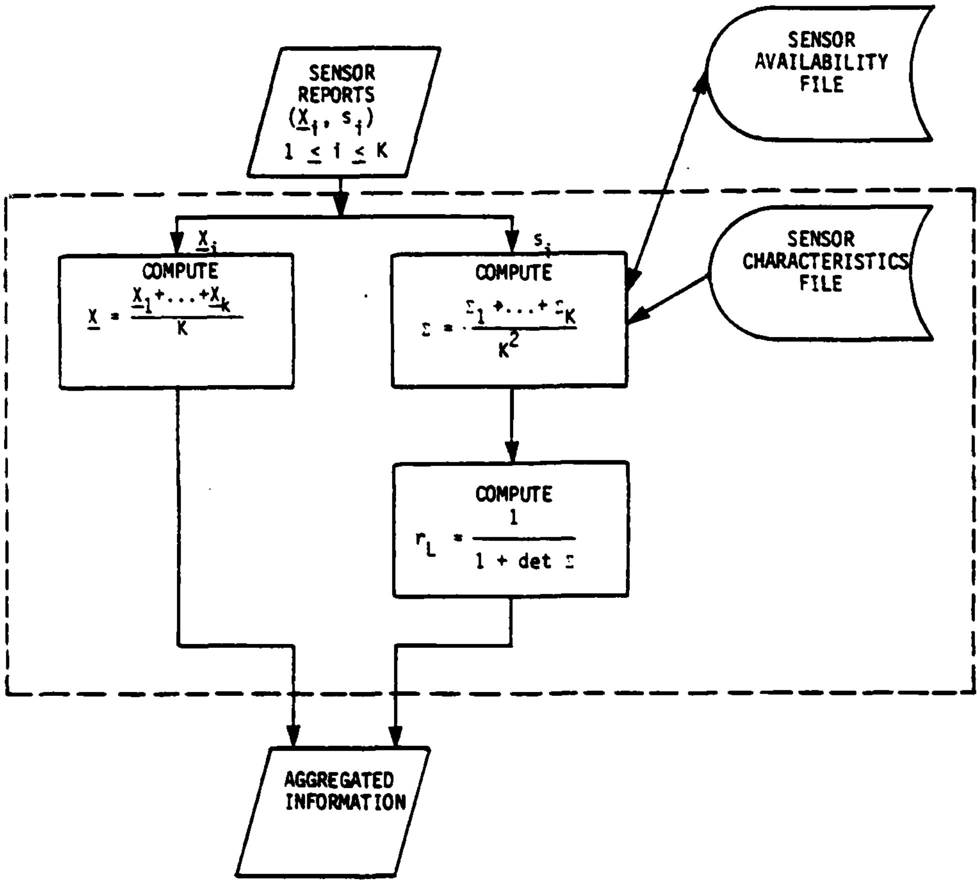
Purpose: This module, which is portrayed in Figure 4-16, aggregates sensor reports about a common entity into a common location. It also computes the aggregated localization score.

Input: Sensor reports. The specific information are:
The entity location reports, and
The sensor used.

Output: Aggregated location
Localization score

Files: Sensor Characteristics File (internal)
Sensor Availability File (external)

Functions: The module computes the simple average of the reported locations as the aggregated location. Concurrently, the module computes the dispersion matrices as described in 4.2.2.4 and determines the simple average of these matrices to finally compute the aggregated localization score.



Functions and files outside dotted lines provided for in the TCO concept.

FIGURE 4-16.
INFORMATION AGGREGATION

4.2.7 Track Record Filtering

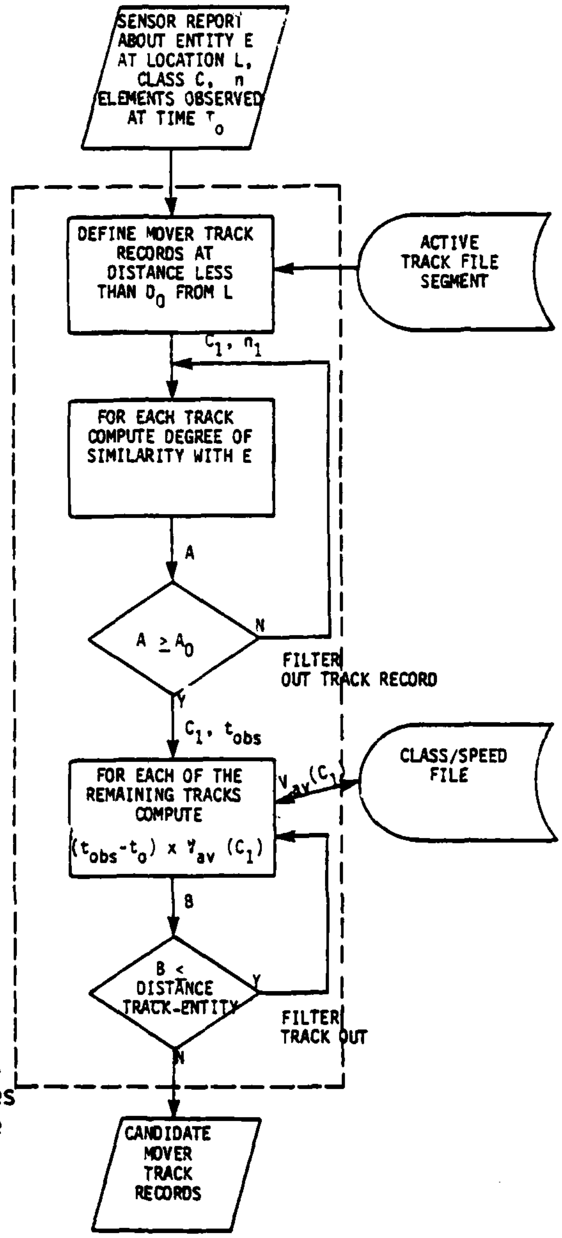
Purpose: This module which is portrayed in Figure 4-17 filters out track which are dissimilar from a given entity.

Input: An entity E defined by a set of data (location, class, number of elements, time of observation)

Output: Candidate tracks (similar to the input entity).

Files: Track Record File (external)
Class/Speed File (external)

Functions: First the system retrieves those track records which are at a distance less than D_o from the entity E. Then the entity class and the number of elements observed are used to compute, for each of the retrieved tracks, a degree of similarity with E. Only those tracks whose degrees of similarity with E are higher than an a priori specified threshold are kept for further processing. For each of the remaining tracks the corresponding average speeds which are stored by class in the class/speed file are retrieved. This allows the computation of an average distance that the tracked entity could have traversed in straight line during the observed time difference. If this distance is smaller than the actual distance between the track record and the entity the track record is filtered out. This results in a list of possible mover candidates which are similar to E and could have been reported as E.



Functions and files outside dotted lines provided for in the TCO concept.

FIGURE 4-17.
TRACK RECORD FILTERING

4.3 Global Correlation

4.3.1 Modification Conflict Identification

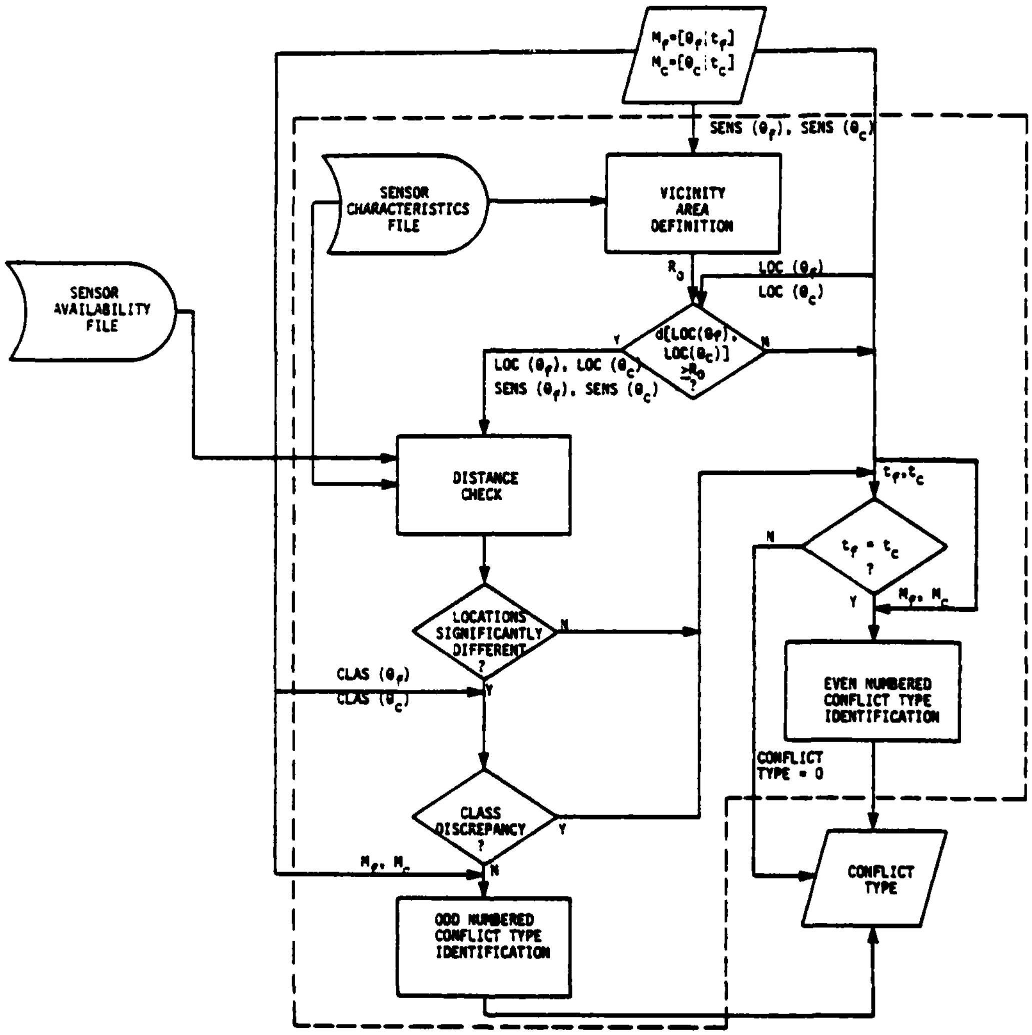
Purpose: This module, which is portrayed in Figure 4-18, determines the conflict type (no conflict if type = 0) between two proposed track file modifications. It is assumed that track file modifications are expressed in the universal format $[\theta|T]$ which stands for: substitute θ for T where θ is a new track (θ can be equal to the void set) and T is an existing track (T also can be equal to the void set).

Input: Two proposed track file modifications.

Output: Conflict Type number

Files: Sensor Characteristics File (internal)
Sensor Availability File (internal)

Functions: Using the sensors which yield track records θ_f and θ_c, the vicinity area is defined (as a function of the sensors employed) as described in 4.2.2.2. If the locations represented by θ_f and θ_c are not in the vicinity of each other the locations represented by θ_f and θ_c are distinct. If these locations are in the vicinity of each other the distance check (same as 4.2.2.4) is applied in order to determine if these locations are distinct. If a class discrepancy is identified the conclusion is that the entities are distinct. Figure 4-18 shows the logic of modification conflict identification. This logic has been designed using the catalogue of all possible conflicts as a basis. Eight



Functions and files outside dotted lines provided for in the TCO concept.

FIGURE 4-18.
MODIFICATION CONFLICT IDENTIFICATION

conflict types were identified. They are graphically portrayed in Figure 4-19. For instance, in a type I conflict one center declares that the mover located at L1 moved to L2 while the other declares that this mover stayed at L1 and that the sighting which just occured at L2 corresponds to a new entity. Table 4-1 depicts typical conflict track record modifications. These modifications illustrate those portrayed graphically in Figure 4-19. Note that the three-digit numbers correspond to existing track identifiers while NEW corresponds to a new track which did not receive an identifier yet. Identifying numbers are provided only after the decision is made to actually implement the corresponding modification.

4.3.2 Confirming Sensor Selection

Purpose: This module which is portrayed in Figure 4-20, determines the best confirming sensor to resolve a modification conflict of a given type.

Input: The two conflicting modifications.
The conflict type.

Output: The best available confirming sensor.

Files: Sensor Characteristics File (internal)
Sensor Type/Action Table (internal)
Sensor Availability File (external)
Enemy Activity File (external)

The conflict type/action table defines information gathering strategies. It is portrayed in Table 4-2 which shows, for each

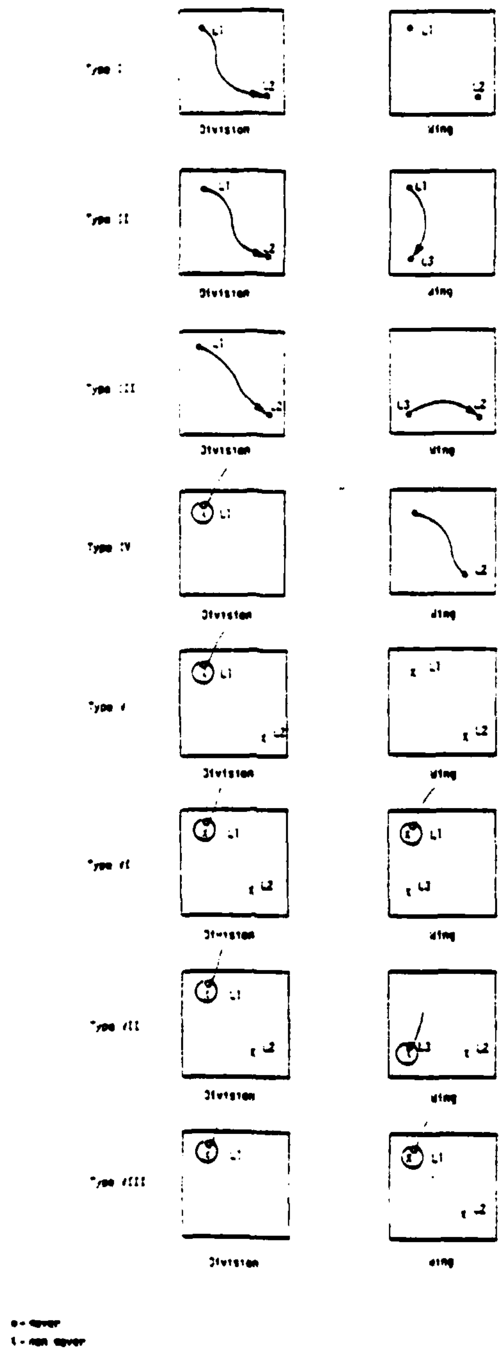
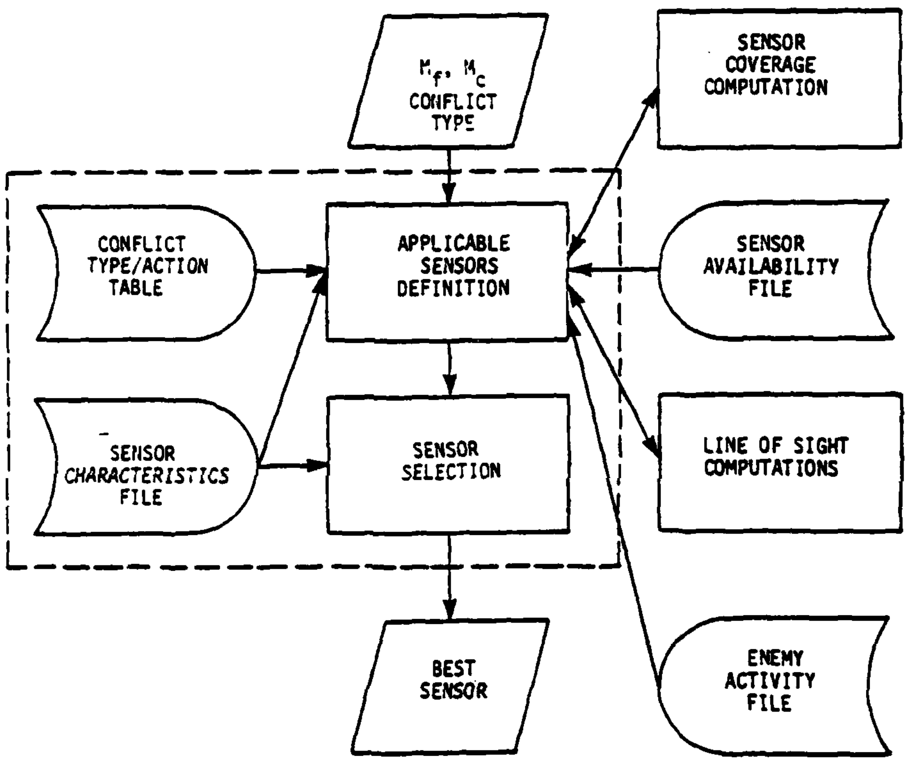


FIGURE 4-19.
GRAPHIC PORTRAYAL OF CONFLICT TYPES

TABLE 4-1

TYPICAL CONFLICTING TRACK
RECORD FILE MODIFICATIONS

Type I	[(125|L2|...)|(125|L1|...)] [(NEW|L2|...)| Ø]
Type II	[(132|L2|...)|(132|L1|...)] [(132|L3|...)|(132|L1|...)]
Type III	[(127|L2|...)|(127|L1|...)] [(142|L2|...)|(142|L2|...)]
Type IV	[Ø |(175|L1|...)] [(175|L2|...)|(175|L1|...)]
Type V	[(187|L2|...)|(187|L1|...)] [(NEW|L2|...)| Ø]
Type VI	[(257|L2|...)|(257|L1|...)] [(257|L3|...)|(257|L1|...)]
Type VII	[(177|L2|...)|(177|L1|...)] [(245|L2|...)|(245|L3|...)]
Type VII	[Ø |(222|L1|...)] [(222|L2|...)|(222|L1|...)]



Functions and files outside dotted lines provided for in the TCO concept.

FIGURE 4-20.
CONFIRMING SENSOR SELECTION

conflict type, the conflict source and the conflict resolving information (the reader is referred to Figure 4-19 which provides a graphic portrayal of the various conflict types, for the meaning of L1, L2 and L3).

Functions: This module is itself composed of two modules to be executed in sequence. Using the conflict type as an input the available sensors definition module consults the conflict type/action table to determine which location(s) to focus on for information gathering. From then on, the applicable sensors definition module performs exactly as described in 4.2.4.2. The output of this module is the list of sensors which can acquire the desired information. To determine the best sensor the sensor characteristics file is consulted, since this file contains a list of sensor types prioritized by decreasing order or appropriateness for confirmation of the presence of an entity of a given class. This consultation immediately yields the sensor which is best suited for the job.

4.4 Summary

In this chapter we have provided a detailed design for the Information Collection and Correlation system including functions, flow-charts and diagrams. A number of human judgments are required for proper system function. Most of these judgments, such as significance thresholds, are obtained prior to the actual use of the system. They are stored in adequate files and can possibly be changed. Other judgments are obtained on-line when the system is used. Four of the ICC system modules require human judgments. They are (1) reliability assessment, (2) significantly close track definition, (3) classification, and (4) track record filtering. In (1), human judgments are required to a priori define classes of environmental characteristics and the corresponding score reduction factors.

TABLE 4-2

CONFLICT TYPE/ACTION TABLE

Conflict Type	Conflict Source	Conflict Resolving Information
Type I	Questioned presence of an entity (a mover) of class C in L1	Confirmation of the presence or absence of an entity of class C in L1
Type II	The same entity (a mover of class C) cannot be in two different places L2 & L3	Confirmation of the presence or absence of an entity of class C in L2 & L3
Type III	The same entity cannot come from two different places	Confirmation of the presence or absence of an entity of class C in L1 & L3
Type IV	Questioned presence of an entity (a mover of class C) in L2	Confirmation of the presence or absence of an entity of class C in L2
Type V	Questioned presence of an entity (non-mover of class C') in L1	Confirmation of the presence or absence of a non-mover of class C' in L1
Type VI	The same entity (non-mover of class C') cannot be at two places	Confirmation of the presence or absence of a non-mover of class C' in L2 & L3
Type VII	The entity sighted in one place cannot have been in two different places earlier	Confirmation of the presence or absence of a non-mover of class C' in L1 or L3
Type VIII	An entity which is non-moving cannot leave	Confirmation of the presence or a non-mover of class C' in L2

Also a priori defined (obtained by a mixture of calculations and human judgments) are the maximum localization and classification scores. In (2), an operator-specified significance threshold is required and stored ahead of time. In (3), both a significance threshold and class-conditional probabilities elicited off-line from experts files, are required. Also required in (3) are a priori class probabilities elicited on-line from operators. In (4), two thresholds are requested off-line from the operator and stored prior to activation of the system.

Finally, it should be mentioned that the interaction between the system and its operators, i.e., the information displays, must be defined. This will constitute the next step in the system design.

5. CONCLUSION

We have presented an Information Collection and Correlation (ICC) system which supports the production of combat information correlation in amphibious operations. The support system was conceptualized and a specific design was provided. The concept selected followed from a system analysis of the correlation functions. Using well-established mathematical techniques, these functions were modelled and aiding modules were designed.

The ICC Support System does not introduce extraneous functions to the present information collection and correlation processes. The system merely makes explicit the required functions and their underlying mental processes. Without the support system, these processes are often performed crudely, mainly in linguistic or fuzzy terms. The system, however, provides a formal quantitative scheme to aid the performance of the same processes more accurately or automatically. Thus the formalism which is inherent to the system does not introduce any additional complexity.

The ICC Support System is directly implementable within the framework of TCO and interacts with a series of its capabilities. The requirement analysis indicated that the system can indeed be implemented in the TCO simulated environment.

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FMFM 2-1, Intelligence

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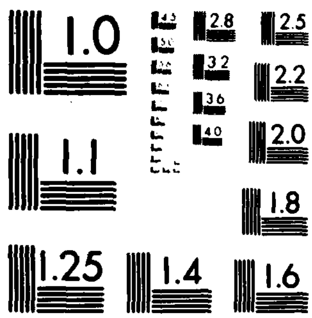
APPENDIX A

AD-A089 617 PERCEPTRONICS INC WOODLAND HILLS CALIF F/G 17/2
INFORMATION COLLECTION AND CORRELATION DECISION SUPPORT SYSTEM --ETC(U)
AUG 80 A CROLOTTE, J SALEH N00014-78-C-0495
UNCLASSIFIED PATR-1069-80-8 NL

2 3



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

A.1 INTRODUCTION

This appendix documents the application of the Marine Decision Taxonomy to decision aid selection for the Tactical Combat Operations System (TCO). During a working session at MCTSSA/TSCRB, it was concluded that such an application will provide necessary means for the design/selection of proper decision aids for TCO. Therefore, the activities reported here were added to the second-year effort of the Taxonomy program.

In order to apply the methodology developed during the first year program, the taxonomic approach was tailored to the specific needs of TCO. TCO-supported decision tasks were identified and classified using the decision-task descriptors defined during the first-year program. The matching principles were applied, and aiding scores were defined. Aiding scores represent the effectiveness of each decision-aiding technique with respect to each specific TCO-supported decision task. Importance weights of the decision task were then assessed through structured expert interviews. Based on these data, the average aiding score for each decision-aiding technique was computed, thus providing a systematic framework for selection of effective decision aids for TCO.

As a by-product of this effort, a methodology for assessment of the importance of TCO capabilities with respect to function performance was established. This methodology is also documented in the present report. It is based on a taxonomy of behaviors and provides a framework, similar to the matching principles developed during the first-year program, for relating the required behaviors to the behaviors enhanced by each TCO capability. The application of this framework yields a score which depicts the degree of effectiveness of a given TCO capability for a specific function.

This appendix is intended to be presentable as a stand-alone document. Also included is an analysis of TCO functions, in Section A.2, as well as an analysis of TCO capabilities in Section A.3. Section A.4 presents the decision aid selection process and the associated results.

A.2 TCO DECISION TASK FUNCTIONAL ANALYSIS

A.2.1 TCO Functional Analysis

A.2.1.1 TCO Functional Decomposition. As part of the on-going TCO development effort, an analysis of the military functions to be supported by TCO has been performed by the Marine Corps Tactical System Support Activity. The results of this study are documented in the preliminary System Description Document (PSDD), which contains, in particular, a hierarchical decomposition of TCO functions. The TCO decomposition yields a logic tree depicted in Figure A-1, which portrays system requirements (also referred to as functional elements) as leaves of the tree. The level of detail thus reached was sufficient to permit the definition of 92 system capabilities that altogether constitute the TCO concept.

The first-year effort provided an analysis based upon Marine Corps doctrine and encompassed the entire spectrum of Marine Amphibious Brigade operations. This part of the second-year effort, documented in this appendix, applies the methodology developed during the first year to the selection of a decision aid for inclusion in the TCO concept. Consequently, it was appropriate to use, as a basis, the TCO functional decomposition developed by the TCO project team described above.

A.2.1.2 TCO Decision-Task Identification. The decision-task analysis performed during the first year program was brought to bear on the TCO functional decomposition. This allowed identification of those bottom-level TCO functions that are decision tasks. Validation of the results of the identification process was sought through structured interview of Marine Corps personnel at MCTSSA. Subjects were requested to focus on the leaves of the logic tree depicting TCO functions (Figure A-1) and identify among them those that involve significant decisions. The results obtained through the interview were identical to those derived from

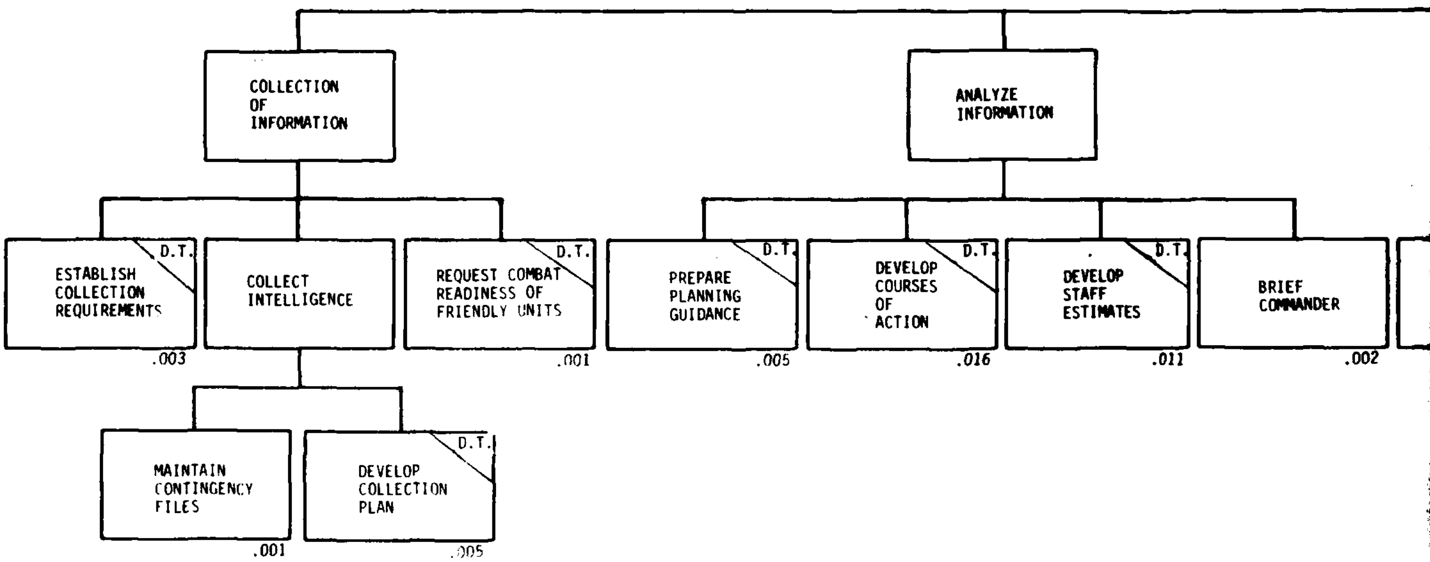
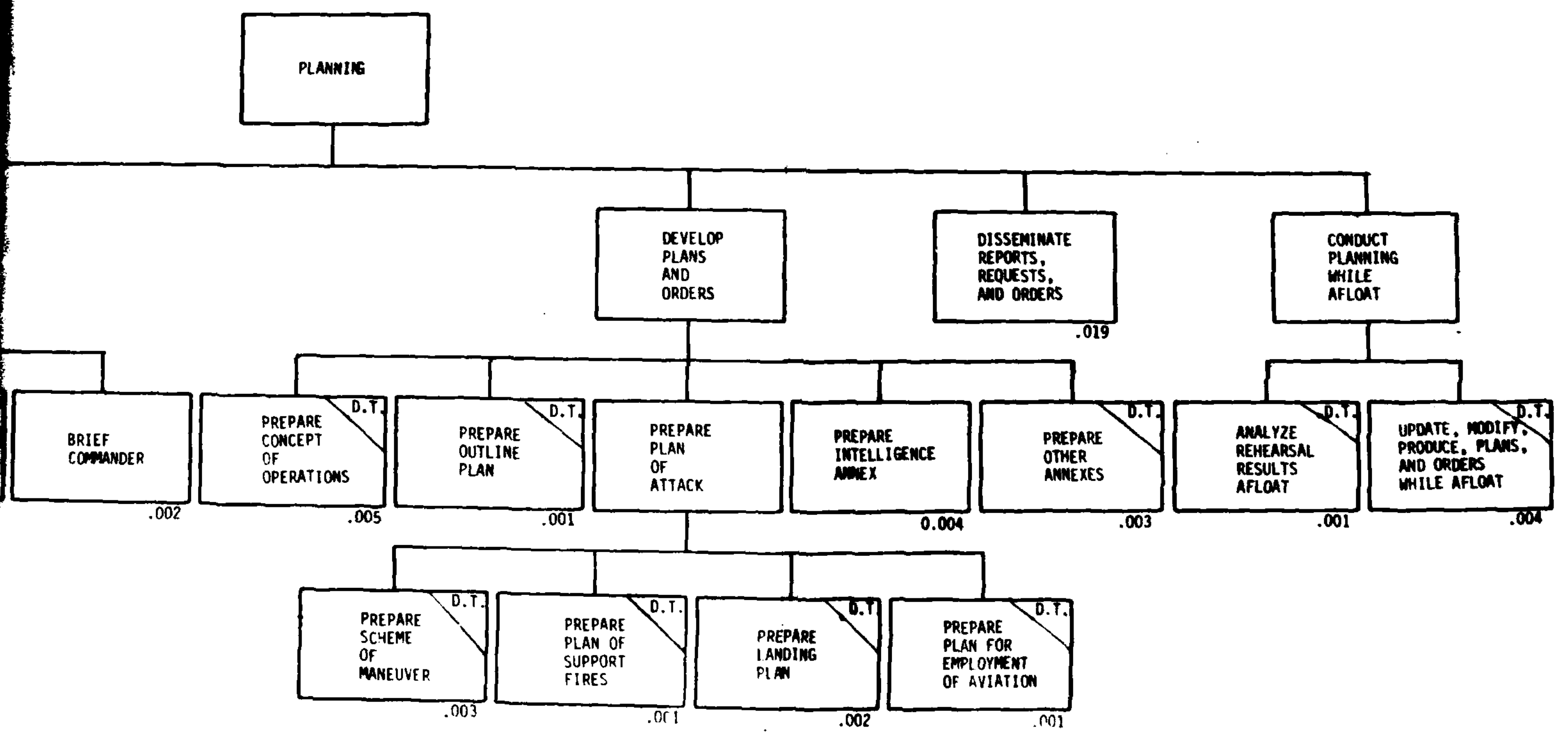


FIGURE A-1a.
TCO FUNCTIONAL DECOMPOSITION: PLANNING


PLANNING
DEVELOP PLANS AND ORDERS
DISSEMINATE REPORTS, REQUESTS, AND ORDERS
.019
CONDUCT PLANNING WHILE AFLOAT
BRIEF COMMANDER
.002
D.T.
PREPARE CONCEPT OF OPERATIONS
.005
D.T.
PREPARE OUTLINE PLAN
.001
PREPARE PLAN OF ATTACK
PREPARE INTELLIGENCE ANNEX
0.004
D.T.
PREPARE OTHER ANNEXES
.003
D.T.
ANALYZE REHEARSAL RESULTS AFLOAT
.001
D.T.
UPDATE, MODIFY, PRODUCE, PLANS, AND ORDERS WHILE AFLOAT
.004
D.T.
PREPARE SCHEME OF MANEUVER
.003
D.T.
PREPARE PLAN OF SUPPORT FIRES
.001
D.T.
PREPARE LANDING PLAN
.002
D.T.
PREPARE PLAN FOR EMPLOYMENT OF AVIATION
.001

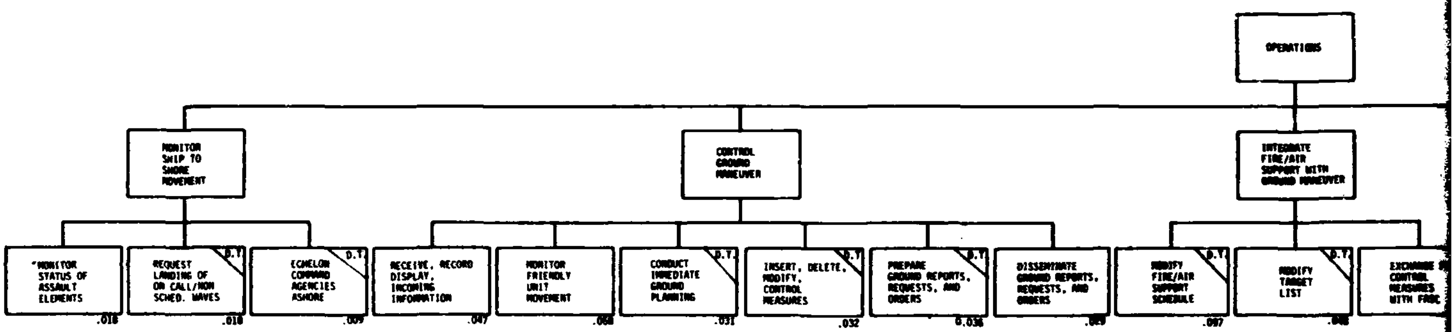
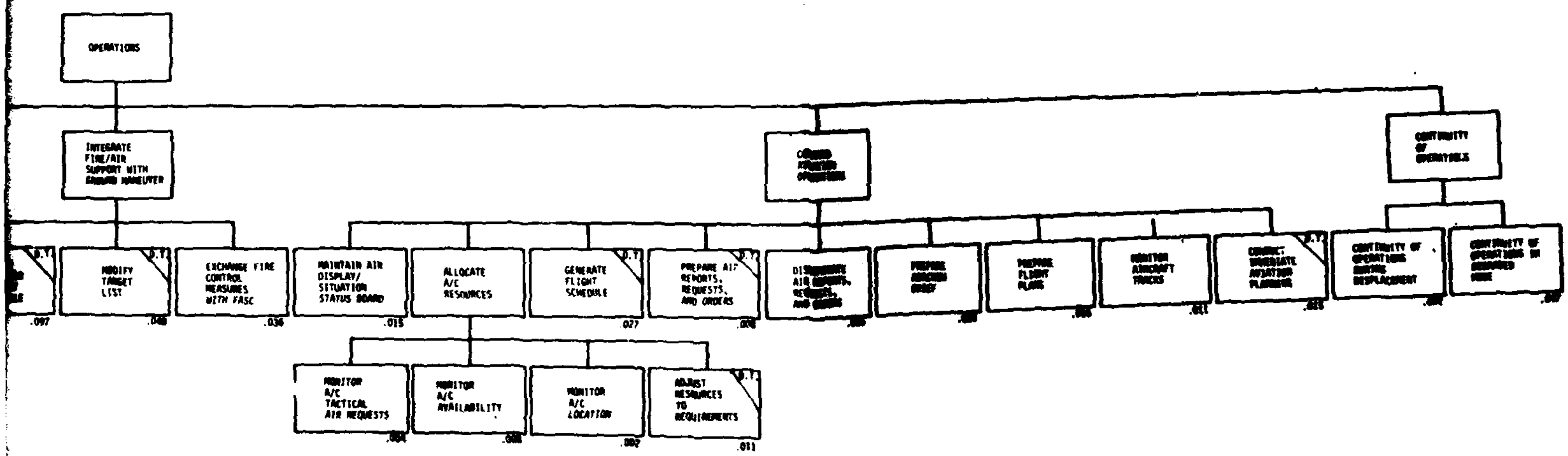


FIGURE A-1b.
TCO FUNCTIONAL DECOMPOSITION: OPERATIONS



OPERATIONS
INTEGRATE FIRE/AIR SUPPORT WITH
MODIFY TARGET LIST
EXCHANGE FIRE CONTROL MEASURES WITH FASC
MAINTAIN AIR DISPLAY/ SITUATION STATUS BOARD
ALLOCATE A/C RESOURCES
GENERATE FLIGHT SCHEDULE
PREPARE AIR REPORTS, REQUESTS, AND ORDERS
MONITOR A/C TACTICAL AIR REQUESTS
MONITOR A/C AVAILABILITY
MONITOR A/C LOCATION
ADJUST RESOURCES TO REQUIREMENTS
.097
.036
.015
.027

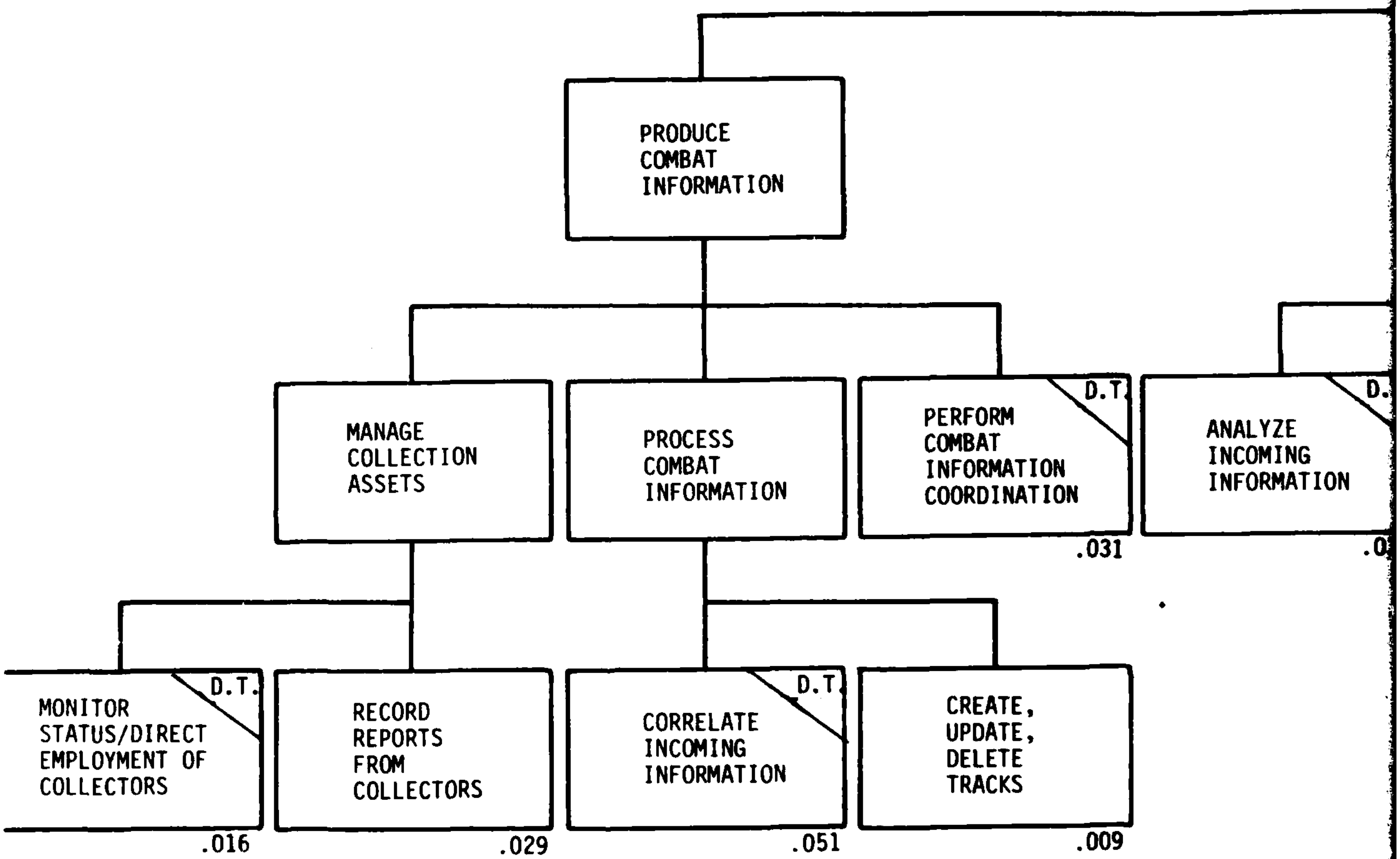
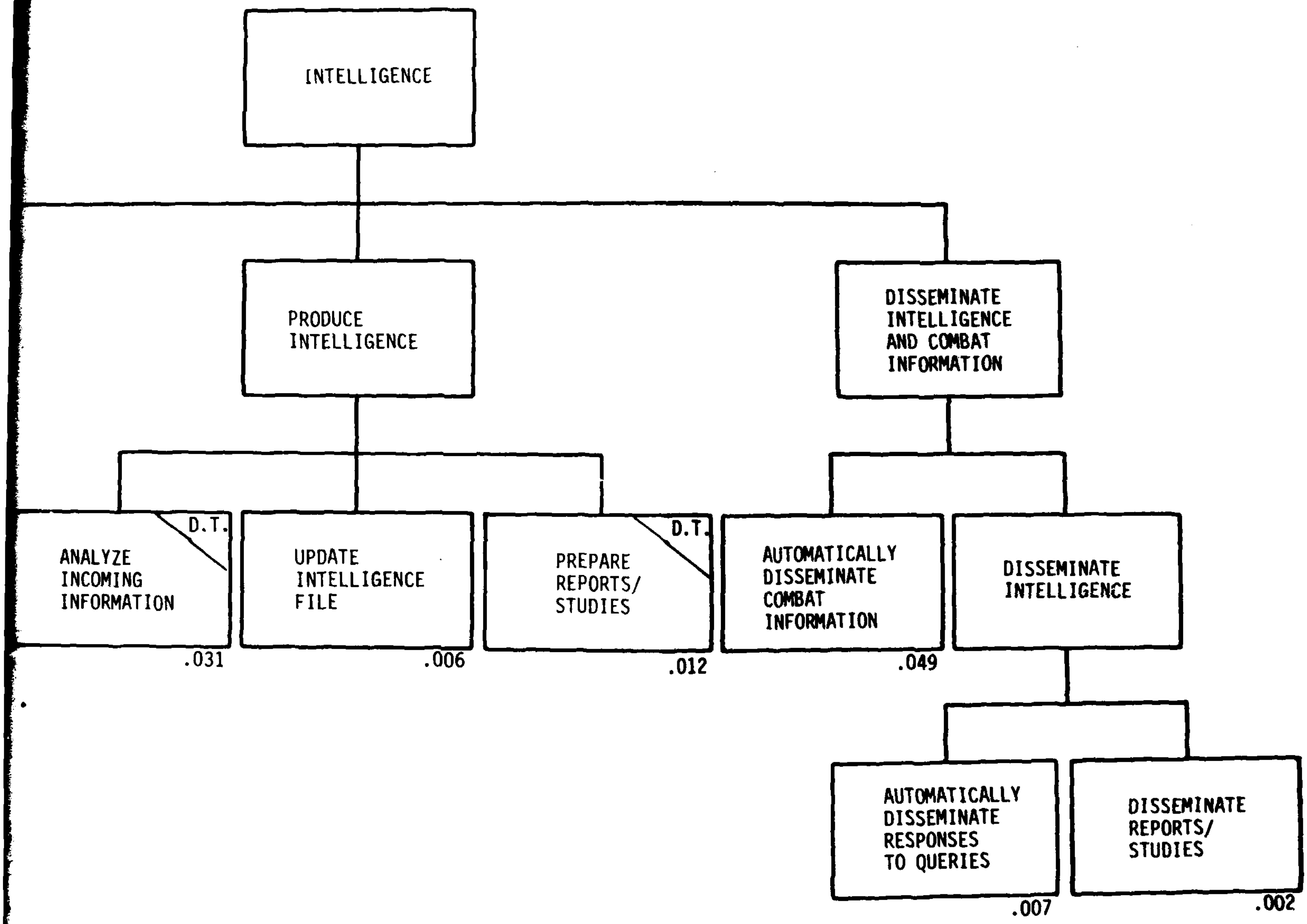


FIGURE A-1c.
TCO FUNCTIONAL DECOMPOSITION: INTELLIGENCE


INTELLIGENCE
PRODUCE INTELLIGENCE
DISSEMINATE INTELLIGENCE AND COMBAT INFORMATION
D.T.
ANALYZE INCOMING INFORMATION
.031
UPDATE INTELLIGENCE FILE
.006
D.T.
PREPARE REPORTS/ STUDIES
.012
AUTOMATICALLY DISSEMINATE COMBAT INFORMATION
.049
DISSEMINATE INTELLIGENCE
AUTOMATICALLY DISSEMINATE RESPONSES TO QUERIES
.007
DISSEMINATE REPORTS/ STUDIES
.002

the methodology established during the first year. These results are depicted in Figure A-1 where decision tasks are singled out with 'D.T.' in the upper right corner of the corresponding box.

A.2.1.3 TCO Functional Weight Assessment. In order to assess the relative importance of the TCO bottom-level functions, i.e., the leaves of the logic tree, a top-down procedure based upon importance weights elicited from experts was applied. It consists of eliciting branch weights, normalizing them and rolling them back to the top of the tree. To illustrate the procedure assume that an expert assessed the relative importance of Operations in Marine Corps missions as .750 and that of Control Ground Maneuver in Operations as .400. Assume further that the subject's estimate of the relative importance of Conduct Immediate Ground Planning for Control of Ground Maneuver is .300. The overall importance of Conduct Immediate Ground Planning for the mission will be .750 x .400 x .300 = .090.

Applying systematically this procedure yields an importance weight w_i for each functional element (leaf of the tree) and consequently for each decision task. Note that the total sum of weights over all functional elements is equal to one, but that the sum of weights over decision tasks is less than one.

In order to assess the relative importance of TCO-supported functions for Marine Corps missions, branch weights were elicited. The SMART elicitation method (Edwards, 1971) was selected due to its main advantages, which are: (1) It is simple and can easily be taught, and (2) it does not require judgments of preference among hypothetical entities. The method roughly consists of the following steps: (1) rank entities in order of importance, and (2) rate the entities in importance while preserving ratios, namely:

(1) Assign 10 to the least important item.

(2) Consider next-least important item and assess how much more important it is than the least important by assigning a number reflecting the ratio.

(3) Continue with next item while checking for consistency.

The steps above were followed during the interview of four Marine Corps personnel based at MCTSSA who served as subject matter experts. Two interviewees had a ground operations background, one had an aviation operations background, and one had an extensive intelligence background. The interviewees' assessments showed a high degree of concordance. Consequently, the final weight was taken as the simple average of the four weights. The results are portrayed in Figure A-2. A striking fact is the apparent imbalance of the three major functions supported by TCO, since Operations account for 67% of the total while Intelligence and Planning respectively account for 25% and 8% of the total. In addition to the general results of Figure A-2, the highly weighted decision tasks are portrayed in Table A-1. All high-weight decision tasks belong to the functional areas Operations or Intelligence. The decision task with the highest weight in Planning is 'Develop Courses of Action' with a weight of .016.

A.2.2 TCO Function Classification

A.2.2.1 Behavioral Function Classification. As mentioned earlier, TCO functional decomposition was carried out until a level of detail sufficient for definition of system capabilities was reached. A matrix of TCO functions by TCO capabilities was established and included in Appendix F of the TCO PSDD. This matrix portrays the function/capability binary relationships, i.e., allows identification of the capabilities required for performance of a given function.

TABLE A-1

HIGHLY WEIGHTED DECISION TASKS

Modify Air Support Schedule	.097
Correlate Incoming Information	.051
Modify Target List	.048
Prepare Ground Reports, Requests, and Orders	.036
Insert, Modify, Delete Control Measures	.032
Conduct Immediate Ground Planning	.031
Analyze Incoming Information	.031

The TCO project team identified a requirement to validate this matrix or find a methodology to accommodate non-binary relations, i.e., to construct a "function x capability" matrix whose entries would be numbers between 0 and 1 measuring "how much" of a given capability is required for performance of a given function. As a by-product of the present effort, a methodology to fulfill this requirement was developed and is described in the following.

The first step of the methodology is to develop a taxonomy of human behaviors, i.e., a set that contains all possible behaviors that could be encountered in analyzing tasks and such that the behavioral categories defined do not overlap. Thus, any task can be represented as a binary vector, with one meaning that the corresponding behavior is required for task performance, and zero that it is not. Another alternative would be to represent each task as a vector of numbers between 0 and 1, each entry measuring how important the corresponding behavior is for task performance. Whatever the solution retained, a task can be symbolically represented as a vector:

$$\underline{t} = (t_1, \ldots, f_{|B|})$$

where the entries are numbers between 0 and 1 as explained above.

The taxonomy of behaviors suggested in this particular case, is that of Berliner, et al. (1964), which is well-known and general considered *"reasonably descriptive of behaviors that can be observed in task performance"* (Meister, 1976). This taxonomy is presented in Table A-2.

A.2.2.2 Decision Task Classification. In the previous paragraph, the importance of having at one's disposal a taxonomy of behaviors was stressed since tasks can be classified according to the categories contained in

TABLE A-2

TAXONOMY OF BEHAVIORS (BERLINER ET AL. 1964)

PROCESSES	ACTIVITIES	BEHAVIORS
1. PERCEPTUAL PROCESSES	1.1 Searching for and Receiving Information	Detects Inspects Observes Reads Receives Scans Surveys
	1.2 Identifying Objects, Actions, Events	Discriminates Identifies Locates
2. MEDIATIONAL PROCESSES	2.1 Information Processing	Categorizes Calculates Codes Computes Interpolates Itemizes Tabulates Translates
	2.2 Problem Solving and Decision Making	Analyzes Calculates Chooses Compares Computes Estimates Plans
3. COMMUNICATION PROCESSES		Advises Answers Communicates Directs Indicates Informs Instructs Requests Transmits
4. MOTOR PROCESSES	4.1 Simple/Discrete	Activates Closes Connects Disconnects Joins Moves Presses Sets
	4.2 Complex/Continuous	Adjusts Aligns Regulates Synchronizes Tracks

the taxonomy. The level of detail that is retained in the taxonomy depends upon the purpose of the analysis. For the purpose of ranking TCO capabilities, one could use only activities (see Table A-2). This was actually done and the results of the analysis of TCO functional elements in terms of activities are depicted in Appendix B.

For selecting a decision aid, it is clear that using the taxonomy of Berliner, et al. at the level of activities would not be satifactory since no discrimination power would be provided. Consequently, the taxonomy of decision-making behaviors (also called functional requirements) developed during the first year program was utilized. Those functional elements identified as decision tasks were classified in terms of their functional requirements, as well as their attributes. The results, which are depicted in Appendix B, served as a basis for application of the matching principles developed during the first year program that produces a degree of merit for each decision-aiding technique with respect to a given decision situation.

A.3 TCO CAPABILITY ANALYSIS

A.3.1 TCO Capabilities and Human Activities

TCO is described at length in the PSDD, and TCO capability definitions can be found in an unpublished document called "TCO Capabilities Identification," prepared for TCO test 02-79 run at MCTSSA. These definitions have been reproduced in "Final MTF TCO Functional Requirements Document," 27 February 1980, prepared by the Planning Research Corporation. TCO capability definitions have been reproduced in Appendix C.

In general, a capability is aimed at certain activities (according to the taxonomy of activities portrayed in Table A-2), i.e., it is designed to aid or facilitate certain types of human activities. Using the definitions, all TCO capabilities were classified according to the activities they aim at. The results of this analysis are portrayed in Table A-3. The capabilities for which N/A (non-applicable) appears are actually requirements in which TCO operators do not play any role; and consequently these capabilities do not lend themselves to the proposed analysis.

Each TCO capability, therefore, (just as any TCO functional element) can now be represented as a binary vector, with one meaning that the corresponding activity is present and a zero meaning that it is absent. Again, the numbers need not be zero or one. It is theoretically possible to define a number representing the degree of facilitation provided by a TCO capability in the performance of an activity. Hence, a capability can be represented as a vector

$$\underline{c} = (c_1, \ldots, c_{|B|})$$

similarly to the representation of $\underline{t}$.

TABLE A-3

CLASSIFICATION OF TCO CAPABILITIES BY ACTIVITIES SUPPORTED

CAPABILITY	CORRESPONDING ACTIVITIES	
1. Enter Graphics Manually on Line	2.1.	3.
2. Exchange Track Data Automatically	N/A	
3. Enter Text Automatically	2.1.	3.
4. Enter Data Via Machine Readable Medium	3.	
5. Enter Text Manually on Line	2.1.	3.
6. Store Graphics Information in Data Base	3.	
7. Process Text in Planning Framework	1.1	2.1
8. Store Text in Journal	1.1.	
9. Store Message Header Incoming Message Queue	1.1.	
10. Store Text in Data Base	3.	
11. Process Text/Graphics Via Remote Terminal	2.1.	
12. Hook to Amplify Graphic Display	1.2.	
13. Inter System Graphic Queries	N/A	
14. Request Graphics by Plain Language Query	3.	
15. Request Graphics by Intrasystem Query	N/A	
16. Request Graphics by SRI	3.	
17. Select Graphics from Prompt List	1.1.	
18. Hook to Amplify Text Display	1.2.	
19. Intersystem Text Queries	N/A	
20. Request Text by Plain Language Query	3.	
21. Intrasystem Text Queries	N/A	
22. Request Text by Standing Request for Information	3.	
23. Select Text from Prompt List	1.1.	
24. Select Preformatted Display	3.	
25. Print Graphics by Operator Action	3.	
26. Print Text Automatically Upon Receipt	3.	
27. Print Text by Operator Action	3.	
28. Display Graphics Automatically Upon Receipt	1.1.	
29. Process Graphics in Scratch Pad	2.1.	
30. Map Display Control	3.	
31. Highlight Graphics	2.1.	
32. Graphic Selective Erase	2.1.	
33. Smooth Graphic Symbols	2.1.	
34. Annotate Source of Symbols	3.	
35. Time Tag Information	3.	
36. Distinguish Friend/Enemy Unit	3.	
37. Distinguish Processed/Unprocessed Intelligence	3.	
38. Control/Display Pointer	2.1.	
39. Construct and Process Symbols	2.1.	
40. Close Control Graphics	1.2.	2.1.
41. Display Text Automatically Upon Receipt	1.1	
42. Display Text by Operator Action	3.	
43. Process Text in Scratch Pad	2.1.	
44. Scroll/Page Text	2.1	
45. Close Control Text	1.2.	2.1.
46. Intra Center Dissemination of Text/Graphics	3.	

TABLE A-3 (CONTINUED)

CAPABILITY	CORRESPONDING ACTIVITIES	
47. Display in Conference Mode	3.	
48. Intra System Dissemination of Text/Graphics	3.	
49. Inter System Dissemination of Text/Graphics	N/A	
50. High Precedence Message Alert	1.1.	1.2.
51. Call Back Upon Receipt of Requested Data Alert	1.1.	
52. Local Parameters Alert	1.2.	
53. Task Identification/Scroll Queue	1.1.	
54. Run Combat Simulation	2.2.	
55. Run Simulation by Snapshots	2.2.	
56. Enter/Delete A/C Sort Rate Parameter	2.2.	
57. Enter/Delete Mission Requirements Parameter	2.2.	
58. Enter/Delete A/C Locations Parameter	2.2.	
59. Enter/Delete A/C Character Parameter	2.2.	
60. Enter/Delete Unit Movement Parameter	2.2.	
61. Calculate Combat Power Ratio	2.2.	
62. Calculate Time/Distance Ratio	2.2.	
63. Calculate Fuel Consumption	2.2.	
64. Calculate Casualty Estimates	2.2.	
65. Calculate A/C to Mission Assignment	2.2.	
66. Calculate Ordnance for Target/Mission	2.2.	
67. Calculate/Display Sensor Placement and Coverage	2.2.	
68. Calculate/Display Minefield Coverage	2.2.	
69. Perform Track Management	2.1.	
70. Automatic Generation of Tables	2.1.	
71. Perform Reasonableness Checks	2.2.	
72. Operate in Local Mode	N/A	
73. Interface PLRS	N/A	
74. Interface MIFASS	N/A	
75. Interface TAOC-85	N/A	
76. Interface MIPS	N/A	
77. Interface MILOGS	N/A	
78. Interface MAGIS	N/A	
79. Interface External System	N/A	
80. Operate with Portion Data Base	N/A	
81. Operate with Portion Equipment Suite	N/A	
82. Load/Reload from Auxiliary Memory	N/A	
83. Decentralization of Operator Functions	N/A	
84. Assumption of Additional Processing Functions	N/A	
85. Shift TCO Functions to MIFASS	N/A	
86. Word Processing	2.1.	
87. Display Information For Group Viewing	3.	
88. Process Graphics Off Line	2.1.	
89. Select/Store Named Display	2.1.	
90. Delete Text/Graphics	3.	
91. Calculate Line of Sight	2.2.	
92. Calculate Materiel Requirements	2.2.	

For each functional element $\underline{t} = (t_1, \ldots, t_B)$ and each capability $\underline{c} = (c_1, \ldots, c_{|B|})$ a degree of matching d can be computed as

$$d = \frac{\sum a_b}{\sum t_b}$$

where

$$a_b = \max(o, t_b - c_b)$$

d is a quantity between 0 and 1 that represents how well a given TCO capability fulfills the activity requirements of a given functional element. Consider functional element, "Monitor A/C Tactical Air Requests," which can be represented as (1 1 0 0 0 0 0) since it requires activities 1.1 and 1.2. Now consider TCO capability #40 Close Control Graphics. It can be represented as (0 1 1 0 0 0 0) thus implying d = 1/2. Similarly, capability #50 High Precedence Message Alert can be represented as (1 1 0 0 0 0 0) thus implying d = 1 for the same functional element.

Consequently, the function x capability matrix can be filled with numbers between 0 and 1, each entry representing how well the corresponding capability fits the corresponding functional element. It can of course be expected that the finer the taxonomy used, the more heterogeneous the numbers will be, thus allowing fine-grained discrimination between capabilities for a given functional element.

A.3.2 TCO Capabilities and Decision Aids

Since it is required to select a decision aid for TCO, it is very important to identify those TCO capabilities that are in fact decision aids. This will avoid duplication of developmental efforts; at the same time, a figure of merit for TCO decision aids will be obtained. Thus if trade-off analyses are conducted to cut costs by suppression of capabilities, a basis will be available.

Preliminary analysis of TCO capabilities revealed that they actually fall into three categories:

(a) Capabilities that are unrelated to decision making (e.g., straight input/output operations).
(b) Capabilities that enhance decision making to some extent (e.g., by providing a graphic display of relevant information).
(c) Decision aids *per se*.

TCO capabilities were consequently screened and classified as belonging to categories a, b, or c. The decision-aiding technique used was identified by using the taxonomy of decision-aiding techniques developed during the first-year effort. The results, which are depicted in Table A-4, show that the following decision-aiding techniques are already used to at least some extent in the TCO concept: Warfare Area Models, Scheduling, Mathematical Programming, Tactical Simulation, Man-Machine Communication, Coverage Templates, Time/Distance Algorithms, and Message Processing.

TABLE A-4

CLASSIFICATION OF TCO CAPABILITIES BY TECHNIQUE EMPLOYED

	CAPABILITY	CLASSIFICATION	TECHNIQUE
1.	Enter Graphics Manually on Line	a	-
2.	Exchange Track Data Automatically	N/A	-
3.	Enter Text Automatically	a	-
4.	Enter Data Via Machine Readable Medium	a	-
5.	Enter Text Manually on Line	a	-
6.	Store Graphics Information in Data Base	a	-
7.	Process Text in Planning Framework	a	-
8.	Store Text in Journal	a	-
9.	Store Message Header Incoming Message Queue	b	Message Processing (MP)
10.	Store Text in Data Base	a	-
11.	Process Text/Graphics Via Remote Terminal	b	Man-Machine Communication
12.	Hook to Amplify Graphic Display	b	Man-Machine Communication (MMC)
13.	Inter System Graphic Queries	N/A	-
14.	Request Graphics by Plain Language Query	b	MMC
15.	Request Graphics by Intrasystem Query	N/A	-
16.	Request Graphics by SRI	b	MP
17.	Select Graphics from Prompt List	b	MMC
18.	Hook to Amplify Text Display	b	MMC
19.	Intersystem Text Queries	N/A	-
20.	Request Text by Plain Language Query	b	MMC
21.	Intrasystem Text Queries	N/A	-
22.	Request Text by Standing Request for Information	b	MMC
23.	Select Text from Prompt List	b	MMC
24.	Select Preformatted Display	b	MMC
25.	Print Graphics by Operator Action	a	-
26.	Print Text Automatically Upon Receipt	a	-
27.	Print Text by Operator Action	a	-
28.	Display Graphics Automatically Upon Receipt	a	-
29.	Process Graphics in Scratch Pad	a	-
30.	Map Display Control	b	MMC
31.	Highlight Graphics	b	MMC
32.	Graphic Selective Erase	b	MMC
33.	Smooth Graphic Symbols	b	MMC
34.	Annotate Source of Symbols	b	MMC
35.	Time Tag Information	b	MMC
36.	Distinguish Friend/Enemy Unit	b	MMC
37.	Distinguish Processed/Unprocessed Intelligence	a	-
38.	Control/Display Pointer	a	-
39.	Construct and Process Symbols	a	-
40.	Close Control Graphics	a	-
41.	Display Text Automatically Upon Receipt	a	-
42.	Display Text by Operator Action	a	-
43.	Process Text in Scratch Pad	a	-
44.	Scroll/Page Text	a	-
45.	Close Control Text	a	-
46.	Intra Center Dissemination of Text/Graphics	a	-
47.	Display in Conference Mode	b	MMC
48.	Intra System Dissemination of Text/Graphics	b	MMC

TABLE A-4 (CONTINUED)

	CAPABILITY	CLASSIFICATION	TECHNIQUE
49.	Inter System Dissemination of Text/Graphics	N/A	-
50.	High Precedence Message Alert	b	MP
51.	Call Back Upon Receipt of Requested Data Alert	b	MP
52.	Local Parameters Alert	b	MMC
53.	Task Identification/Scroll Queue	a	-
54.	Run Combat Simulation	c	Tactical Simulation
55.	Run Simulation by Snapshots	c	Tactical Simulation
56.	Enter/Delete A/C Sort Rate Parameter	a	-
57.	Enter/Delete Mission Requirements Parameter	a	-
58.	Enter/Delete A/C Locations Parameter	a	-
59.	Enter/Delete A/C Character Parameter	a	-
60.	Enter/Delete Unit Movement Parameter	a	-
61.	Calculate Combat Power Ratio	c	Warfare Area Models
62.	Calculate Time/Distance Ratio	c	Time/Distance Algorithms
63.	Calculate Fuel Consumption	c	Time/Distance Algorithms
64.	Calculate Casualty Estimates	c	Time/Distance Algorithms
65.	Calculate A/C to Mission Assignment	c	Scheduling/Mathematical Programming
66.	Calculate Ordnance for Target/Mission	c	Mathematical Programming
67.	Calculate/Display Sensor Placement and Coverage	c	Mathematical Programming/Coverage Template
68.	Calculate/Display Minefield Coverage	c	Problem Solving/ Coverage Template
69.	Perform Track Management	b	MMC
70.	Automatic Generation of Tables	b	Time/Distance Algorithms
71.	Perform Reasonableness Checks	c	MMC
72.	Operate in Local Mode	N/A	-
73.	Interface PLRS	N/A	-
74.	Interface MIFASS	N/A	-
75.	Interface TAOC-85	N/A	-
76.	Interface MIPS	N/A	-
77.	Interface MILOGS	N/A	-
78.	Interface MAGIS	N/A	-
79.	Interface External System	N/A	-
80.	Operate with Portion Data Base	N/A	-
81.	Operate with Portion Equipment Suite	N/A	-
82.	Load/Reload from Auxiliary Memory	N/A	-
83.	Decentralization of Operator Functions	N/A	-
84.	Assumption of Additional Processing Functions	N/A	-
85.	Shift TCO Functions to MIFASS	N/A	-
86.	Word Processing	a	-
87.	Display Information for Group Viewing	b	MMC
88.	Process Graphics Off Line	a	-
89.	Select/Store Named Display	a	-
90.	Delete Text/Graphics	a	-
91.	Calculate Line of Sight	c	Time/Distance Algorithms
92.	Calculate Materiel Requirements	c	Time/Distance Algorithms

A.4 DECISION AID SELECTION

A.4.1 Decision Aid Ranking

Using the matching principles set forth during the first-year program, it is now possible to define a degree of merit (called aiding score) for every decision-aiding technique with respect to every TCO decision task. Let this aiding score be s_{ij}, where i stands for the decision task and j for the decision-aiding technique. In order to obtain an overall assessment of the potential benefit of each decision-aiding technique for TCO-supported decision tasks, it is required to summarize these aiding scores into a single figure of merit. An obvious solution is to compute an average aiding score, the average being taken over all TCO-supported decision tasks. All decision tasks, however, are not equally important as demonstrated by TCO functional analysis that yielded an importance weight for each functional element, hence for each decision task. Consequently, we can calculate

$$S_j = \sum_{\substack{i\ \text{TCO} \\ \text{decision} \\ \text{task}}} w_i \, s_{ij}$$

where w_i is the importance weight of decision task i. Note that the w_i's are not normalized, i.e., the sum of w_i's over decision tasks is strictly lower than one. However, this is of not consequence since it is only required to rank decision-aiding techniques. In other words, the S_j's are used for the purpose of comparison only and not as absolute numbers.

The calculations required, although simple, were in overwhelmingly large numbers so that a program was written to automatically compute the S_j's.

Inputs to the program were TCO-supported decision task descriptions in terms of the attributes and functional requirements as depicted in Appendix A. Also, inputs to the program were the aiding technique x functional requirement and aiding technique x decision-task attribute relevance matrices (Figures 5-2 and 5-3 of first year final report). The results are depicted in Table A-5. Note that the highest score is that of Tactical Simulation, which is already included in the TCO concept. Similarly, Man-Machine Communication, which is to a large extent already included in the TCO concept, also receives a very high score. The analysis therefore supports the early decision of TCO concept designers to include these techniques.

A.4.2 Decision Aid Selection

The average aiding scores were of course used as a basis for selection of a decision-aiding technique for inclusion in the TCO concept. However, other considerations preside over this selection. A working session was therefore organized at MCTSSA in order to select an effective decision-aiding technique within the constraints imposed by the project and satisfying user's desiderata.

Table A-6 presents thirteen decision-aiding techniques which are *a priori* candidates due to their high score. First, it was noted that three of these techniques were already included in the TCO concept and were thus disqualified on the basis of non-duplication of efforts. Another five techniques were readily transferable and thus rejected since the program affords a unique opportunity to develop available techniques for a new concern (Partial Information Based Decision Analysis was developed by Perceptronics under a DARPA program while the four other decision-aiding techniques are part of Perceptronics' Group Decision Aid, which is a stand-alone, portable device). Finally, another two techniques required

TABLE A-5

AVERAGE DECISION-AIDING TECHNIQUE AIDING SCORES FOR TCO-SUPPORTED DECISION TASKS

TACTICAL SIMULATION	.376
PROBLEM SOLVING	.346
DECISION TREE STRUCTURING	.344
DATABASE ORGANIZATION	.341
GROUP DECISION ANALYSIS	.337
PATTERN-DIRECTED INFERENCE SYSTEMS	.330
MAN-MACHINE COMMUNICATION	.324
INFORMATION AND DISCRIMINATION MEASURES	.323
PLANNING MECHANISMS	.322
CLASSIFICATION	.305
PARTIAL INFORMATION BASED DECISION ANALYSIS	.295
MULTI-ATTRIBUTE UTILITY ANALYSIS	.291
SUBJECTIVE EXPECTED UTILITY	.289
FUZZY DECISION ANALYSIS	.290
WARFARE AREA MODELS	.274
COVERAGE TEMPLATES	.271
LINEAR DISCRIMINANT FUNCTIONS	.270
LANCHESTER'S THEORY OF COMBAT	.267
COST-BENEFIT ANALYSIS	.253
RISK-BENEFIT ANALYSIS	.253
DISCOUNTING MODELS	.245
PROBA MULTI-ATTRIBUTE UTILITY ANALYSIS	.239
GAME THEORY	.239
SIMULATION AND WAR GAMING	.232
GROUP UTILITY AGGREGATION	.205
SCHEDULING	.199
UTILITY ASSESSMENT TECHNIQUES	.193
CLUSTERING	.183
TIME/DISTANCE ALGORITHMS	.173
MATHEMATICAL PROGRAMMING	.152
MESSAGE PROCESSING	.141
BAYESIAN UPDATING	.137
SIGNAL DETECTION	.133
GROUP PROBABILITY AGGREGATION	.128
MONTE CARLO METHODS	.113
PROBLEM REPRESENTATION	.101
SENSITIVITY ANALYSIS	.099
TIME INVARIANT STATISTICAL DETECTION	.092
SEARCH MODELING	.081
PROBABILITY ELICITATION	.079
LEARNING SYSTEMS	.054

TABLE A-6

HIGH-SCORED DECISION AIDING TECHNIQUES

✓	Tactical Simulation	.376
	Problem Solving	.346
-	Decision Tree Structuring	.344
✓	Man-Machine Communication	.342
✓	Database Organization	.341
-	Group Decision Analysis	.337
x	Pattern-Directed Inference Systems	.330
	Information and Discrimination Measures	.323
x	Planning Mechanisms	.322
	Classification	.305
-	Partial Information Based Decision Analysis	.295
-	Multi-Attribute Utility Analysis	.291
-	Subjective Expected Utility	.289

✓ Already Included in TCO
- Readily Available for Transfer
x Requires Long-Term Effort

a very long term effort due to their present stage of development and were therefore rejected as beyond the scope of the project.

Three decision-aiding techniques were left for discussion. They are portrayed, together with their aiding scores with respect to TCO-supported decision tasks, in Table A-7. Simultaneous inspection of the figures portrayed in Table A-7 and the decision-task weights led to the selection of a few good matches between selected decision-aiding techniques and particularly important TCO-supported decision tasks. This table of correspondance depicted in Table A-8 was used as a basis for the last phase of the decision-aid selection process.

First it was noted that problem-solving techniques mainly apply to tasks that are currently studied under the auspices of another program and were consequently not selected. MCTSSA personnel emphasized their interest in Combat Information Correlation. Since Classification matches this task well, it was decided to select it as a decision-aiding technique and to initiate development for Information Correlation. In addition, a subtask of Information Correlation, which is the management of information gathering sources, lends itself to Information and Discrimination Measures as a decision-aiding technique. Consequently, the development of Classification (primarily) and Information and Discrimination Measures (secondarily) was initiated for Combat Information Correlation. Examination of the task attributes revealed, through use of the decision-task attribute x decision-aid feature relevance matrix (Figure 5-4 of the first-year final report) that the required decision-aid features are:

- flexible
- interactive
- real time

These requirements provide guidelines for maximum implementation efficiency.

TABLE A-7

INDIVIDUAL AIDING SCORES FOR SELECTED DECISION-AIDING TECHNIQUES

	PROBLEM SOLVING	INFORMATION & DISCRIMINATION MEASURES	CLASSIFICATION
Establish Collection Requirements	.67	.60	.30
Develop Collection Plan	1.00	1.00	.50
Request Combat Readiness of Friendly Units*	1.00	.90	.45
Prepare Planning Guidance	.35	.40	.00
Develop Courses of Action	.50	.50	.50
Develop Staff Estimates	1.00	1.00	1.00
Prepare Concept of Operations	1.00	1.00	1.00
Prepare Outline Plan	.50	.45	.50
Prepare Scheme of Maneuver	1.00	.80	.90
Prepare Plan of Support Fires	.50	.40	.45
Prepare Landing Plan	.50	.40	.45
Prepare Plan for Employment of Aviation	.50	.40	.45
Prepare Intelligence Annex	1.00	1.00	.50
Prepare Other Annexes	1.00	.50	1.00
Analyze Rehearsal Results While Afloat	1.00	.40	.90
Update, Modify, Produce, Plans, and Orders While Afloat	.45	.45	.45
Request Landing of On Call/Non Scheduled Waves	.50	1.00	1.00
Echelon Command Agencies Ashore	.90	.90	.90
Conduct Immediate Ground Planning	.45	.67	.67
Insert, Delete, Modify, Control Measures	.50	.45	.45
Prepare Ground Reports, Requests, and Orders	.90	.45	.45
Modify Fire/Air Support Schedule	.45	.45	.45
Modify Target List	.90	.90	.90
Adjust Resources to Requirements**	.45	.30	.60
Generate Flight Schedule	.53	.45	.45
Prepare Aviation Reports, Requests, and Orders	.45	.45	.45
Prepare Flight Plans	.90	.45	.45
Conduct Immediate Aviation Planning	.45	.67	.67
Monitor Status/Direct Employment of Collectors	.60	.67	.33
Correlate Incoming Information	.60	.33	.67
Perform Combat Information Coordination	.90	1.00	.50
Analyze Incoming Information	.53	.53	.27
Prepare Reports/Studies	.60	.67	.30

* Includes assessment of combat readiness.

** Was added as a subtask of allocate aircraft resources, the other subtasks being of the monitoring type.

TABLE A-8

IMPORTANT DECISION TASKS MATCHING WELL SELECTED DECISION-AIDING TECHNIQUES

DECISION-AIDING TECHNIQUE	DECISION TASKS
. Problem Solving	. Conduct Immediate Aviation Planning . Allocate Aircraft Resources
. Information and Discrimination Measures	. Perform C.I. Coordination . Modify Target List
. Classification	. Correlate Incoming Information . Conduct Immediate Ground Planning . Conduct Immediate Aviation Planning

APPENDIX B

TCO FUNCTIONAL ANALYSIS

TASK:	ESTABLISH COLLECTION REQUIREMENTS
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Group
	Static
	One Shot
	Risk
	Well Defined
	Decision Making
	Time Relaxed
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development
	3. Information Acquisition and Evaluation
	4. Alternative Evaluation/Selection

TASK: MAINTAIN CONTINGENCY FILES

NATURE: 1.1. Searching for and Receiving Information

2.1. Information Processing

TASK:	DEVELOP THE COLLECTION PLAN
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Individual
	Static
	One Shot
	Risk
	Well Defined
	Decision Making
	Time Relaxed
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	3. Information Acquisition and Evaluation
	4. Alternative Evaluation/Selection

TASK:	REQUEST COMBAT READINESS OF FRIENDLY UNITS*
NATURE:	1.1. Searching for and Receiving Information
ATTRIBUTES:	Multi-Attribute
	Group
	Static
	One Shot
	Risk
	Well Defined
	Decision Making
	Time Relaxed
	Normal Range
	Type 2
FUNCTIONAL REQUIREMENTS:	3. Information Acquisition and Evaluation
	4. Alternative Evaluation/Selection

*This should include assessment of combat readiness in which case it becomes a decision task classified as above.

TASK:	PREPARE PLANNING GUIDANCE
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute Individual Dynamic Repetitive Risk Ambiguous Decision Making Time Relaxed Normal Range Type 1
FUNCTIONAL REQUIREMENTS:	2. Alternative Development 3. Information Acquisition and Evaluation

TASK:	DEVELOP COURSES OF ACTION
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Individual
	Static
	One Shot
	Risk
	Well Defined
	Decision Making
	Time Relaxed
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development
	4. Alternative Evaluation/Selection

TASK:	DEVELOP STAFF ESTIMATES
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Individual
	Static
	One Shot
	Risk
	Well Defined
	Decision Making
	Time Relaxed
	Normal Range
	Type 2
FUNCTIONAL REQUIREMENTS:	4. Alternative Evaluation/Selection

TASK: BRIEF COMMANDER

NATURE: 3. Communicating

TASK:	PREPARE CONCEPT OF OPERATIONS*
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Individual
	Static
	One Shot
	Risk
	Well Defined
	Decision Making
	Time Relaxed
	Normal Range
	Type 2
FUNCTIONAL REQUIREMENTS:	4. Alternative Evaluation/Selection

*Including CMDR's decision. Actually the concept of ops is only an amplification of the decision.

TASK:	PREPARE OUTLINE PLAN
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Individual
	Static
	One Shot
	Certainty
	Well Defined
	Decision Making
	Time Relaxed
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development
	4. Alternative Evaluation/Selection

TASK:	PREPARE SCHEME OF MANEUVER
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Group
	Static
	One Shot
	Certainty
	Well Defined
	Decision Making
	Time Relaxed
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	4. Alternative Evaluation/Selection

TASK:	PREPARE PLAN OF SUPPORTING FIRES
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Group
	Static
	One Shot
	Certainty
	Well Defined
	Decision Making
	Time Relaxed
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development
	4. Alternative Evaluation/Selection

TASK:	PREPARE THE LANDING PLAN
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Group
	Static
	One Shot
	Certainty
	Well Defined
	Decision Making
	Time Relaxed
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development
	4. Alternative Evaluation/Selection

TASK:	PREPARE THE PLAN FOR EMPLOYMENT OF AVIATION
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Group
	Static
	One Shot
	Certainty
	Well Defined
	Decision Making
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development
	4. Alternative Evaluation/Selection

TASK:	PREPARE INTELLIGENCE ANNEX
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Individual
	Static
	One Shot
	Risk
	Well Defined
	Decision Making
	Time Relaxed
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	3. Information Acquisition and Evaluation
	4. Alternative Evaluation/Selection

TASK:	PREPARE OTHER ANNEXES
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Individual
	Static
	One Shot
	Risk
	Well Defined
	Decision Making
	Time Relaxed
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	4. Alternative Evaluation/Selection

TASK:	ANALYZE REHEARSAL RESULTS WHILE AFLOAT
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Group
	Static
	One Shot
	Certainty
	Well Defined
	Decision Making
	Time Relaxed
	Normal Range
	Type 2
FUNCTIONAL REQUIREMENTS:	1. Problem Recognition
	4. Alternative Evaluation/Selection

TASK:	UPDATE, MODIFY, PRODUCE PLANS AND ORDERS WHILE AFLOAT
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Group
	Dynamic
	Repetitive
	Risk
	Well Defined
	Decision Making
	Time Relaxed
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development
	4. Alternative Evaluation/Selection

TASK:	MONITOR STATUS OF ASSAULT ELEMENTS
NATURE:	1.1. Searching for and Receiving Information
	1.2. Identifying Objects Actions Events

TASK:	REQUEST LANDING OF ON CALL/NON SCHEDULED WAVES
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Individual
	Dynamic
	Repetitive
	Risk
	Well Defined
	Decision Making
	Time Critical
	Normal Range
	Type 2
FUNCTIONAL REQUIREMENTS:	4. Alternative Evaluation/Selection

TASK:	ECHELON COMMAND AGENCIES ASHORE
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Group
	Dynamic
	One Shot
	Risk
	Well Defined
	Decision Making
	Time Critical
	Normal Range
	Type 2
FUNCTIONAL REQUIREMENTS:	4. Alternative Evaluation/Selection

TASK:	RECEIVE, RECORD, DISPLAY, INCOMING INFORMATION
NATURE:	1.1. Searching for and Receiving Information
	3. Communicating

TASK: MONITOR FRIENDLY UNIT MOVEMENT

NATURE:

1.1. Searching for and Receiving Information

1.2. Identifying Objects Actions Events

TASK:	CONDUCT IMMEDIATE GROUND PLANNING
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Individual
	Dynamic
	Repetitive
	Risk
	Well Defined
	Decision Making
	Time Critical
	Normal Range
	Type 2
FUNCTIONAL REQUIREMENTS:	3. Information Acquisition and Evaluation
	4. Alternative Evaluation/Selection
	5. Feedback Monitoring

TASK:	INSERT, DELETE, MODIFY, CONTROL MEASURES
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute Group Dynamic Repetitive Risk Well Defined Decision Making Time Critical Normal Range Type 3
FUNCTIONAL REQUIREMENTS:	1. Problem Recognition 2. Alternative Development 3. Information Acquisition and Evaluation 4. Alternative Evaluation/Selection

TASK:	PREPARE GROUND REPORTS, REQUESTS AND ORDERS
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Group
	Dynamic
	Repetitive
	Risk
	Well Defined
	Decision Making
	Time Critical
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development
	4. Alternative Evaluation/Selection

TASK:	DISSEMINATE GROUND REPORTS, REQUESTS AND ORDERS
NATURE:	3. Communicating

TASK:	MODIFY FIRE/AIR SUPPORT SCHEDULE
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute Group Dynamic Repetitive Risk Well Defined Decision Making Time Critical Normal Range Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development 4. Alternative Evaluation/Selection

TASK:	MODIFY TARGET LIST
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Group
	Dynamic
	Repetitive
	Risk
	Well Defined
	Decision Making
	Time Critical
	Normal Range
	Type 2
FUNCTIONAL REQUIREMENTS:	4. Alternative Evaluation/Selection

TASK: EXCHANGE CONTROL MEASURES WITH FASC

NATURE: 1.1. Searching for and Receiving Information

TASK: MAINTAIN AIR DISPLAY SITUATION STATUS BOARD

NATURE: 3. Communicating

TASK:	MONITOR AIRCRAFT TACTICAL AIR REQUESTS
NATURE:	1.1. Searching for and Receiving Information
	1.2. Identifying Objects Actions Events

TASK:	MONITOR AIRCRAFT AVAILABILITY
NATURE:	1.1. Searching for and Receiving Information
	1.2. Identifying Objects Actions Events

TASK: MONITOR AIRCRAFT LOCATION

NATURE:

1.1. Searching for and Receiving Information

1.2. Identifying Objects Actions Events

TASK: ADJUSTS RESOURCES TO REQUIREMENTS (ALLOCATE AIRCRAFT RESOURCES)

NATURE: Decision Task

ATTRIBUTES:

Multi-Attribute

Individual

Dynamic

Repetitive

Risk

Ambiguous

Decision Making

Time Critical

Normal Range

Type 3

FUNCTIONAL REQUIREMENTS:

2. Alternative Development
4. Alternative Evaluation/Selection
5. Feedback Monitoring

TASK:	GENERATE FLIGHT SCHEDULE
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Group
	Dynamic
	Repetitive
	Risk
	Well Defined
	Decision Making
	Time Critical
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development
	4. Alternative Evaluation/Selection

TASK:	PREPARE AVIATION REPORTS, REQUESTS AND ORDERS
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute Group Dynamic Repetitive Risk Well Defined Decision Making Time Critical Normal Range Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development 4. Alternative Evaluation/Selection

TASK: DISSEMINATE AVIATION REPORTS, REQUESTS AND ORDERS

NATURE: 3. Communicating

TASK: PREPARE AIRCREW BRIEF

NATURE: 3. Communicating

TASK:	PREPARE FLIGHT PLANS
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Group
	Static
	One Shot
	Risk
	Well Defined
	Decision Making
	Time Critical
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development
	4. Alternative Evaluation/Selection

TASK:	MONITOR AIRCRAFT TRACKS
NATURE:	1.1. Searching for and Receiving Information
	1.2. Identifying Objects Actions Events

TASK:	CONDUCT IMMEDIATE AVIATION PLANNING
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Individual
	Dynamic
	Repetitive
	Risk
	Well Defined
	Decision Making
	Time Critical
	Normal Range
	Type 2
FUNCTIONAL REQUIREMENTS:	3. Information Acquisition and Evaluation
	4. Alternative Evaluation/Selection
	5. Feedback Monitoring

TASK:	CONTINUITY OF OPS DURING DISPLACEMENT
NATURE:	N/A

TASK: CONTINUITY OF OPS DURING DEGRADED MODE

NATURE: N/A

TASK:	MONITOR STATUS/DIRECT EMPLOYMENT OF COLLECTORS
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Individual
	Dynamic
	Repetitive
	Risk
	Well Defined
	Decision Making
	Time Critical
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development
	3. Information Acquisition and Evaluation
	4. Alternative Evaluation/Selection

TASK: RECORD REPORTS FROM COLLECTORS

NATURE: 1.1. Searching for and Receiving Information

2.1. Information Processing

TASK:	CORRELATE INCOMING INFORMATION
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Individual
	Dynamic
	Repetitive
	Risk
	Well Defined
	Decision Making
	Time Critical
	Normal Range
	Type 3
FUNCTIONAL: REQUIREMENTS:	1. Problem Recognition
	3. Information Acquisition and Evaluation
	5. Feedback Monitoring

TASK: CREATE/UPDATE, DELETE TRACKS

NATURE: 2.1. Information Processing

TASK:	PERFORM COMBAT INFORMATION COORDINATION
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Individual
	Dynamic
	Repetitive
	Risk
	Well Defined
	Decision Making
	Time Critical
	Normal Range
	Type 2
FUNCTIONAL REQUIREMENTS:	3. Information Acquisition and Evaluation
	4. Alternative Evaluation/Selection

TASK:	ANALYZE INCOMING INFORMATION
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Group
	Dynamic
	Repetitive
	Risk
	Ambiguous
	Decision Making
	Time Critical
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development
	3. Information Acquisition and Evaluation
	4. Alternative Evaluation/Selection

TASK: UPDATE INTELLIGENCE FILE

NATURE: 2.1. Information Processing

TASK:	PREPARE REPORTS/STUDIES RESPONSES
NATURE:	Decision Task
ATTRIBUTES:	Multi-Attribute
	Group
	Dynamic
	Repetitive
	Risk
	Well Defined
	Decision Making
	Time Critical
	Normal Range
	Type 3
FUNCTIONAL REQUIREMENTS:	2. Alternative Development
	3. Information Acquisition and Evaluation
	4. Alternative Evaluation/Selection

TASK:	AUTOMATICALLY DISSEMINATE COMBAT INFORMATION
NATURE	1.1 Searching for and Receiving Information

TASK:	AUTOMATICALLY DISSEMINATE RESPONSES TO QUERIES
NATURE:	1.1. Searching for and Receiving Information

TASK:	DISSEMINATE REPORTS/STUDIES
NATURE:	1.1. Searching for and Receiving Information

APPENDIX C

DEFINITION OF TCO CAPABILITIES

Test 02-79
TCO Capabilities Identification

CAP #	Capability
1.	ENTER GRAPHICS MANUALLY ON LINE

The capability to use a TCO terminal to interact directly with the TCO Data Base to create graphic displays.

2. EXCHANGE TRACK DATA AUTOMATICALLY

The capability to display graphically or textually, position location information from other Marine Corps Tactical Automated Command and Control systems (such as PLRS and TAOC-85) automatically, i.e., without human intervention between the systems.

3. ENTER TEXT AUTOMATICALLY

The capability to view information that is not already in the data base (e.g., an incoming message) on a display and, when ready, without having to manually retype it, to enter it by means of a simple operator action, such as pressing a button.

4. ENTER DATA VIA MACHINE READABLE MEDIUM

The capability to enter data into TCO by devices such as magnetic tape, OCR equipment and so on.

5. ENTER TEXT MANUALLY ON LINE

The capability to use a TCO terminal to interact directly with the TCO Data Base to create textual displays.

6. STORE GRAPHICS INFORMATION IN DATA BASE

The capability to store data which was input graphically. The TCO Data Base will retain the data for subsequent recall and use. The graphics data can be in the form of control measures, symbols (newly drawn or from existing library), charts or graphs, terrain features, and so on.

7. PROCESS TEXT IN PLANNING FRAMEWORK

The capability to enter, delete, and store textual information in the TCO Planning Framework. The Planning Framework is a structured file in which all information, irrespective of level of command, developed during planning for an operation is stored in doctrinal formats for an Op Plan/Annexes. It provides users at all echelons the best information, available within the MAGTF TCO during the planning phase. It provides the capability to review, correlate, store and retrieve planning information, so as to assist concurrent planning.

8. STORE TEXT IN JOURNAL

The capability of the system to store textual information in the unit journal format. Both automatic and manual entry capabilities are available.

9. STORE MESSAGE HEADER INCOMING MESSAGE QUEUE

A capability whereby the header (title) information of messages coming into a TCO terminal are filed in a queue until such time as the operator is able to review them and take a subsequent action.

10. STORE TEXT IN DATA BASE

The capability of TCO to be able to store textual data and information in the data base. TCO is more than an automated typewriter or printer. Messages, orders, plans, and so on can be retained through automation for future recall and use. Other capabilities describe some designated methods of 'how' the text information should be stored, processed and manipulated, (e.g., store by preformatted display, select text from prompt list, word processing, etc).

11. PROCESS TEXT/GRAPHICS VIA REMOTE TERMINAL

The capability to interact and perform textual and graphics operations such as inputting, manipulating, sorting, storing and retrieving data while at locations away from a TCO center, by using such devices as the hand-held Digital Communications Terminal connected to a field radio.

12. HOOK TO AMPLIFY GRAPHIC DISPLAY

The capability of an operator at a terminal working on a graphic display to use a device such as a light pen or cursor to select a particular item on the screen, thereby identifying this item to the system, at which time information such as UTM coordinate, unit ID, etc., is displayed in the textual portion of the display screen.

13. INTER SYSTEM GRAPHIC QUERIES

The capability to automatically query for graphic information from other systems. For example, MIFASS can be queried for the display of fire control measures such as the FCL, FSCL, etc.

14. REQUEST GRAPHICS BY PLAIN LANGUAGE QUERY

The capability to enter a question requesting the display of graphics information using English-like language instead of code.

15. REQUEST GRAPHICS BY INTRASYSTEM QUERY

The capability to retrieve graphic information from any other TCO centers without the need to exchange operator-to-operator messages.

16. REQUEST GRAPHICS BY SRI

The capability to establish a request for graphic information against the data base. The information requested will be automatically provided on a continuous basis as new information becomes available or data is updated.

17. SELECT GRAPHICS FROM PROMPT LIST

The capability to call into view a menu of all available graphic symbols and select what one wants.

18. HOOK TO AMPLIFY TEXT DISPLAY

The capability of an operator working on a display terminal to use a device such as a light pen or cursor to select a particular word or phrase on the screen thereby identifying this item to the system, at which time information such as unit strength, supply status, etc., is displayed. An expansion of this capability is called Close Control Text, see #45.

19. INTERSYSTEM TEXT QUERIES

The capability to automatically query for textual information from other systems. For example, MAGIS can be queried for intelligence summaries.

20. REQUEST TEXT BY PLAIN LANGUAGE QUERY

The capability to enter a question requesting the display of textual information using English-like language instead of code.

21. INTRASYSTEM TEXT QUERIES

The capability to query textual information resident in another TCO center without requiring an exchange of messages between operators.

22. REQUEST TEXT BY STANDING REQUEST FOR INFORMATION

The capability to establish a request for text information against the data base. The information requested will be automatically provided on a continuous basis as new information becomes available or data is updated.

23. SELECT TEXT FROM PROMPT LIST

The capability to select the desired textual data display from a menu/list provided as a display on the screen.

24. SELECT PREFORMATTED DISPLAY

The capability to select the desired format required from a list of all formats resident in the TCO System.

25. PRINT GRAPHICS BY OPERATOR ACTION

The capability to have a hard copy print made of a graphic display by simple means, such as pressing a button.

26. PRINT TEXT AUTOMATICALLY UPON RECEIPT

The capability to designate a category or class of messages that would be automatically printed in hard copy upon receipt at a center.

27. PRINT TEXT BY OPERATOR ACTION

The capability to have a hard copy print made of a text display by simple means, such as pressing a button.

28. DISPLAY GRAPHICS AUTOMATICALLY UPON RECEIPT

The capability to update an in-view graphics display to immediately display new information received at the center without requiring operator action.

29. PROCESS GRAPHICS IN SCRATCH PAD

The capability to assemble, compile, interpret, generate, sort, manipulate, etc., graphic data and information at a terminal without the work being accessible by all TCO centers. After using his "local" scratch pad to accomplish his work, the operator can then enter the data into the main data base where it becomes accessible to all.

30. MAP DISPLAY CONTROL

The capability of the computer to orient the graphics on a display screen to the map placed behind it.

31. HIGHLIGHT GRAPHICS

The capability to enhance specified symbology on a graphic display using techniques such as increasing light intensity. The capability may be programmed or operator generated.

32. GRAPHIC SELECTIVE ERASE

The capability to unclutter a graphic display on a terminal by removing from sight selected symbols or lines (also referred to as "suppressing"). This capability is not to be confused with deleting the symbol from the data base.

33. SMOOTH GRAPHIC SYMBOLS

The capability to automatically simplify a graphic display whenever the symbology being requested by the operator can be displayed as a set rather than in terms of its subsets. Example, a Company CO may enter his platoon positions. Regiment may wish to call up a display of Company positions. The system will automatically combine the platoon positions to produce a single symbolic depiction of the company position.

34. ANNOTATE SOURCE OF SYMBOLS

The capability to automatically display alphanumeric identification of the source of graphic information. For example, when Position Location information is entered into the system either manually or received from PLRS it is automatically displayed, and the source of the information is distinguished so the operator may ascertain its reliability.

35. TIME TAG INFORMATION

The capability to automatically display the date/time/group representing the time of receipt (TOR) of information. For example, the display of enemy location information utilizes standard military symbology. When an enemy unit location is displayed the symbol will be time-tagged.

36. DISTINGUISH FRIEND/ENEMY UNIT

The capability on a display to visually differentiate between symbols representing enemy and those which represent friendly.

37. DISTINGUISH PROCESSED/UNPROCESSED INTELLIGENCE

The capability to tell the difference between displayed intelligence data which has been processed by MAGIS (Intel analysts) and combat report information (raw) not yet processed.

38. CONTROL/DISPLAY POINTER

The capability to move a "pointer" on a display screen in order to interact with a display.

39. CONSTRUCT & PROCESS SYMBOLS

The capability to draw or create symbols on a display screen and then have them entered into the data base, as opposed to being able to only select symbols already existing in a library.

40. CLOSE CONTROL GRAPHICS

The capability to designate by cursor or "hook" an element of a graphics display and then perform other operations on the system, all of which will be in relation to the designated element.

41. DISPLAY TEXT AUTOMATICALLY UPON RECEIPT

The capability of an in-view dedicated textual display to be automatically updated upon receipt of new information.

42. DISPLAY TEXT BY OPERATOR ACTION

The capability to display on a terminal, textual information.

43. PROCESS TEXT IN SCRATCH PAD

The capability to assemble, compile, interpret, generate, sort, manipulate, etc., text data and information at a terminal without the work being accessible by all TCO centers. After using his "local" scratch pad to accomplish his work, the operator can then enter the data into the main data base where it becomes accessible to all.

44. SCROLL/PAGE TEXT

The capability to read text information on the terminal screen by either rolling it from top to bottom or bottom to top, or by looking at a section at a time, like turning pages, depending upon your own preference.

45. CLOSE CONTROL TEXT

The capability to designate by cursor or "hook" an element of a text display and then perform other operations on the system, all of which will be in relation to the designated element, e.g., further queries.

46. INTRA CENTER DISSEMINATION OF TEXT/GRAPHICS

The capability to transfer display information between terminals in the same center.

47. DISPLAY IN CONFERENCE MODE

The capability of users at different centers to use voice communications and identical TCO displays (usually graphic) for a conference. As any user modifies or "points" on the display, the modification or "pointer" is displayed at all the terminals linked in the conference mode.

48. INTRA SYSTEM DISSEMINATION OF TEXT/GRAPHICS

The capability to display text or graphics which is on one terminal in one center on any terminal located in another center within the TCO System. Such dissemination may be specifically designated by the operator, as in the case of a distribution list addressee, or as a general update of the data base.

49. INTER SYSTEM DISSEMINATION OF TEXT/GRAPHICS

The capability to exchange data with other systems so that information identical to what was on the sender's terminal can be displayed on the recipient's terminal.

50. HIGH PRECEDENCE MESSAGE ALERT

The capability to warn the operator by visible (blinking light, etc.) or audible alert that a message exceeding a threshold of precedence he has set has arrived and has not yet been looked at.

51. CALL BACK UPON RECEIPT OF REQUESTED DATA ALERT

The capability to alert an operator when the answer to a one-time request (as opposed to an SRI discussed in #16 and #22) has become available in the system.

52. LOCAL PARAMETERS ALERT

The capability of an operator to set thresholds of values for certain quantitative data which, if exceeded, will trigger alerts; this includes tickler/alarm clock alerts, as well as unit status information.

53. TASK IDENTIFICATION/SCROLL QUEUE

The capability to scroll through those items which have been stored in the action queue (an automated "Pending" basket) and select one to work on.

54. RUN COMBAT SIMULATION

The capability to wargame a proposed course of action in a manner similar to what is done on the TWSEAS map maneuver controller.

55. RUN SIMULATION BY SNAPSHOTS

The capability to select any moment in time during the simulation discussed in #54 and display the situation at that moment.

56. ENTER/DELETE A/C SORT RATE PARAMETER

The capability to set the appropriate sortie rate value for the computer to use in performing flight scheduling algorithms.

57. ENTER/DELETE MISSION REQUIREMENTS PARAMETER

The capability to specify mission requirements such as Time on Target, Target location, etc., for the computer to use in performing flight scheduling algorithms.

58. ENTER/DELETE A/C LOCATIONS PARAMETER

The capability to enter the locations (bases) of aircraft available for scheduling for the computer to use in flight scheduling algorithms.

59. ENTER/DELETE A/C CHARACTER PARAMETER

The capability to enter/delete the characteristics (range, ceiling, speed, payload, etc.) of aircraft available for scheduling for the computer to use in flight scheduling algorithms.

60. ENTER/DELETE UNIT MOVEMENT PARAMETER

The capability to enter a movement rate (e.g., 2.5 mph, subject to terrain) for a unit to be represented in the combat simulation discussed in #54.

61. CALCULATE COMBAT POWER RATIO

The capability of the system to compute relative combat power of opposing units when it knows the weapons, dispositions, etc., of each unit.

62. CALCULATE TIME/DISTANCE RATIO

The capability to predict the time needed to travel a given distance over given terrain by a given means.

63. CALCULATE FUEL CONSUMPTION

The capability to predict the point at which A/C or ground vehicles will require fuel or how much fuel will be required by A/C or ground vehicles to execute a given mission.

64. CALCULATE CASUALTY ESTIMATES

The capability to produce casualty estimates based on combat power ratios of units in a combat simulation.

65. CALCULATE A/C TO MISSION ASSIGNMENT

The capability to recommend allocation of A/C to missions based on parameters entered as addressed in #56-#59, #62 and #63.

66. CALCULATE ORDNANCE FOR TARGET/MISSION

The capability to perform "weaponeering" for aviation missions by analyzing target characteristics and available weapon characteristics and matching the two.

67. CALCULATE/DISPLAY SENSOR PLACEMENT AND COVERAGE

The capability to analyze terrain data and recommend locations suitable for various types of unattended ground sensors; the capability to display the coverage which would be provided (e.g., circles/fans) by a proposed placement of the sensors.

68. CALCULATE/DISPLAY MINEFIELD COVERAGE

The capability to calculate the number and type of mines required to lay a minefield of a desired density over a given area; the capability to display the location of minefields and the pattern of mines in the field (safe lanes, etc.)

69. PERFORM TRACK MANAGEMENT

The capability to take input from real-time trackers (specifically PLRS, radar and manually entered reports of position location) and assign appropriate military identifying symbology to the tracks while displaying them at the correct location on a screen over a map background.

70. AUTOMATIC GENERATION OF TABLES

The capability to perform computations to produce a table, or update tables, as specifically illustrated by the development of the Landing Plan. In the case of the Landing Plan, once the "Landing serial file" format is filled out by planners at each echelon, TCO produces the doctrinal Landing Plan Tables i.e., Serial Assignment Table, Assault Schedule, etc., on demand. A similar capability is used in the development of the Air Combat Element Flight Schedule.

71. PERFORM REASONABLENESS CHECKS

The capability to check human inputs against allowable values in appropriate cases and to alert the operator when incorrect values have been entered. For example, in preparing a landing plan, if more personnel are assigned to an LVTP7 than it can carry or more helicopters are assigned than are available, the system will alert the operator.

72. OPERATE IN LOCAL MODE

The capability of a TCO center to operate independent of digital radio communications with the rest of the system, as in the case during movement to the objective area aboard ship. While in local mode, each center is capable of displaying or providing hardcopy printouts of data contained within its own computer's portion of the data base and accepting updates to that data, via operator inputs either manually or by machine readable medium.

73. INTERFACE PLRS

The capability to display friendly unit location information provided by the Position Location Reporting System (PLRS) by exchanging data with PLRS without human intervention.

74. INTERFACE MIFASS

The capability to exchange data with the MIFASS in order to display fire and air support information or provide maneuver information to fire support personnel.

75. INTERFACE TAOC-85

The capability to exchange data with the Tactical Air Operations Central-85 such as aircraft locations, alerts, etc.

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INFORMATION COLLECTION AND CORRELATION DECISION SUPPORT SYSTEM --ETC(U)
AUG 80 A CROLOTTE, J SALEH N00014-78-C-0495
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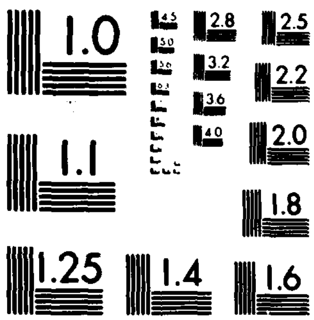

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76. INTERFACE MIPS

The capability to exchange data with the Marine Corps Integrated Personnel System; this enables the TCO user to display personnel status, unit readiness information, and so on.

77. INTERFACE MILOGS

The capability to exchange data with the Marine Corps Integrated Logistics Support System. This enables the TCO user to display logistic status and readiness information.

78. INTERFACE MAGIS

The capability to exchange intelligence information with the Marine Corps Air-Ground Intelligence System. Examples of such information include: spot reports, INTSUMS, area studies, intelligence analysis information, EEI's.

79. INTERFACE EXTERNAL SYSTEM

The capability of TCO to exchange data with systems external to the MAGTF in conformance with Joint Interoperability for Tactical Command and Control Systems (JINTACCS) standards. Examples of such systems would be Integrated Tactical Amphibious Warfare Data System - Navy (ITAWDS), Navy Tactical Data Systems (NTDS), Tactical Operations System - U.S. Army (TOS), and so on.

80. OPERATE WITH PORTION DATA BASE

The capability of a TCO center and or the system to continue to operate although a portion of the data base has become inoperable, or unavailable as during displacement.

81. OPERATE WITH PORTION EQUIPMENT SUITE

The capability of a TCO center to continue to operate in a degraded mode when some equipment has been rendered inoperable, or when some equipment is unavailable during displacement.

82. LOAD/RELOAD FROM AUXILIARY MEMORY

The capability of a TCO center to divide its equipment suite into an 'A' and 'B' command group configuration. Selected programs would be stored off-line and designated critical functions would be performed on both groups of equipment until the center was re-established, as in the case of displacement ashore.

83. DECENTRALIZATION OF OPERATOR FUNCTIONS

The capability of some of a TCO center's functions to be temporarily assigned to another center during degraded operations.

84. ASSUMPTION OF ADDITIONAL PROCESSING FUNCTIONS

The capability of a TCO center to perform functions temporarily on behalf of another degraded center.

85. SHIFT TCO FUNCTIONS TO MIFASS EQUIPMENT

The capability of TCO functions to be performed on MIFASS equipment during degraded mode operations or displacement. The Commander may designate MIFASS equipment or capabilities to perform functions normally assigned to TCO. TCO software will be operational on MIFASS equipment.

86. WORD PROCESSING

The capability of the operator to use several automated features beyond the typical automated typewriter to aid in composition and editing of documents, examples are:

(1) paragraph/sentence manipulation, additions, and deletions
(2) word/number searching
(3) auto advance/backup
auto/capitalization, etc.,

87. DISPLAY INFORMATION FOR GROUP VIEWING

The capability to create a large visual display of either graphics and/or text suitable for viewing by a group of people simultaneously.

88. PROCESS GRAPHICS OFF LINE

The capability to draw a graphical overlay while not directly linked up to the computer data base, i.e., not at an interactive terminal. Upon completion of the overlay the operator can, by a switch action, update the data base.

89. SELECT/STORE NAMED DISPLAY

The capability of the operator to compose a graphic or textual display, name it, store it and retrieve it later.

90. DELETE TEXT/GRAPHICS

The capability to purge text and graphic data from the data base.

91. CALCULATE LINE OF SIGHT

The capability to identify any two points on a graphic display and have the system tell you if line of sight exists between them.

92. CALCULATE MATERIEL REQUIREMENTS

The capability to allow the planner to compute such items as ammunition expenditure, POL consumption, and anticipated materiel replacement for items such as weapons, vehicles, and equipment.

APPENDIX D

SURFACE OF THE α-LEVEL CONFIDENCE ELLIPSE

APPENDIX D

In this appendix a formula is derived for the surface of the α-level confidence ellipse associated with a two dimensional normal distribution. Consider

$$f(\underline{x}) = \frac{1}{2\pi|\Sigma|^{\frac{1}{2}}} e^{-\frac{1}{2}\underline{x}'\Sigma^{-1}\underline{x}} \quad \text{(2-dimensional normal distribution p.d.f.)}$$

Let E_α be the α-level confidence ellipse which is such that:

$$\alpha = \iint_{E_\alpha} f(\underline{x})d\underline{x}$$

E_α is also defined by:

$$E_\alpha = \{\underline{x}|\underline{x}'\Sigma^{-1}\underline{x} \leq C\}$$

Where C is a function of α to be computed.

Since it is assumed that Σ is regular, there exists a diagonal matrix

$$D = \begin{pmatrix} a^2 & o \\ o & b^2 \end{pmatrix}$$

and an orthogonal matrix P such that:

$$\Sigma = PDP^{-1}$$

and

$$\underline{x} = P\underline{y}$$

Thus,

$$d\underline{x} = |P|d\underline{y} = d\underline{y}$$

and

$$\alpha = \iint_{E_\alpha} f(\underline{x})d\underline{x} = \frac{1}{2\pi|\Sigma|^{\frac{1}{2}}} \iint_{E'_\alpha} e^{-\frac{1}{2}\underline{y}'D^{-1}\underline{y}} d\underline{y}$$

where

$$E'_\alpha = \{\underline{y}|\underline{y}'D^{-1}\underline{y} \leq C\} = \{\underline{y}|\frac{y_1^2}{a^2} + \frac{y_2^2}{b^2} \leq C\}$$

Thus,

$$\alpha = \frac{1}{2\pi|\Sigma|^{\frac{1}{2}}} \int_0^{a\sqrt{C}} e^{-\frac{1}{2}y_1^2/a^2} dy_1 \int_0^{b\sqrt{C}} e^{-\frac{1}{2}y_2^2/b^2} dy_2.$$

Noting that $|\Sigma| = |D| = a^2b^2$, and performing the change of variables $u_1 = y_1/a \quad u_2 = y_2/b$ yields

$$\alpha = \frac{1}{2\pi}\left(\int_0^{\sqrt{C}} e^{-x^2/2}dx\right)^2 = [\mathrm{erf}(\sqrt{C})]^2$$

where erf(u) is defined by:

$$\mathrm{erf}(u) = \frac{1}{\sqrt{2\pi}} \int_0^u e^{-x^2/2}dx$$

Consequently, the surface S_α of the α-level confidence ellipse is given by:

$$S_\alpha = \pi abC = \pi[\mathrm{erf}^{-1}(\sqrt{\alpha})]^2|\Sigma|$$

S_α is consequently proportional to the determinant of Σ.

APPENDIX E

ANALYSIS OF ICC SYSTEM BEHAVIOR

APPENDIX E

This appendix proposes a model for the analysis of the ICC system behavior. The model selected is graphically portrayed in Figure E-1. It is, of course, a queuing model since the overall system can be viewed as a queue. It is assumed that local correlation being the same at MAF, division and wing level, these three processes can be viewed similarly. Local correlation is viewed as a birth-death process: sensor reports arrive according to a Poisson process with parameter λ and the correlation operator acts as an exponential server. The interdeparture time is then a Poisson process of parameter λ (Burke's theorem). It is logical to assume that the rates of arrival of sensor messages to MAF, wing and division could be different. Thus, the various arrival rates have been indexed by the level which serves them, i.e., λ_M, λ_D and λ_W.

Proposed modifications thus arrive to the track modification queue according to a Poisson process of parameter $\lambda = \lambda_M + \lambda_D + \lambda_W$. Global correlation can be modeled as a birth-death process where the service time, when there are n modifications in the queue, is a function of n. This is due to the fact that M_f, the modification in front of the track modifications queue, must be compared to all the modifications which are in the queue. If no conflict is found the processing time is negligible and we do not expect more than a few conflicts (for instance, 3) no matter how large the number in the queue is. Thus, we can assume that μ_n = constant = μ for $n \geq 3$, for instance.

Using the state-transition-rate diagram depicted in Figure E-2, we can immediately solve $\{P_k\}$, the distribution of the number in the system:

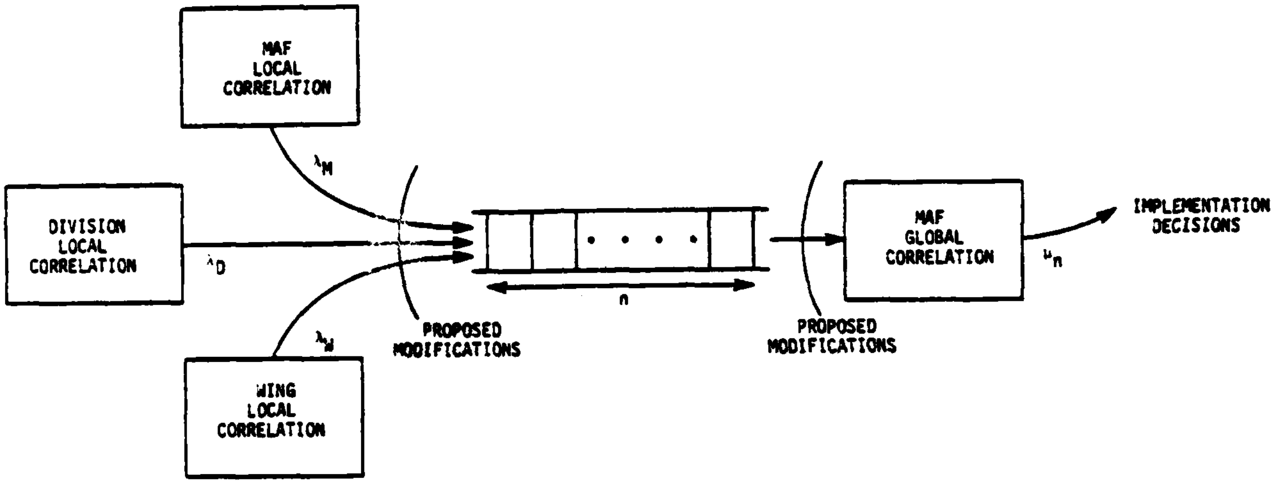

FIGURE E-1.
QUEUING MODEL FOR ICC DECISION SUPPORT SYSTEM

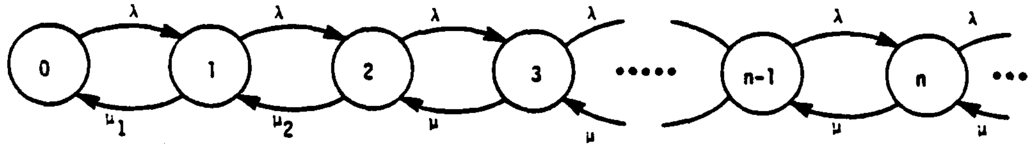

FIGURE E-2.
STATE-TRANSITION-RATE DIAGRAM FOR
ICC QUEUING PROCESS

$$P_k = \begin{cases} P_o \dfrac{\lambda}{\mu_1} & k = 1 \\ P_o \dfrac{\lambda^2}{\mu_1 \mu_2} & k = 2 \\ P_o \dfrac{\lambda^k}{\mu_1 \mu_2 \mu^{k-2}} & k \geq 3 \end{cases}$$

$$F(z) = \sum_{k=0}^{\infty} P_k z^k = P_o \left[1 + \frac{\lambda}{\mu_1} z + \frac{\lambda^2}{\mu_1 \mu_2} z^2 \left(1 + \frac{\lambda}{\mu} z + \ldots\right)\right]$$

$$= P_o \left[1 + \frac{\lambda}{\mu_1} z + \frac{\lambda^2}{\mu_1 \mu_2} z^2 \frac{1}{1 - \frac{\lambda}{\mu} z}\right] \quad (1)$$

if $\frac{\lambda}{\mu} < 1$ (ergodicity condition)

Letting $z = 1$ in (1) will yield P_o using $F(1) = 1$. The average number in the system will be computed as $\overline{N} = F'(1)$. Thus, $\overline{N}$ can easily be obtained as a function of the system parameters λ, μ_1, μ_2 and μ. The average time in the system, T, will then be computed using Little's result $\overline{N} = \lambda T$. Thus, T can be obtained in function of the system parameters, hence, the system can be analyzed with a few realistic assumptions. It should, however, be realized that only simulations could actually yield the modelization of μ_n. Once this is done, the expected behavior of the system can easily be predicted.

APPENDIX F

APPENDIX F

This appendix describes a decision-aid concept for situation assessment using Bayesian classification techniques. The application of the matching principles developed during the first-year program to the MAB decision task situation assessment yielded the following desirable decision-aid features: (1) interactive, (2) real-time, (3) flexible, and (4) alert capability. Implementation of these features will result in a maximum suitability score.

The decision aid concept development was guided by an analysis of the decision task situation assessment during control of ground operations. Marine Corps experts with experience in operations and intelligence based at Camp Pendleton were consulted. Doctrinal publication FMFM 2-1 (Intelligence) was also used as a basis for the analysis.

Figure F-1 portrays an overview of the decision aid concept. In this model of situation assessment, information is received by the G2 located in the intelligence station of the Intelligence Center. Upon receipt of this information, events are detected and taken into account by the decision aid which issues the latest assessment of the situation and an updating of the priors. The G2/Decision aid interaction takes place within the doctrinal framework of Essential Elements of Information (EEI's) which correspond to possible enemy courses of action and Indications which correspond to events. Examples of EEI's and Indications are presented in Table F-1. This doctrinal framework was also used by Spall (1979) for the purpose of situation assessment; his method of approach, however, was different. The resulting decision aid concept has the following major attributes:

(1) Is adaptive.
(2) Provides an aiding framework to both G2 and commander.

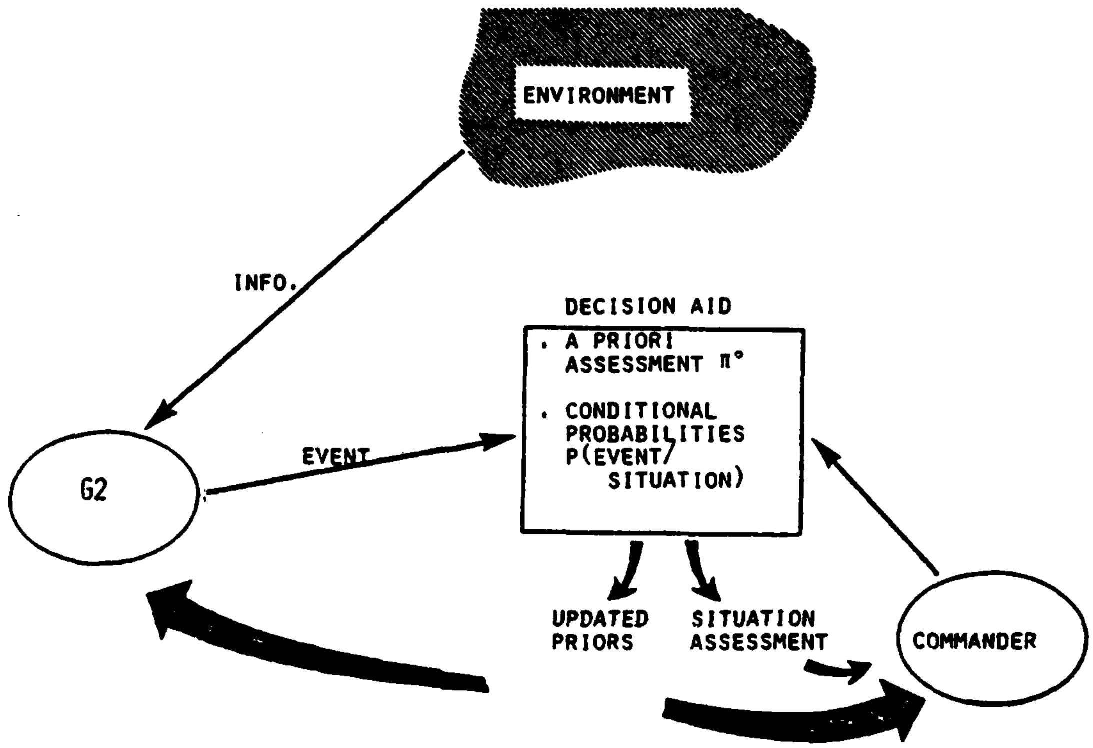

FIGURE F-1.
DECISION AID CONCEPT OVERVIEW

TABLE F-1

EXAMPLE OF AN MAF INTELLIGENCE COLLECTION WORKSHEET (ADAPTED FROM FMFM 2-1)

EEI	INDICATIONS	SPECIFIC INFO TO BE SOUGHT
DETERMINE IF THE ENEMY WILL DEFEND LANDING BEACHES AGAINST ASSAULT.	A. LOCATION AND STRENGTH OF (1) INFANTRY UNITS (2) ARTILLERY UNITS (3) TANK UNITS (4) ANTI-TANK UNITS	(1) REPORT LOCATION, IDENTIFICATION, STRENGTH, ACTIVITIES OF ENEMY IN VICINITY OF LANDING BEACHES.
		(2) . . .
	B. EXTENSIVE PREPARATION OF FIELD FORTIFICATIONS	(6) REPORT PREPARATION OF FIELD FORTIFICATIONS IN THE VICINITY OF LANDING BEACHES . . .
	C. DUMPING AMMUNITION AND ENGINEER SUPPLIES AND EQUIPMENT	(8) REPORT DUMPING OF AMMUNITION AND ENGINEER SUPPLIES AND EQUIPMENT IN THE VICINITY OF THE LANDING BEACHES . . .

(3) Establishes a communication link between G2 and commander facilitating commander's access to information in real-time.

(4) Generates timely information by enhancing speed of information aggregation process.

(5) Provides a structured data base to incorporate information relevant to mission accomplishment.

(6) Exploits human ability to assess conditional probabilities accurately and provides aiding for updating, thus overcoming conservatism.

(7) Provides a framework for incorporation of other aiding techniques into the system (e.g., value of information for collection plan).

This decision aid concept will be refined and described in a forthcoming paper.