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INFORMATION EXCHANGE ARCHITECTURE FOR INTEGRATING UNMANNED VEHICLES INTO MARITIME MISSIONS

by

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June 2004

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The United States Navy is committed to implementing and using unmanned vehicles (UVs). Battlegroups have deployed and will continue to deploy with UVs because of their potential effectiveness. However, current UV doctrine does not set forth a standardized set of techniques and procedures for UV information exchange during maritime missions. The focus of this study is to analyze the structure of information flow for unmanned systems and suggest an exchange architecture to successfully inform and build decision maker understanding based on data from UVs in support of these missions. Through analysis of the knowledge-information-data (KID) model, and definition of high-level functions and tasks created from fleet input, this thesis develops an IDEF0 and PERT representation. It outlines tasks and roles for successfully accomplishing information exchange from UV payload sensors to tactical decision makers. The study concludes with suggested measures of effectiveness and performance to determine the strength and validity of the architecture.

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INFORMATION EXCHANGE ARCHITECTURE FOR INTEGRATING UNMANNED VEHICLES INTO MARITIME MISSIONS

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ABSTRACT

The United States Navy is committed to implementing and using unmanned vehicles (UVs). Battlegroups have deployed and will continue to deploy with UVs because of their potential effectiveness. However, current UV doctrine does not set forth a standardized set of techniques and procedures for UV information exchange during maritime missions. The focus of this study is to analyze the structure of information flow for unmanned systems and suggest an exchange architecture to successfully inform and build decision maker understanding based on data from UVs in support of these missions. Through analysis of the knowledge-information-data (KID) model, and definition of high-level functions and tasks created from fleet input, this thesis develops an IDEF0 and PERT representation. It outlines tasks and roles for successfully accomplishing information exchange from UV payload sensors to tactical decision makers. The study concludes with suggested measures of effectiveness and performance to determine the strength and validity of the architecture.

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TABLE OF CONTENTS

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LIST OF FIGURES

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LIST OF TABLES

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I. INTEGRATING UNMANNED VEHICLES INTO MARITIME MISSIONS

A. INTRODUCTION

The United States Navy is committed to implementing and using unmanned vehicles (UVs). The Navy sees UVs as "integral components of future tactical formations" (OSD 2002). Reasons for the transformation from manned craft to unmanned platforms include technological improvements, potential cost reductions, and manpower risk mitigation. With the current reduction in force structure and personnel, there is a necessity to pursue alternative solutions for accomplishing missions effectively (OSD 2002).

The greatest factor in increasing UV use is that technology enables their advanced levels of performance and capability. Unmanned technology "offers profound opportunities to transform the manner in which this country conducts a wide array of military and military support operations" (OSD 2002). It is no longer a question of when UVs will be a part of the mission, but how well they integrate in order to ensure successful Navy and joint missions (OSD 2002).

Some UVs provide real-time or near real-time high-resolution imagery which has improved battlespace responsiveness, enabling adaptive decision-making (Cordesman 2003). Battlegroups deploy with UVs because of their potential effectiveness. According to the CNO, there is no reason for this to change in the near future. In his 2004 Guidance, the CNO states, "if we are to extend our current advantage, we must capitalize on revolutions in information, stealth, and precision technologies and develop new warfare concepts that will lead us not just towards jointness, but true interdependence."

Relative to using helicopters and other manned aircraft, UVs have prospects for being cost and mission effective in many traditional mission areas (OSD 2002). The tactical unmanned surface vehicle (USV) is near the top of the Navy's spending priorities, ahead of some prominent shipbuilding programs such as DD(X) and LPD 17

(Brown 2003). There are expectations throughout the Navy's senior leadership that unmanned platforms will dominate many war fighting roles.

B. INTEGRATION FOR MARITIME USE

UVs will free manned aircraft to execute other missions, and will conduct reconnaissance previously inaccessible or impractical for manned platforms. UVs are preferred in high-threat or heavily defended areas where high-cost, manned system survivability is at risk. For example, UAVs can provide visual identification of surface vessels during maritime interdiction operations (MIO) in potentially hostile scenarios. With future conflicts taking place in littoral regions, against adversaries who possess increasingly asymmetric weapon systems, UVs provide more options for readiness in combating over-the-horizon threats (Gansler 1998).

UVs proved effective for overland surveillance, reconnaissance, and targeting mission during recent conflicts. UAVs provided near real-time surveillance of the battlefields in Kosovo, Afghanistan, and Iraq. In Yemen, an armed UAV destroyed a carload of suspected terrorists (Thompson 2004). Overland UV missions have matured in their support of the ground commander for battlespace success.

However, current UV doctrine does not set forth a standardized set of techniques and procedures for UV information exchange during maritime missions. These missions range from building and maintaining a Recognized Maritime Picture (RMP), to Force Protection and Maritime Interdiction Operations (MIO). These missions rely heavily on gathered intelligence and information. Tactical commanders, as well as high-level operational commanders who oversee the units, demand timely, complete, and accurate information. The focus of this study is to analyze the structure of information flow for unmanned systems and suggest an exchange architecture to successfully inform and build decision maker understanding based on data from UVs in support of these missions.

Maritime missions have been accomplished in the past using legacy systems such as helicopters, shipboard sensors, radar, space-based systems, and manned station lookouts. Over time, tactics, techniques, and procedures provided structure for integrating these systems into a ship's Combat Information Center (CIC) operations. Current doctrine for these assets supports information exchange with the manned sensor and the unit or high-level commanders. This exchange features collaboration among humans to resolve data for evaluation and dissemination. The key for success in integrating UVs is to do the same; provide information flow to facilitate action by decision makers.

C. INFORMATION EXCHANGE

Distributed sensors from UVs transmit data across several networks in order to reach decision makers. Tactical information exchange requires timely interpretation, analysis, and reporting. The distributed unmanned sensors provide data to the operator randomly. As the first human contact with the data, the operator ensures that the data received can support actionable information.

A typical information exchange model features sensors, communications, operators, and decision makers. A description of the perceived transmission of data from an unmanned asset in a shipboard setting is below and displayed in Figure 1:

- The deployed UV, equipped with sensors, sends electrical signals on a contact of interest (COI) to a shipboard operator through a network.
- The mission payload operator in the ship receives the signals via interface and interprets the data. The operator then fills database entries about the contact (course, speed, heading, etc.).
- The local unit-level commander fields database entries, through intelligence evaluation, and sends a report to high-level commanders. The database entries then undergo analysis to develop a RMP.
- A communication link is available for the high-level commander to provide feedback to notify the local unit if more data is required and to advise a course of action.

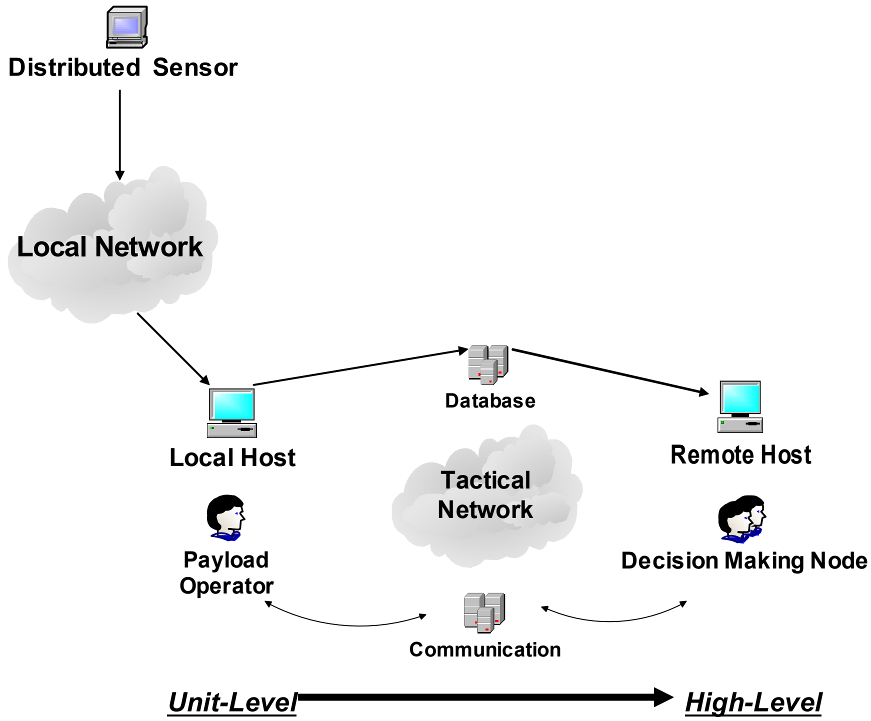

Figure 1. Perceived Data Transmission Using Distributed Sensors

Figure 1 suggests the flow does not occur on its own. In general, a consideration of the procedures underlying integration of distributed sensor data into the RMP requires further review. Critical to this issue is how information propagates through the system from remote distributed sensor, to operator, to high-level commanders (Gottfried & Woolsey 2004). This thesis decomposes the interfaces, integration, and interpretation of UV data for maritime tactical decision-making.

The raw data itself cannot facilitate action. Processing transforms the data into information. In addition, the acquired information undergoes analysis for action or decision. The problem lies in understanding where data becomes information and where information becomes operational knowledge for high-level commander use. The study addresses this issue in order to facilitate UV use for maritime missions.

D. DEFINING PROCESS AND PROCEDURE

In the last 25 years, the military has focused more on technological improvement than process and organizational improvement (Boger, personal communication, April 1, 2004). However, procedure and organizational improvements redefine the structure of the entire system. The new technology has to consider the organization, people, procedures, culture, and other key factors for proper integration (Nissen 2002). Many times organizations have tried to throw technology at a problem, without a change in procedure, only to find that the problem still exists. Thus, for an organization to be successful with new technology, procedures must change accordingly.

This study focuses on building an accurate surface picture using UVs in a maritime setting through examination of information propagation. The results of this study define architecture for maritime use and an initial set of procedures for maritime fleet integration. Chapter II outlines a typical maritime mission structure and presents an adapted version of the knowledge-information-data (KID) model, including the relationship between KID and distributed sensors. Chapter II also discusses the layers comprising the information understanding flow path. Chapter III unravels the elements of system architecture and develops an initial model for analysis.

Discussion and interviews with operators and fleet staff assisted in revising the model. The results produce a set of high-level functions and the roles to support those functions along with associated diagrams. Chapter III also examines the relationship between high-level functions, the adapted KID model, and understanding layers. Chapter IV presents a discussion of measures of effectiveness and performance to determine the strength and validity of the architecture, along with improving the process through experimentation and observation. Chapter V concludes with applying the information exchange architecture, proposals for test and evaluation, insights, and future considerations for integration.

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II. UNDERSTANDING/INFORMATION FLOW

A. DECISION MAKING

Making a decision is a human task. As long as decision makers are accountable for naval operations, automation cannot supplant the roles and responsibilities of personnel. There are decision support systems to provide the decision maker appropriate options, but it is ultimately a human choice. To make an informed decision, there is a need for timely and available data, information, and knowledge (Nissen 2002).

However, advances in technology to assist decision-making, such as computer-assisted data fusion, have not progressed as rapidly as information gathering technology. The commander's ability to process and act on the increased volume of information depends on many factors including experience, stress level, cognitive processes, and other human factors (Nissen, personal communication, March 26, 2004). Human factors directly affect the decision at the organizational level. These include uncertainty management, mental simulation, situation awareness, attention management, problem detection, and option generation (Miller & Shattuck 2004). Therefore, with the introduction of a new system, in this era of technological advancement, it is critical that the proper command and control procedures evolve.

B. UV MARITIME SCENARIO

This study uses the following scenario, which involves UVs in a tactical maritime setting:

> A deployed surface action group (SAG) is conducting maritime interdiction operations (MIO) within a focused area of responsibility (AOR). This area includes multiple contacts, most of which are neutral and some classified as critical contacts of interest (CCOI). The goal of the SAG is to process as many contacts as possible. This includes identification and maintaining understanding of the CCOI's actions.
>
> The SAG identifies areas of interest, sea routes, and potential threat profiles and accumulates contact detection and locating data. Amplifying information, such as identity or intent, is available via a combination of shipboard and UV based visual, infrared (IR), signals intelligence (SIGINT), synthetic aperture radar (SAR), and acoustic or laser-based sensors. The SAG relays data collected from the sensors to the joint force

> maritime component commander (JFMCC) staff, which processes the contact information to generate a recognized maritime picture (RMP) to support MIO.

The scenario provides a basic maritime framework to analyze information flow. In observing the actions in the scenario, there are potential disconnects where information from the UV is transmitted to the SAG and JFMCC. The elements and actions taking place in between the UV and the JFMCC require definition. How does the data provided by the mission payload operator become informed data, or information, and how does this information support knowledgeable decision-making by the SAG and JFMCC?

C. UNDERSTANDING FLOW (NISSEN 2002)

Many models are available for information flow and decision making problems. However, the problem is mapping an unmanned element to a generic model. From analysis, there is generation of a new set of information collection procedures and dissemination paths. A new roadmap ensures timely transmission is made to local (SAG) and high-level (JFMCC) commanders.

The primary effort of this research is to develop a roadmap tracing the understanding flow (knowledge-information-data). The major understanding flow components are: the physical layer (network to which the unmanned vehicle is attached), the interface layer (which engages and transmits the incoming electrical signals provided by the distributed sensor), the cognitive layer (reception and interpretation of the signals), and the social layer (which facilitates action with the newly acquired information) (Nissen, personal communication, March 26, 2004, and Alberts & Hayes 2003). The following are Alberts and Hayes' (2003) layers incorporating the UV maritime scenario.

Physical-The physical layer consists of the UV, onboard sensors, and surface and airborne remote nodes. The physical layer encompasses the Open System Interconnection (OSI) 7-layer model for networks (Nissen, personal communication, March 26, 2004).

Interface-The interface layer is composed of the human-machine interface where the mission payload operator receives the electrical signals. This is the first contact between the signals and the human who filters the signals as data or noise. This layer includes all software the operator may use in receiving and transmitting data within the AOR (Alberts & Hayes 2003).

Cognitive-The cognitive layer is composed of the mental activity that takes place for the filtered data to make its way towards decision makers. This is where the payload operator interprets the data based on a number of factors (experience, stress level/work load, human factors etc.), and transmits the refined data to SAG/JFMCC levels (Alberts & Hayes 2003).

Social-The social layer incorporates the process of receiving and applying data based on understanding. This is the point where data becomes information. With the newly acquired information, the SAG/JFMCC use inherent operational skills and organizational learning techniques to formulate action plans (Alberts & Hayes 2003).

D. KNOWLEDGE FLOW HIERARCHY

For each layer, there is corresponding data, information, or knowledge defining it. The information exchange architecture improves the quality of data throughout the system to provide knowledge for decision makers. The adapted knowledge-information-data (KID) model with military conceptual mapping (Figure 2) supports this flow in an organization (Nissen 2002).

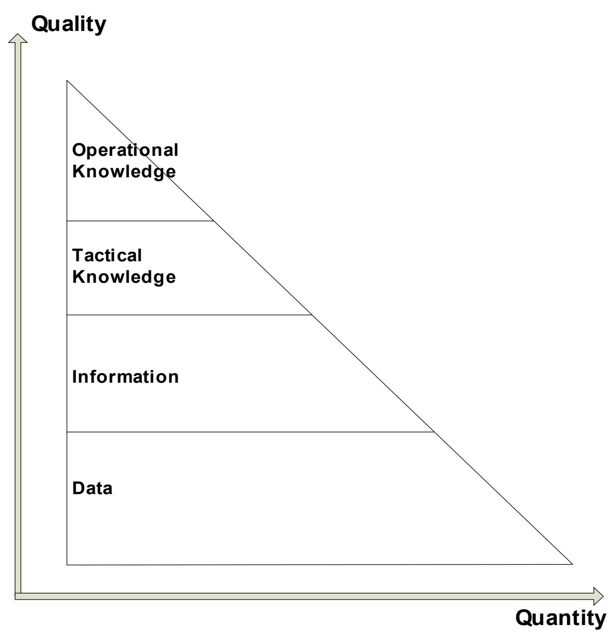

Figure 2. Adapted KID Model with Military Conceptual Mapping (After: Nissen 2002)

The broad base of the triangle represents the amount of data available to that level relative to other levels. Quantity, however, does not translate to quality. As an organization moves further up the y-axis, it comes closer to taking appropriate action (e.g. making action decisions) (Nissen 2002).

Figure 2 addresses the importance of these factors with respect to quality and quantity. It represents the hierarchical nature of understanding flow: data is required to produce information, which in turn produces knowledge, and moves the organization in the direction of an action plan (Nissen 2002). This directly relates to UV sensor support in maritime missions, as depicted in Figure 3, which represents a tactical application of the adapted KID model. This figure shows a natural progression of the data required during naval missions, such as MIO.

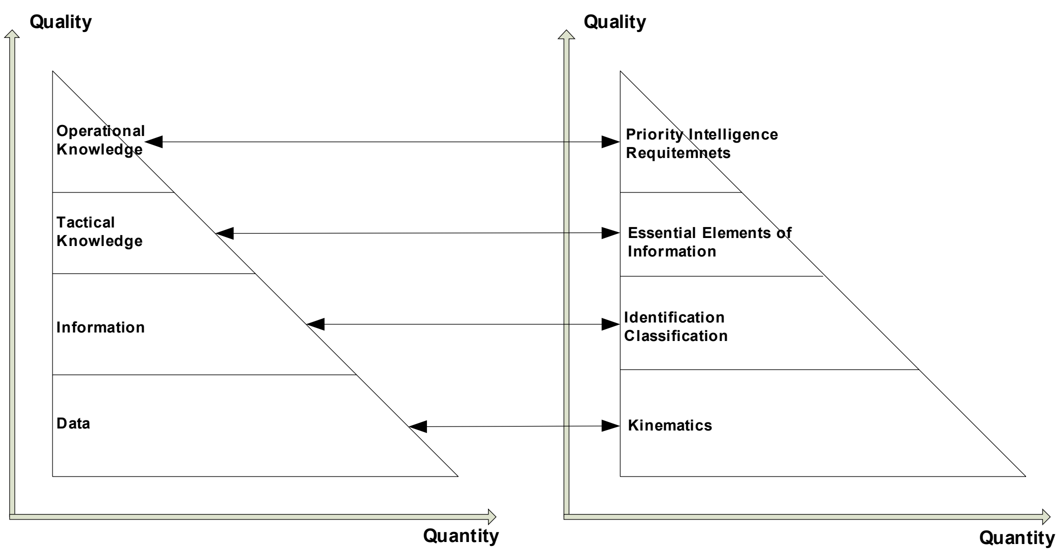

Figure 3. Adapted KID Model with Corresponding Maritime Information Model

In order to move up a level in Figure 3, the level below must be complete and each successive level containing enough data below to sustain it. Operationally, with the acquisition of data from distributed sensors, the quality of information received by high-level decision makers depends on the quality and quantity of the data collected locally by distributed UV sensors, which is processed by operators, analysts, and unit-level decision makers.

E. DATA MANAGEMENT

In a tactical scenario, analyzing the data flow from the UV requires definition of data and the context. Assuming the mission payload operator is aware of what to look for when monitoring the electrical signals sent by the UV, the operator establishes a hypothesis test. For example, by comparing the evidence for or against the presence or identity of a contact, each new data signal contributes to a judgment in the cognitive layer. For MIO, the mission payload operator would decide whether there are CCOI indications in the AOR. The operator either rejects or fails to reject this null hypothesis based on received data.

Testing this process begins with each new contact. The larger the number of contacts recorded by the payload operator, the greater the amount of data accumulated and the more powerful the decision regarding each hypothesis test. The operator's inherent knowledge of the situation, as well as the acquired data from the UVs, accumulates, correlates, and combines to form a single record for complete and timely assessment of the situation (Cristi 2003). Figure 4 depicts data flow from sensors to operators and decision makers, through respective layers and interfaces.

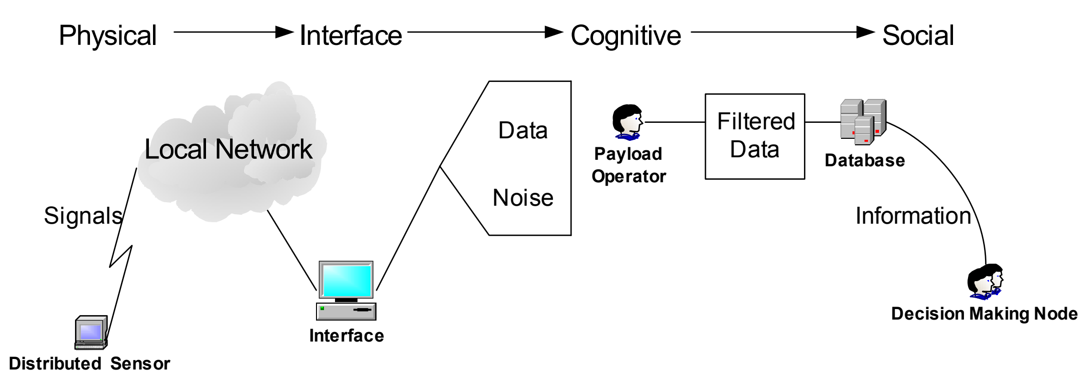

Figure 4. Understanding Flow Path for Transmission of Signals to Decision Maker

F. INFORMATION/KNOWLEDGE MANAGEMENT

Decision makers process and manage accumulated data, where it becomes information. The social layer handles information in an operational environment with "experienced people who are engaged in goal directed behavior" (Miller & Shattuck 2004). In the MIO scenario, this involves the JFMCC staff receiving signals of a potential COI in the AOR, and processing the contact and amplifying information to generate a RMP. Whether by an individual, such as the Tactical Action Officer (TAO), or a group of decision makers, such as the JFMCC staff, the social layer generates a complete analysis of the information based on the individuals viewing it.

Once there is a complete understanding of the information, based on the cognizance of the decision makers, the information has reached the level of knowledge. It is at the knowledge level where action may take place depending on the context and mission. In the maritime scenario, the TAO or JFMCC staff can render a decision based on the information from the RMP and take action based upon the acquired knowledge.

III. INFORMATION EXCHANGE ARCHITECTURE

A. MODELING INTRODUCTION

Abstract views of the information exchange process assist in developing an architecture framework. Models in this thesis represent selected aspects of the structure, behavior, and operation associated with cooperative search and identification. In particular, the models demonstrate the activities occurring in the Chapter II UV maritime scenario.

In the case of an information system, each activity receives data as input and produce information/knowledge as output. The activities are sequential and based on the initial conditions of the system. However, many activities occur concurrently and asynchronously, as is the case with tactical systems (Levis & Wagenhals 2000).

B. SYSTEM ARCHITECTURE

The intent of the UV information exchange architecture is to build a method according to the requirements of the user. The current maritime architecture features manned platforms that send data by means of electrical signals, including voice reporting. A manned platform's personnel analyze gathered information. For example, in a helicopter, the aircrew collaborates with the shipboard air controller to process data. However, with current tactical unmanned platforms, the information processing does not begin until the signals arrive at the ship. Therefore, there is a requirement to develop a new set of techniques, and procedures for this information exchange.

Developing an architecture means conceptualizing the client's needs and building a unique concept as a set of abstract views or models. In the MIO scenario, the requirement is to deliver timely and accurate information collected via unmanned distributed sensors to the JFMCC. The model should demonstrate information flow from remote sensor to decision maker, while the architecture specifies how to effect this process.

C. INITIAL APPROACH TO INFORMATION EXCHANGE MODELING

Initial attempts to capture the information exchange architecture included use of Integrated Computer Aided Manufacturing Definition Language 0 (IDEF0), a modeling language for developing structured graphical representations of the activities or functions of a specific system (FIPS 183). The IDEF0 model has two elements: a box, which represents an activity, and a directed arc that represents data or objects related to the activity. The sides of the boxes have standard meanings: arcs entering the left side represent inputs, arcs exiting the right represent outputs, top arcs represent controls, and bottom arcs are mechanisms. The activity boxes define the function using verbs. A functional decomposition includes a context or "parent" diagram with activities necessary for it to operate. A "child" diagram shows the same inputs and outputs as the parent, as these are required for both sets of diagrams to function (Levis & Wagenhals 2000).

The first step in the development of the IDEF0 model is the context diagram. This diagram displays the operational concept modeled along with the inputs, outputs, controls, and mechanisms needed for the activity. In the case of the UV model, the operational concept is information exchange, shown in Figure 5.

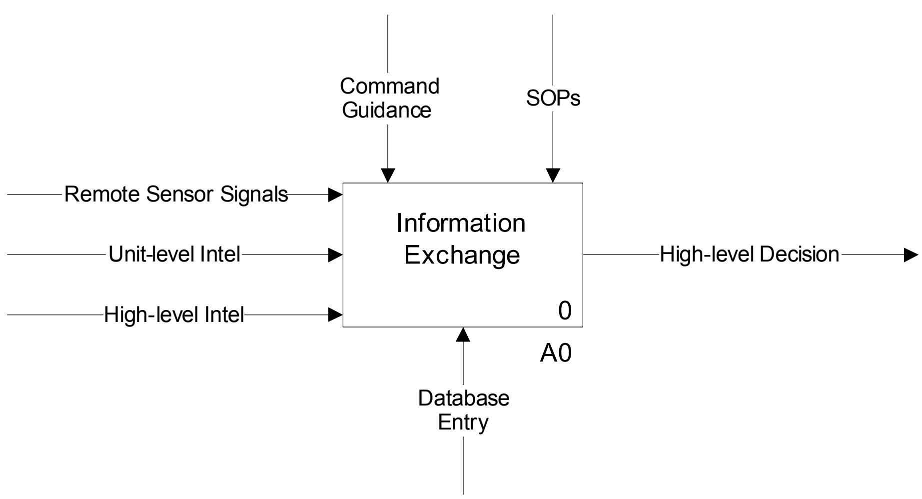

Figure 5. IDEF0 Context or "Parent" Diagram

The inputs for the model are the raw remote sensor electrical signals, provided by the UV, and unit-level/high-level intelligence reports. The controls are the standard operating procedures (SOPs) for UV use, and unit-level command guidance. One mechanism through which information exchange occurs is GCCS-M database entry, which populates the RMP. The final product, or output, of the activity is a high-level decision.

As the context diagram is decomposed, three main activities reveal what is necessary for information exchange to occur. The child diagram shows the activities comprising the operational concept in detail. These activities include operator analysis, information input, and making the operational decision. Each of the activities in Figure 6 has inputs, controls, mechanisms, and outputs that relate to the parent diagram. For example, the operator performing the analysis receives data provided by the UV, as well as any unit-level intelligence reports. These inputs, along with commander's guidance, allow the operator to spot visual cues more effectively while concentrating on CCOI. The mission payload operator then enters the data into the database. Upon receipt by the decision makers, relevant characteristics of interest pulled from the database enable appropriate decisions through collaboration and use of decision-making tools.

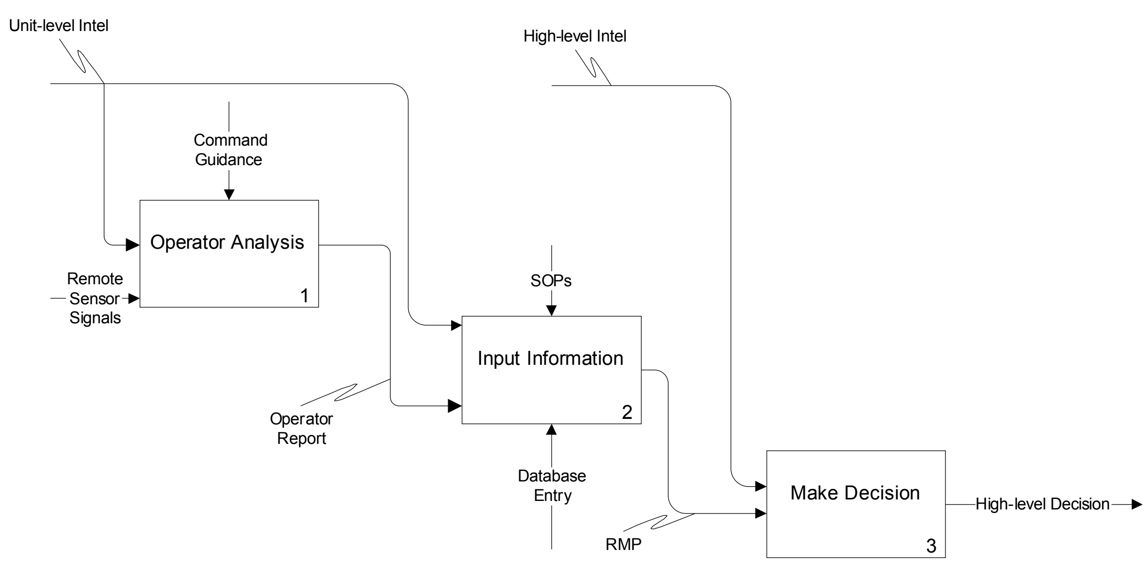

Figure 6. IDEF0 "Child" Diagram

D. DISCUSSION OF INITIAL UV SYSTEM ARCHITECTURE

The IDEF0 diagram provides some insight into the logical and behavioral portions of the system and discovery of possible problem areas in the proposed architecture, but do not capture both the depiction of actual information exchange and hierarchical value enhancement. According to operator and fleet staff interviews conducted at a limited objective experiment (Camp Roberts, experiment, May 3-4, 2004), it is apparent that the IDEF0 diagram does not fully explain how the information travels through the system in order to facilitate understanding by decision makers.

The three IDEF0 functions, analysis, input, and decision, require more in-depth examination. From the initial diagram, the roles for each function require definition. For instance, the payload operator report, or output of the operator analysis activity, is the first activity of interest. With the payload operator's attention focused on the incoming UV signal, there are too many opportunities to lose vital data. In this case, there is risk of overlooking signals and providing distorted information (Frankenhaeuser 2001). UV mission payload operators may not be able to perform the sensor duties required and be able to input information for the next echelon of the architecture. A database manager (DBM) is able to record the activities of the payload operator and input these for database/RMP use.

From warfare publication research and model discussion/interview, the IDEF0 diagram decomposes into new functions composed of tasks. Investigation decomposed the three functions of operator analysis, information input, and decision making into nine high-level functions. These functions, numbered one through nine and shown in Figure 7, trace UV sensor data progression into information for high-level decision maker use.

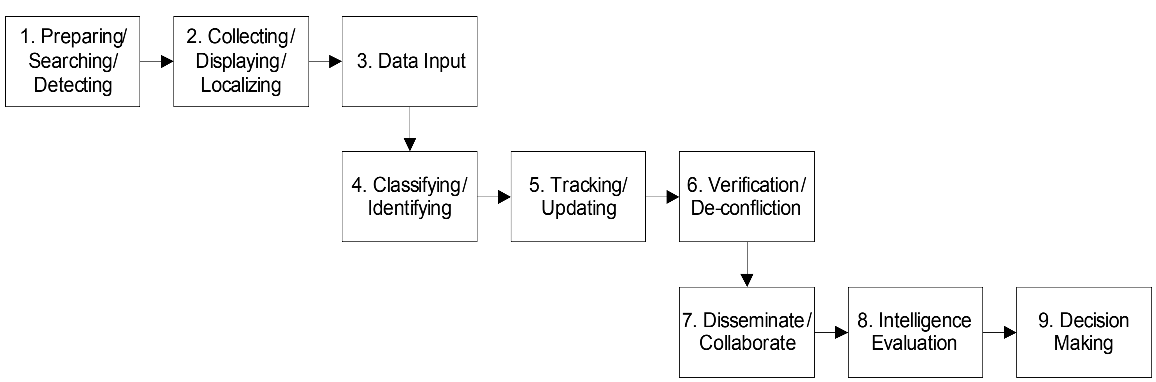

Figure 7. High-Level Functions Necessary for UV Information Exchange

The nine high-level functions address what is necessary to accomplish a maritime information exchange with UVs, in order to commit a contact to a RMP and process it for tracking, targeting, and interception. Each high-level function is composed of different tasks with inputs and outputs. These tasks form the procedural foundation for the information architecture.

Some tasks begin and end before others and some require continuous updating and refreshing. Table 1 shows the perceived order of operations, along with the complexity required and whether or not the process includes any automation. The number of steps within a task, the amount of mental effort required, and where the task resides within the adapted KID model correlate to form a complexity factor. Automation is factored according to whether or not the process involves any computer assistance. For example, tactical units promulgate a situation report (SITREP) to commanders through a network interface, where collaboration among operators is a mental exercise. The tasks are in process order and use a letter coding system. The table also includes the associated high-level function and inputs/outputs for each task.

Table 1. Functional Decomposition of Information Exchange

Tasks	**Complexity**	**Automation**	**Inputs**	**Fxn. #**	**Outputs**
A. Conduct intelligence preparation of the battlespace	MED	YES	intel reports, DB query	1	search areas, potential COI
B. Develop search areas/track	MED	NO	intel reports, DB query	1	surveillance pattern
C. De-conflict airspace/water-space	MED	YES	current air/sea asset info	1	air/sea/UV de-confliction
D. Setup/Deploy UV	LOW	NO	launch time, weather, SOPs	1	launched UV
E. Detect Contact Signature from UV sensor data	HIGH	YES	UV signal	1	initial COI report
F. Provide report to Information Watch Supervisor	LOW	NO	known/unknown COI, UV signal	2	report to IWS
G. Query database for COI	LOW	YES	DB query	2	known AOR COI
H. Gather kinematics on contact	HIGH	YES	course, speed, location	4	increased awareness
I. Create file in database	LOW	YES	Data on COI	3	new DB file

J. Collaborate among operator and signature analyst	MED	NO	acquired operator information	7	understanding among operators
K. Input contact attributes/characteristics	LOW	NO	COI attributes	3	update DB
L. Report unknown contact to high-level commander	LOW	NO	COI info, SITREPs	7	commanders aware of COI
M. Prepare SITREPs for chain of command	LOW	YES	acquired intel on COI	7	SITREP
N. Promulgate SITREPs for chain of commander	LOW	YES	SITREPs	7	decision maker awareness
O. Direct payload	MED	YES	COI info	5	fixed location for COI
P. Provide cueing for CSG/ESG assets	LOW	NO	high-level commander authorization	6	directed assets
Q. Gather data for satisfying EEI	HIGH	NO	COI reports, kinematics	8	satisfaction of EEI
R. Fuse intel from UV w/ locally held contact info	MED	YES	local unit intel	6	updated DB
S. Fuse intel from UV w/ CSG/ESG asset info	MED	YES	CSG/ESG intel	6	updated DB
T. Correlate tactical intel with contact	MED	YES	tactical intel	8	situation awareness
U. Correlate operational intel with contact	MED	YES	operational intel	8	awareness of mission
V. Relay information to unit-level commanders	LOW	NO	COI report	7	Unit-level understanding
W. Relay information to high-level commanders	LOW	NO	COI report	7	decision maker understanding
X. Process contact identity	HIGH	NO	operational intel, COI info	6	COI identified
Y. Classify contact	HIGH	NO	DB entry, identification report	4	COI classified
Z. Verify contact	HIGH	NO	DB entry, classification	6	COI verified
AA. Refine/Revise/Update information on contact	LOW	YES	Refined classification and identification	5	updated DB and situational awareness
BB. Judge information confidence	HIGH	NO	COI info, intel reports, SITREP	9	decision maker knowledge
CC. Make tactical or operational decision	HIGH	NO	decision maker knowledge	9	action decision
DD. Dedicate unit-level assets, or	LOW	NO	decision maker understanding	9	assets deployed
EE. Dedicate high-level assets	LOW	NO	decision maker understanding	9	assets deployed
FF. Assess decisions	LOW	NO	results of deployed assets	9	situation assessment

Figure 8 displays an information task flow diagram using a PERT representation, showing task dependency information. Each square represents a specific letter-coded task outlined in Table 1. The arrows represent the paths data and information take within the exchange architecture. For example, R is an input for U, while H leads to K and Q. The blocks show the paths necessary in order to facilitate information flow.

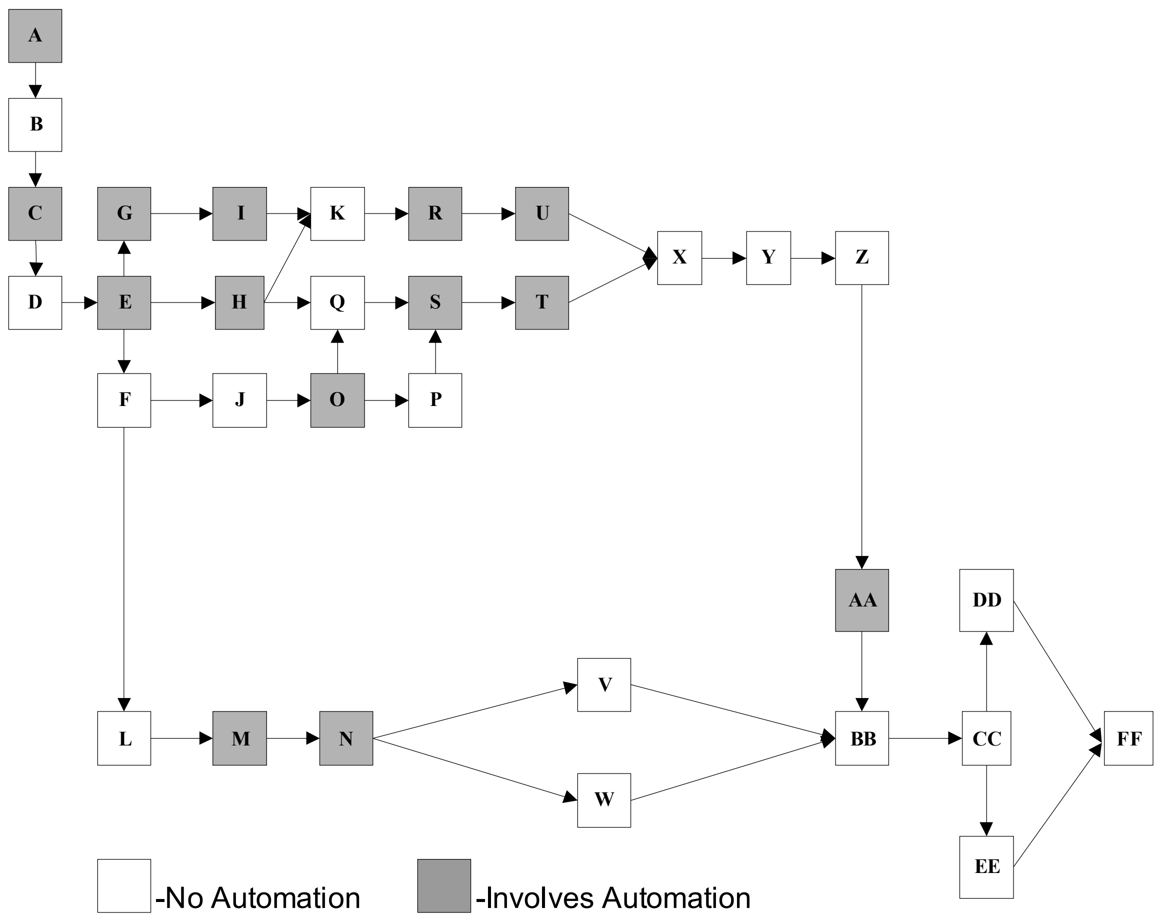

Figure 8. Information Task Flow Diagram

The diagram shows paths data traverse for delivery to a decision maker. The data take multiple paths simultaneously, but each is required for proper exchange. Each path includes tasks that are manual and automated. Despite there being automation involved, many of these tasks precede and follow manual processes, which inherently slow the information exchange. The paths show that humans are a part of every aspect of the information exchange and errors and delays affect every process. Therefore, when analyzing the flow, it should be noted where the paths can be improved by automating some of the manual tasks.

E. ARCHITECTURE SUPPORTING PERSONNEL

From the Camp Roberts interviews (May 3-4, 2004), and a review of current UV practices, the revised high-level functions and defined tasks yield an initial set of personnel required for the information exchange architecture. The personnel defined herein are for generic maritime mission use and may change titles accordingly. In the Chapter I MIO scenario, the high-level commander is the JFMCC, but in other instances, the decision maker may be the Sea Combat Commander (SCC) or ship's Commanding Officer. Members of the operational team will have responsibilities dedicated to them, as outlined in Table 2. In some cases, there are multiple roles performing the same task for collaboration and discussion. The personnel may change according to the mission of the unit and the circumstances of operation.

Table 2. Roles and Responsibilities for Information Exchange Personnel

Role	Responsibility
Internal Pilot	Vehicle operator. Guides and controls UV.
External Pilot	Conducts launch and recovery operations. Assists in UV Navigation.
Mission Payload Operator	Operates payloads aboard UV. Provides initial and follow-on signal assessment.
Mission Commander	Supervisor for all UV operations. Liaison between UV operations center and ship's intelligence center.
Intelligence Specialist	Assists payload operator in signal interpretation. Provides incoming data reports to DBM and Information Watch Supervisor.
Database Manager	Inputs data from UV sensors into manageable database files for RMP development. Notifies supervisors on update.
Intelligence Watch Supervisor	Supervisor of intelligence center watch operations. Coordinates UV data with acquired local and CSG/ESG asset data. Provides reports to commanders.
Unit-level Intelligence Officer	Responsible for unit level intelligence analysis and dissemination of information.
Unit-level Decision Maker	Overall ship operation and employment of shipboard systems. Responsible for delivery of information to RMP and deployment of unit-level assets.
High-level Intelligence Officer	Assists in interpreting information from RMP at operational level. Responsible for delivery of information to high-level commanders.
High-level Decision Maker	Ultimate decision authority. Interprets information from RMP and various sources. Responsible for action decisions to deploy low/high level assets.

Figure 9 displays the personnel hierarchy for operations. The hierarchy shows a chain of command structure for maritime information exchange operations according to the responsibilities and personnel descriptions listed in Table 2.

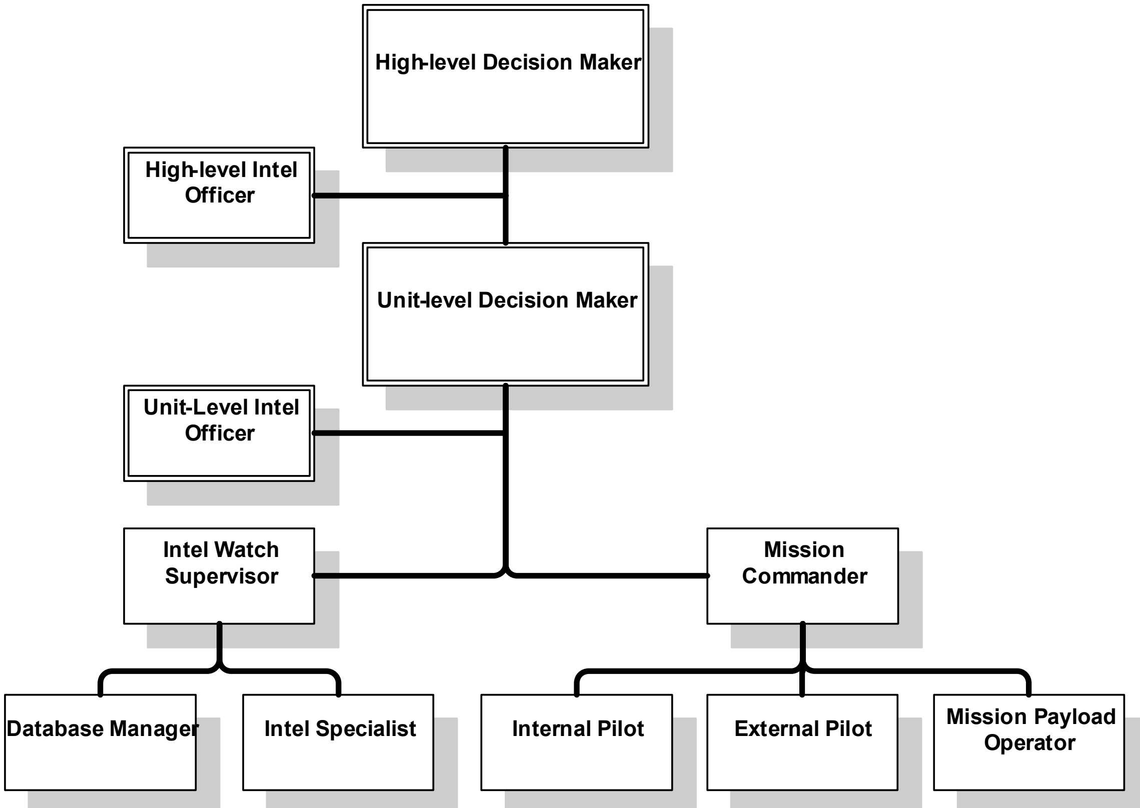

Figure 9. Personnel Hierarchy for Maritime Operation

F. HIGH-LEVEL FUNCTIONS, UNDERSTANDING LAYERS, AND KID MODEL

The technical, system, and operational views are necessary in defining relationships in information exchange and C4ISR system architecture (Levis & Wagenhals 2000). The high-level functions necessary to perform the UV information exchange directly correlate to the understanding layers (physical-interface-cognitive-social) and the adapted KID model. Each of the functions performs a specific job within the layers of understanding to elevate data to the level of knowledge. As a piece of information makes its way through the architecture, it undergoes improvement at certain levels by satisfying the specific tasks within each of the functions. Figure 10 is a representation of these relationships.

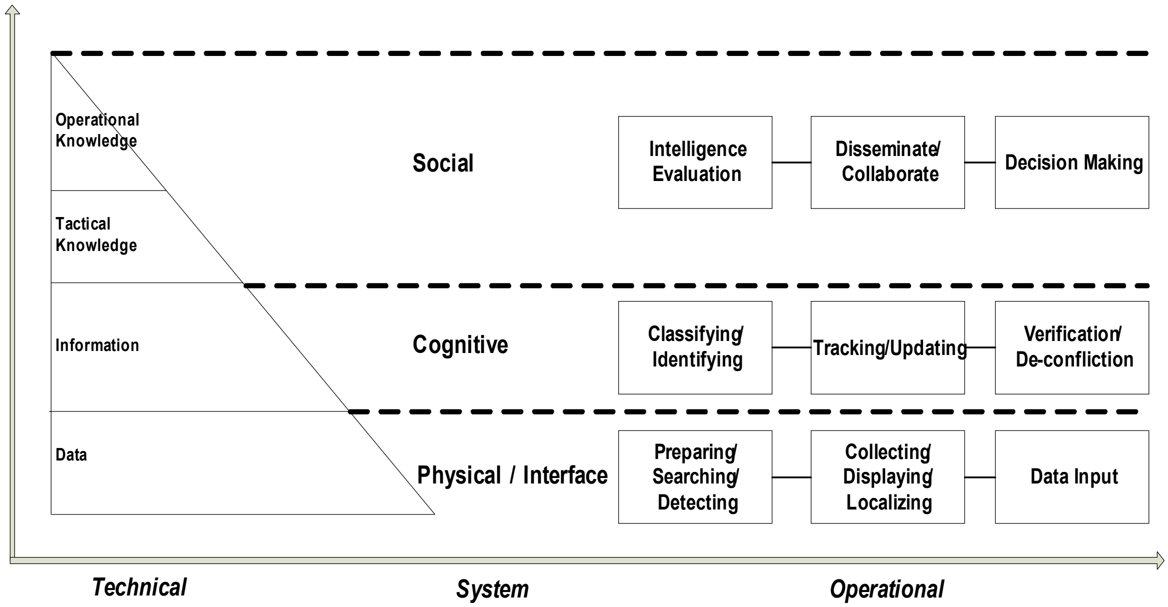

Figure 10. High-Level Functions Related to Understanding Layers and Adapted KID

The C4ISR Architecture Framework, issued by the Department of Defense, specifies three views of information architecture. As described by Levis and Wagenhals (2000), the three views (technical-system-operational) represent a "particular characterization of the architecture using a set of products that are graphical, tabular, or textual". The operational view is a description of the tasks, activities, and information flows required to accomplish or support a military operation. The nine high-level functions represent the operational view. The blocks symbolize organization through missions, or tasks, and the connectors show the function role in information flow (Levis & Wagenhals 2000).

The system view is an account of supporting systems and interconnections for military operations. This view symbolizes the physical implementation of one or more operational elements and displays the interfaces in-between. The physical, interface, cognitive, and social layers of the architecture, represented in Figure 4 (page 11), identify the interfaces among the system nodes, including the unmanned platform, distributed sensors, communications network, control systems, data entry systems, decision support systems, and displays (Levis & Wagenhals 2000).

A technical view is a set of rules leading the understanding of the elements whose purpose is to ensure that "a conformant system satisfies a specified set of requirements" (Levis & Wagenhals 2000). The requirement set forth by the architecture is a smooth transition of data to the level of decision maker knowledge. The KID model adapted from Nissen (2002), Figure 3 (page 10), represents the technical view (Levis & Wagenhals 2000).

This study has taken the initial steps in developing these views. Figure 10 represents the three views combined, showing the interrelationships among them. Analyzing the results of these views will serve as the basis for proper C4ISR system development.

IV. ANALYZING INFORMATION ARCHITECTURE

A. INTERPRETING OPERATOR OVERLOAD

Measures of effectiveness (MOEs) and measures of performance (MOPs) determine how well the system conforms to operational objectives. They are quantifiable and measurable. MOEs focus on how a force "performs its mission or the degree to which it meets its objectives" (NATO 2002) and MOPs analyze the "internal system structure, characteristics and behavior" (NATO 2002). One critical MOP for information architecture, tied to operational objectives, is operator overload. In attempting to assess the architecture, potential for operator overload is examined for its link to errors and delays in an information exchange (Frankenhaeuser 2001).

It is crucial to analyze the unmanned system for overload points in order to prevent mistakes previously made with manned systems. One interpretation of the USS Vincennes (CG-49) case, where a civilian airliner was mistaken for a hostile contact and shot down, involves worker overload. An inexperienced and unqualified console operator could not handle the numerous tasks given to him at that position. Subsequently, the console operator failed to verify identification and ensure a consistent track profile on a contact, resulting in information delivery error. In effect, there was a breakdown in the position serving as a filter for information flow to decision makers. Due to overloading, the console operator could not support critical information validation. This resulted in misleading and erroneous information in the system, allowing no time for independent verification by commanders. The mismanagement of information, along with other unforeseen events, resulted in the tactical failure (Dotterway 1992).

Overloading an operator is a key factor to consider in this architecture. For personnel management metrics, measuring proper tasking requires calculating workload (Heacox 2004). An analysis of available tasks, listed in Table 1, results in distribution of tasks amongst personnel assigned to the mission (Table 2).

Figure 11 (page 26) displays the division of labor assigned to personnel for both manual and automated tasks. The personnel are shown left to right according to operational sequence. Figure 11 not only shows the proportion of automated tasks (shaded gray), but also shows the Payload Operator, Intelligence Specialist, Intelligence Watch Supervisor, and Unit-level Intelligence Officer performing a majority of the tasks. However, since some tasks are manual and others automated, the amount of relative workload among these personnel is unclear.

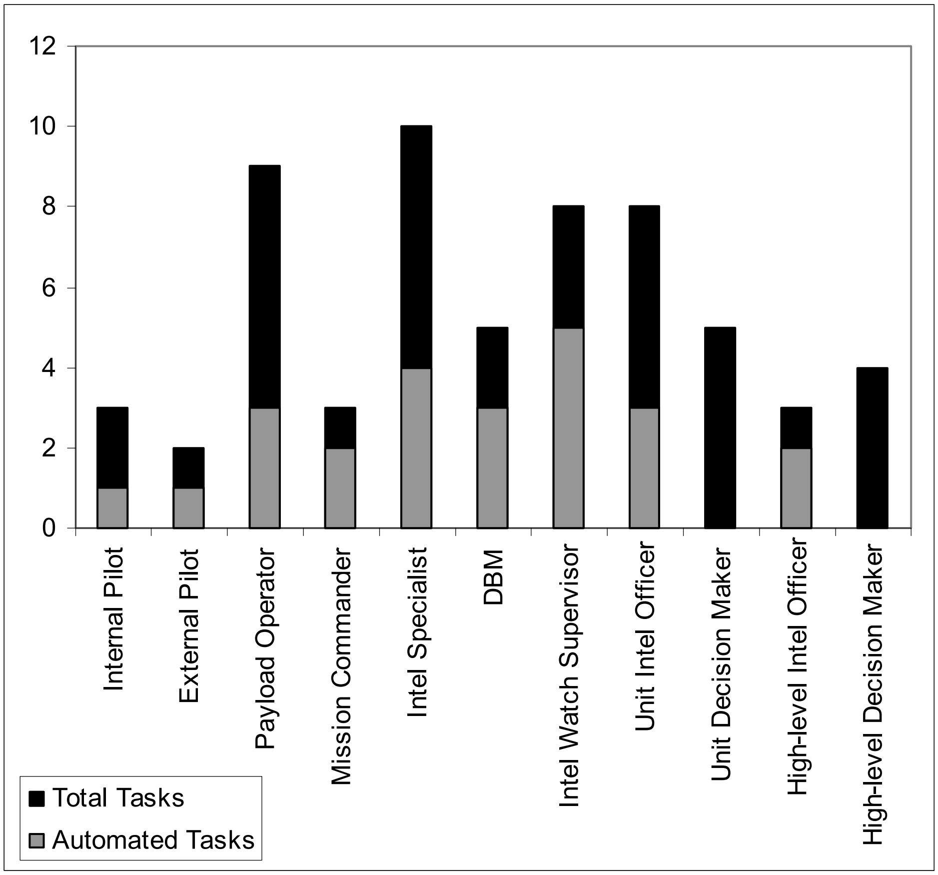

Figure 11. Number of Tasks Distributed To Personnel

A revised workload accounts for the number of tasks assigned to personnel, the complexity involved (from Table 1), and an adjustment factor for using automation. Figure 12 (page 27) shows the calculated values for workload using these three criteria. The values for each task were determined by multiplying the level of complexity (low=1, medium=2, high=3) by an automation factor. The automation factor is due to manual tasks requiring more time to complete and classifies the workload incurred by tasks performed manually. Figure 12 shows automation in conjunction with manual tasks. The factor is 1 if the process includes automation. Manual tasks are displayed in factors of 3, 2, and 1.25. These factors provide a range to depict whether automation significantly assists the process or if it only incrementally decreases workload. This more accurately reflects the overall distribution of tasking. From left to right, the roles are listed according to diminishing amount of workload.

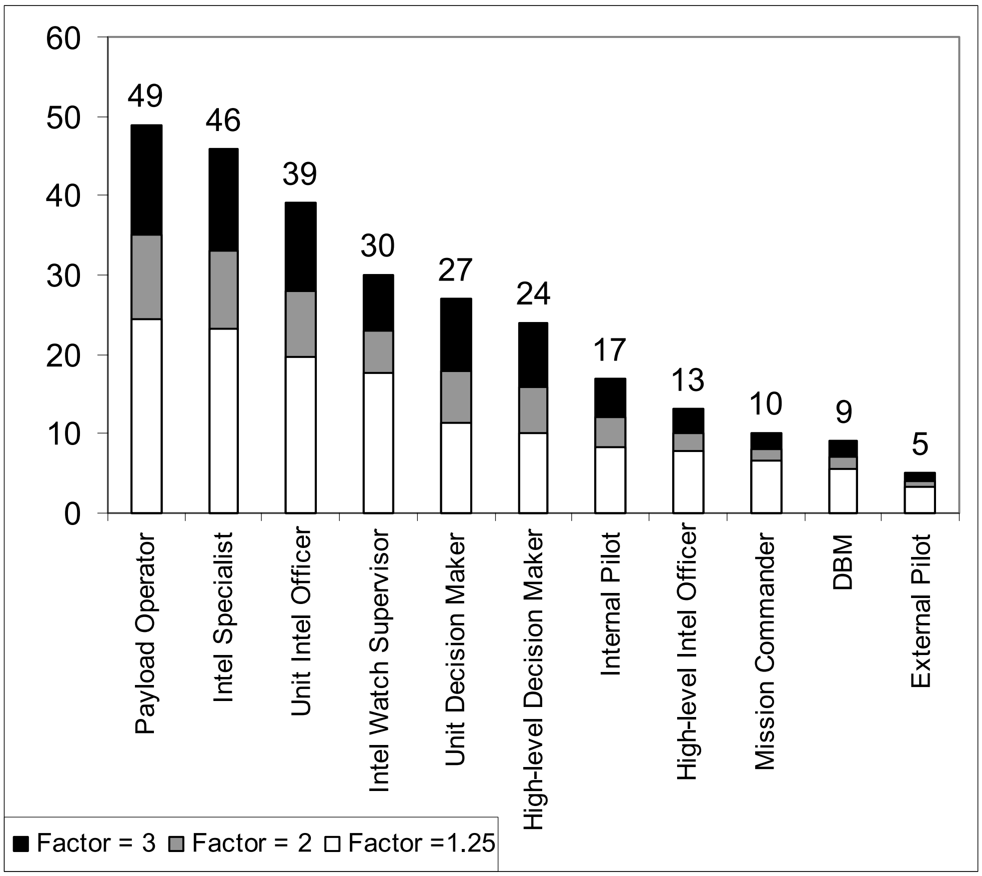

Figure 12. Revised Personnel Workload With Various Automation Factors

Manual tasks require more time, potentially introducing delay and error into the system. From Figure 12, the Payload Operator, Intelligence Specialist, Intelligence Watch Supervisor, and Unit-level Intelligence Officer appear to be under heavy demand, performing over 60% of the workload depending on the contribution of automation. Overloading these operators is a concern because they are the initial source of data analysis. If these positions lose focus on their specific tasks, it results in possible neglect of vital data. Overloading could create interruptions in high-level functions four (classifying/identifying) and five (tracking/updating), resulting in information exchange errors and delays. One simple way to overcome this is by adding additional assistance for handling extra tasks. Human factors analysis will identify the proportion of extra work performed by these personnel. Like overloading, additional metrics allow analysis of the information exchange architecture.

B. MOE-MOP FOR NEW TECHNOLOGY ASSESSMENT ON AN ORGANIZATION

Recent studies in assessing how an organization operates with new technology have addressed MOE/MOP issues in information and personnel management. These metrics determine how well the proposed information exchange architecture accomplishes its intended purpose. Metrics must be quantifiable and measurable in order to determine accuracy, completeness, and timeliness of the tasks. Task consistency measures the level of shared understanding among personnel at any time during the process. For example, the task is consistent if the personnel (from Payload Operator to High-level Decision Maker) perceive the same characteristics and attributes on a COI. Accomplishing this requires polling and observation at each workstation (Heacox 2004). MOE/MOP for new technology assessment, on an organization's information management, is required. They include:

MOE: Availability of information technology and procedures for personnel.

MOP:

1. Ability to monitor the status of the task environment.
   (Situation-relevant information update rate (**# tasks/min**))
2. Ability to establish and maintain needed collaborative links.
   (Match info source and destination (**% matched correctly**))

MOE: Level of shared understanding among personnel.

MOP:

1. Consistency of understanding the status of the task environment.
   (Various time intervals, how often the status is understood
   (**% understanding over time**))
2. Accuracy of understanding the status of the task environment.
   (Various time intervals, how close to true understanding
   (**% accuracy**))

Process output metrics include:

MOE: The level of quality and effectiveness of resources to produce the output.

MOP:

1. Value of the output.
   (Extent output conforms to standards (**% standards achieved**))
2. Time required to complete task.
   (Time aspects of task, record times (**seconds or minutes**))
3. Proportion of time spent at each task.
   (Found from analysis of process time (**% time per task**))
4. Personnel required to complete the process (Heacox 2004).
   (In addition to personnel initially assigned (**additional # required**))

These metrics ensure timely and accurate information exchange among personnel in the architecture when adding new technology to an organization. Using the results from the MOEs and MOPs, a refinement of the information exchange process may occur. In particular, the consistency and accuracy of understanding among operators, and time delays in the task environment may undergo modification.

C. PROCESS IMPROVEMENT THROUGH EXPERIMENTATION

When the information exchange architecture undergoes experimentation, the results will show:

1. How long individual tasks take to complete.
2. How long it takes to report and enter data.
3. The variability and distribution of the time required for the entire process.

Improving information exchange comes from insights available from experiments. Experimentation can discover failure modes, critical paths, and workarounds not foreseen in design. These results should lead to robustness and stability. For instance, overcoming errors caused by overloaded operators requires controlling and updating SOPs and adding assisting personnel as the mission and situation warrant. Determining if the process is robust requires finding the critical parts of the process causing most errors. Minimizing these errors provides consistency in the information exchange process.

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V. CONCLUSIONS

A. APPLYING THE INFORMATION EXCHANGE ARCHITECTURE

The ability to get information to high-level commanders is only as good as the ability to situate and manage data provided by sensors. A simultaneous adjustment in procedure must occur in order to facilitate a useful transition in introducing technology. This is the case with the UV platform. The difficulty in arriving at a solution is recognizing that UV technology is developing quicker than the basic command and control foundation. There must be a development of architecture in order to align the task organization, tactical procedures, and emerging technology to ensure proper incorporation of UV platforms into maritime missions.

The capability of remote sensors linking real-time and near real-time data throughout the chain of command provides rapid situational awareness and a level of detailed information. This greatly aids both the reporting and decision-making processes outlined in the information architecture. This information can be adapted to directly support planning and execution of maritime missions. A continual refreshment process will enable commanders and staffs to visualize the full spectrum of adversary capabilities and potential courses of action across all dimensions of the battlespace (MIO NTTP).

The purpose of this study was to develop an architecture to properly track and employ remote sensor data from a payload operator to a decision maker. After establishing proper information propagation, a definition of data, information, knowledge, and understanding of the physical, interface, cognitive, social layers of the system, a basic architecture diagram (IDEF0) emerged. This diagram showed weaknesses in displaying, to actual operators and fleet staffs, what was happening to the information as it made its way through the system. It provided limited insight into sources of error and delay in UV information exchange.

Through research, discussion, and fleet input, the basic flow diagram developed into nine high-level functions that are necessary to facilitate information flow. Functional decomposition of the roles and responsibilities made analysis possible. A comparison of the high-level functions to the adapted KID model and understanding layers showed parallels to where data becomes information, and where the information becomes knowledge for decision actions.

B. INSIGHTS AND FUTURE CONSIDERATIONS

The important insight to remember for information flow is the requirement set by the user. If the user demands flexibility for maritime mission use, then the architecture should incorporate flexibility within its design. In this study, the design is fully adaptable to any maritime mission incorporating UVs. If the situation warrants, the system allows for additional personnel to aid in satisfying tasks. It may be necessary to add personnel to the roles and responsibilities list in order to overcome obstacles such as operator overload. However, the division of responsibility depends on the mission and the number of personnel available to fill the roles. The important aspect for this architecture, and the adjustments, is to remain balanced.

This study only addressed single sensor UV interpretation. Single sensors were necessary in developing the architecture; however, multiple sensors are aboard unmanned platforms. Likewise, a number of UV platforms may deploy concurrently. When multiple sensors are delivering information, correlation issues should materialize, increasing the complexity of the entire process. Analysis of the architecture must reflect this.

Experimentation will provide for complete PERT analysis of the task flow diagram through discovery of task duration and distribution. Using these numbers, the PERT chart may undergo analysis for critical paths. Improving the process includes the discovery of these critical paths and designing for them in the architecture. Minimizing critical path time, through developing technologies, decreases the time the process takes to complete. For example, integrating systems that automate tasks will resolve this issue.

Automating some of the tasks in the architecture may minimize errors and delays in reporting information to decision makers. However, automating the processes does not free the system from error, as was the case with USS Vincennes. Human error and delay affect every process in information exchange. The key to automation comes from studying the information exchange architecture, noting where the errors and delays are, and developing technologies to minimize them. Experimentation provides an opportunity to identify processes that may require automating.

To further the research, simulation and experimentation will show adaptability and flexibility within the architecture by using MOE/MOP appropriate to assessing advanced technology's impact on an organization. Gathering these metrics requires interview and observation, of a maritime information exchange experiment, where the personnel roles are manned and well defined.

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LIST OF REFERENCES

Alberts, David and Hayes, Richard. (2003). Power to the Edge: Command…Control…in the Information Age. Washington, D.C.: CCRP Publication Series.

Boger, Dan. (2004, April 1). [Interview]. CC4913 Course Notes.

Brown, David. (2003, December 1). Surface Chief Underscores Unmanned Vehicle Revolution. Navy Times. p. 10.

Camp Roberts Limited Objective Experiment. (2004, May 3-4). [Interviews].

Chief of Naval Operations. (2004). Accelerating our Advantages. CNO Guidance for 2004.

Cordesman, Anthony. (2003, July). The Lessons of the Iraqi War. Center for Strategic and International Studies. Retrieved from http://www.csis.org/features/iraq_instantlessons.pdf on March 10, 2004.

Cristi, Roberto. (2003, September). Protection of Sea Base. [Integrated Project]. Monterey, CA: Naval Postgraduate School.

Dotterway, Kristen. (1992, June). Systematic analysis of complex dynamic systems : the case of the USS Vincennes. [Thesis]. Monterey, CA: Naval Postgraduate School.

Frankenhaeuser, Marianne. (2001). To Err is Human: Nuclear War by Mistake? Palo Alto, California: Foundation for Global Community.

Gansler, Jacques. (1998). Affordable Weapons Systems: A Design For The Future. Defense Issues, 13. Retrieved from http://www.pentagon.mil/speeches/1998/s19980519-gansler.html on April 1, 2004.

Gottfried, Russell and Woolsey, Aaron. (2004, March). Unmanned Vehicle Distributed Sensor Management and Information Exchange Demonstration. [Tech Report]. Monterey, CA: Naval Postgraduate School.

Heacox, Nancy. (2004, May 16). [Interview] Impact Assessment of New Technology on an Organizational Unit.

Integration Definition for Function Modeling (IDEF0). (1993, December 21). Federal Information Processing Standards Publication 183. Retrieved March 5, 2004 from http://www.itl.nist.gov/fipspubs/idef02.doc.

Kress, Moshe. (2002). Operational Logistics: The Art and Science of Sustaining Military Operations. Boston: Kluwer Academic Publishers.

Levis, A. and Wagenhals L. (2000, April). C4ISR Architectures: Developing a Process for C4ISR Architecture Design. Systems Engineering, 3. London: John Wiley & Sons, Inc.

Maier, M. and Rechtin, E. (2000). The Art of Systems Engineering (Second Edition). New York: CRC Press.

Maritime Interdiction Operations. (2003, November). Naval Tactics Techniques and Procedures (3-07.11). Newport, RI: Department of the Navy.

Miller, N. and Shattuck, L. (2004). A Process Model of Situated Cognition in Military Command and Control. Command and Control Research and Technology Symposium.

Nissen, Mark. (2002). An extended model of knowledge-flow dynamics. Communication of the Association for Information Systems, 8. Baylor University, TX: Reagan Ramsower.

Nissen, Mark. (2002, June). Understanding "Understanding" Flow for Network-Centric Warfare: Military Knowledge Flow Mechanics. Monterey, CA: Naval Postgraduate School.

Nissen, Mark. (2004, March 26). [Interview]. Conversation notes.

NIST/SEMATECH e-Handbook of Statistical Methods. (1998). Retrieved from http://www.itl.nist.gov/div898/handbook/ on March 5, 2004.

North Atlantic Treaty Organization. (2002). Code of Best Practice for C2 Assessment. Washington, D.C.: CCRP Publication Series.

Office of the Secretary of Defense. (2002, December). Unmanned Aerial Vehicles Roadmap (2002-2027). Washington, D.C.: Office of the Secretary of Defense.

Standard Glossary of Software Engineering Terminology. (1990). IEEE-STD 610.12-1990. Retrieved from http://ieeexplore.ieee.org/xpl/tocresult.jsp?isNumber=4148 on April 3, 2004.

Thompson, Phillip. (2004 February 16). Thinker UAVs on the Horizon. Navy Times. p.30.

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