Integrating Human-Computer Interaction Artifacts into System Development

Megan Moundalexis, Janet Deery, and Kendal Roberts

Johns Hopkins University Applied Physics Laboratory,
20723 Laurel, Maryland
Megan.Moundalexis@jhuapl.edu

Abstract. This paper introduces a methodology for developing and leveraging Human Computer Interaction (HCI) artifacts into systems design within the Antisubmarine Warfare (ASW) domain. The method is structured with four integrated steps: Scenario Development, Personas, Operational Concept Documentation, and Usability. Explicit links are made between the artifacts to allow a more efficient use of design resources including legacy documentation for developers while improving the quality of design. As with current systems engineering practices this approach relies upon requirement analysis, prototyping, design iteration, and test and evaluation. Unlike current practice, however, this approach can improve the process of iteration as well as feedback on additional unanticipated requirements. Often overlooked, this process also yielded effective design team interaction. These improvements are made possible by the structured methodology that makes the HCI products attractive to systems developers: the artifacts are well organized, adaptable, and inspectable.

Keywords: Systems Design, Decision Support Systems, Human Computer Interaction.

1 Introduction

This paper introduces a methodology for systems development within the Antisubmarine Warfare (ASW) community. With reduction in defense acquisition dollars, increased technology sophistication, independent standalone legacy systems, reduced manning, and the need for improved command and control, there is a need for more effective integration and development. These opposing variables often prohibit fielding new technological capabilities to the Fleet. This is the primary challenge that our methodology aimed to overcome.

Typically, the traditional systems engineering (SE) paradigm follows a top-down approach where the project team creates designs based on the top-level requirements (TLRs). Those requirements, in essence, are understood to be the high- level goals that are completed by the user. However, this method does not lend itself to the potential design discoveries that come from interactions between real users while completing real tasks on a system. These discoveries are traditionally found by the training instructors and the fleet, but only after the system have been deployed. This is exaggerated within a

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command and control network with different operator positions having varied and overlapping goals.

This paper/case proposes four design principles that the authors have used successfully in developing and evaluating the Undersea Warfare Decision Support System (USW-DSS) Build 2: ASW scenario, Click Stream Task Analysis, ASW personas, and Operational Concept Document (OCD), which are summarized here but described in greater detail below.

1. Scenario development is a fundamental element for systems development within context of user tasks. As a top-down approach, scenario development begins the requirement-gathering process.
2. Then, as a task-centered approach, a task analysis of the scenario dissects mission requirements to understand the user's mental model about the tasks that the requirements support within the context of the broader scenario.
3. Personas are HCI artifacts that contain characteristics of the user. Employing this bottom-up strategy enables the systems engineering designer/researcher to gather insight into user processes that are unique to the ASW domain.
4. Creation of an Operational Concept Document (OCD) is a documentation and evaluation process that links the cognitive and collaborative demands within the scenario to particular system capabilities that they are intended to support.

Top-down systems engineering was executed with the benefits of bottom-up analyses, which was synchronized in an end-to-end analysis (see Figure 1). In other words, a top-down project was verified using a bottom-up approach.

2 Scenario Development

Identification of a system's functional requirements often begins with scenario development, which identifies the properties and constraints of the work domain [7]. A study conducted by [4] emphasizes the need for requirements analysis in order to develop a shared vision of the system regarding the context of the design problem that we are trying to understand. Having a scenario developed also supports use case development, assessment of the design during testing and evaluation (T&E) and traceability.

As a starting point, our approach utilized an ASW scenario that must be supported by the system. This was the context of the problem for which we derived requirements to solve the problem. Functional requirements were identified that met the high-level scenario goals. Then, those requirements were decomposed into as many lower levels as were necessary, while ensuring that each level mapped back to the scenario (Figure 1). Assessing the completeness of the scenario is then a function of ensuring that allocated capabilities, functions, and requirements are captured at each subsequent level. Explicit links are made between particular system capabilities, specific collaborative demands, and external clients (e.g. interfaces) that are intended to support the scenario and operator. These linkages provide the basis for traceability and informed testing of the effectiveness of proposed designs and are captured in the operational concept document (OCD).

An issue to consider within this iterative framework is the complicated tasks that are often problematic for operators. Bottom-up task analysis provides task details. Coupled with prototyping and usability heuristic analysis, task analysis can reveal the complicated tasks that can arise during the scenario, specifically in ASW. These are areas where potential user errors might occur. Identifying these tasks early in the process affords opportunities during bottom-up design to develop sub-systems (e.g., tactical decision aids) to support the full USW-DSS system. This task-centered approach is a process of decomposing mission requirements and then designing information and control interfaces that support operator task performance in order to complete the mission. This ensures that complicated tasks are not design afterthoughts that result in interface usability problems for Fleet operators, which is traditionally a problem handed off to training instructors after the system is fielded.

While top-down and bottom-up can be used to identify system relationships as well as operational and task demands associated with them, scenario developers must consider the skills, capabilities, and training level of the operators (i.e. Personas) and any factors (e.g. chain of command, goals) that arise in the ASW dynamic high risk domain. ASW operators are capable of processing complex information. However, insufficient system design and training can lead to poor decision making. Introducing a system like USW-DSS into the decision making process will have a positive impact only if designed for the problem (e.g. scenario) and the operators are fully understood.

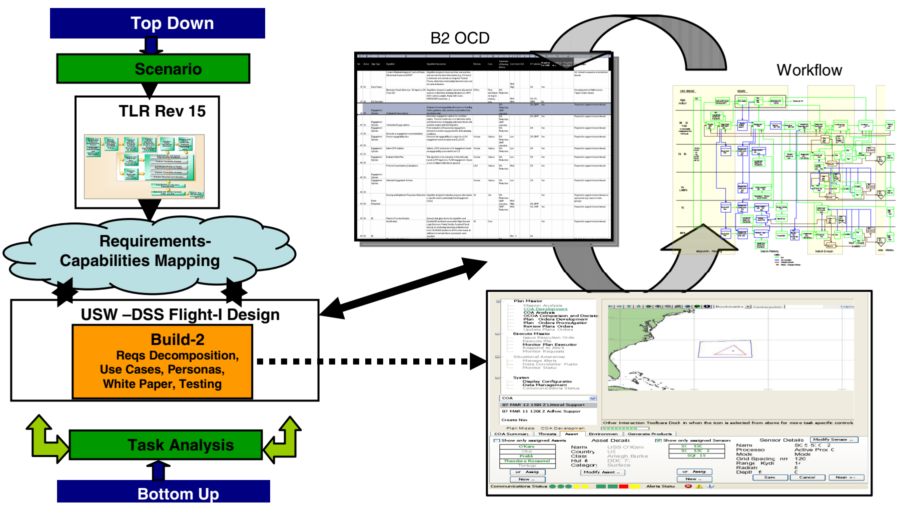
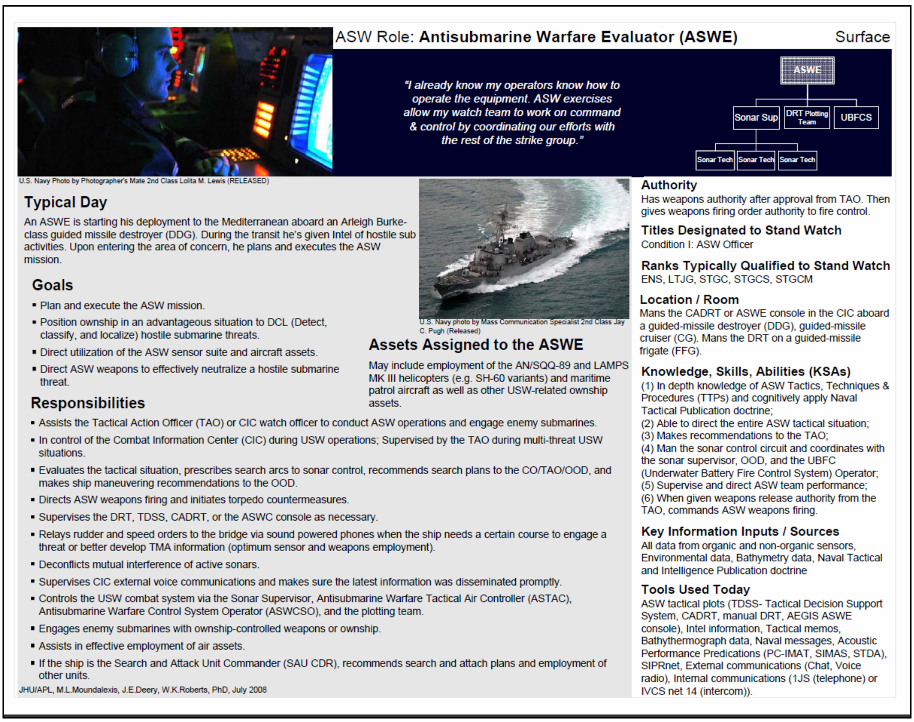


Fig. 1. System development diagram indicating scenario-to-design-to-testing

3 Personas

The authors developed personas to profile ASW users. Personas are a single page description of a specific user group [2, 3]. They do not contain information about a specific person, but is instead an amalgamation of multiple real people from the same user group. These concise user profiles are a means for the engineering team to understand the various operators who will use a system by communicating user characteristics, such as domain, responsibilities, goals, and tasks. Personas do not serve solely as deliverables. The entire process of researching, creating, validating, and sharing the user profiles engages systems developers from multiple disciplines. Reading Navy doctrine and duties to create the personas decreased the learning curve with Naval operations. Involvement with the fleet and other SMEs was essential to getting the drafts reviewed and significantly increased the engineering team's understanding of the system's purpose in the process. Engineers are then able to quickly look at the page description to get an idea of who they need to consider when developing a system.

The USW-DSS user interface (UI) working group (WG) developed 14 personas to understand various ASW roles that will interact with the system (Figure 2). Personas proved to be a valuable design research tool that created understanding between designers and Fleet stakeholders. Personas developed were for surface, subsurface, shore, and air roles including: Sea Combat Commander (SCC), Antisubmarine Warfare Evaluator (ASWE), Tactical Action Officer (TAO), Underwater Battery Fire Control System Operator (UBFCS), Computer Aided Dead Reckoning Tracker (CADRT) Plotter, Sonar Supervisor (both Surface and Subsurface), Officer of the Deck (OOD), Theater Antisubmarine Warfare Commander (TASWC), Sensor Station Operator (Sensor One), Tactical Coordinator (TACCO), Operations Specialist (OS), and Sonar Technician (ST).


ASW Role: **Antisubmarine Warfare Evaluator (ASWE)** Surface

"I already know my operators know how to operate the equipment. ASW exercises allow my watch team to work on command & control by coordinating our efforts with the rest of the strike group."

U.S. Navy Photo by Photographer's Mate 2nd Class Lolita M. Lewis (RELEASED)

Typical Day

An ASWE is starting his deployment to the Mediterranean aboard an Arleigh Burke-class guided missile destroyer (DDG). During the transit he's given Intel of hostile sub activities. Upon entering the area of concern, he plans and executes the ASW mission.

Goals

- Plan and execute the ASW mission.
- Position ownship in an advantageous situation to DCL (Detect, classify, and localize) hostile submarine threats.
- Direct utilization of the ASW sensor suite and aircraft assets.
- Direct ASW weapons to effectively neutralize a hostile submarine threat.

U.S. Navy photo by Mass Communication Specialist 2nd Class Jay C. Pugh (Released)

Assets Assigned to the ASWE

May include employment of the AN/SQQ-89 and LAMPS MK III helicopters (e.g. SH-60 variants) and maritime patrol aircraft as well as other USW-related ownship assets.

Responsibilities

- Assists the Tactical Action Officer (TAO) or CIC watch officer to conduct ASW operations and engage enemy submarines.
- In control of the Combat Information Center (CIC) during USW operations; Supervised by the TAO during multi-threat USW situations.
- Evaluates the tactical situation, prescribes search arcs to sonar control, recommends search plans to the CO/TAO/OOD, and makes ship maneuvering recommendations to the OOD.
- Directs ASW weapons firing and initiates torpedo countermeasures.
- Supervises the DRT, TDSS, CADRT, or the ASWC console as necessary.
- Relays rudder and speed orders to the bridge via sound powered phones when the ship needs a certain course to engage a threat or better develop TMA information (optimum sensor and weapons employment).
- Deconflicts mutual interference of active sonars.
- Supervises CIC external voice communications and makes sure the latest information was disseminated promptly.
- Controls the USW combat system via the Sonar Supervisor, Antisubmarine Warfare Tactical Air Controller (ASTAC), Antisubmarine Warfare Control System Operator (ASWCSO), and the plotting team.
- Engages enemy submarines with ownship-controlled weapons or ownship.
- Assists in effective employment of air assets.
- If the ship is the Search and Attack Unit Commander (SAU CDR), recommends search and attach plans and employment of other units.

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Authority

Has weapons authority after approval from TAO. Then gives weapons firing order authority to fire control.

Titles Designated to Stand Watch

Condition I: ASW Officer

Ranks Typically Qualified to Stand Watch

ENS, LTJG, STGC, STGCS, STGCM

Location / Room

Mans the CADRT or ASWE console in the CIC aboard a guided-missile destroyer (DDG), guided-missile cruiser (CG). Mans the DRT on a guided-missile frigate (FFG).

Knowledge, Skills, Abilities (KSAs)

(1) In depth knowledge of ASW Tactics, Techniques & Procedures (TTPs) and cognitively apply Naval Tactical Publication doctrine;
(2) Able to direct the entire ASW tactical situation;
(3) Makes recommendations to the TAO;
(4) Man the sonar control circuit and coordinates with the sonar supervisor, OOD, and the UBFC (Underwater Battery Fire Control System) Operator;
(5) Supervise and direct ASW team performance;
(6) When given weapons release authority from the TAO, commands ASW weapons firing.

Key Information Inputs / Sources

All data from organic and non-organic sensors, Environmental data, Bathymetry data, Naval Tactical and Intelligence Publication doctrine

Tools Used Today

ASW tactical plots (TDSS- Tactical Decision Support System, CADRT, manual DRT, AEGIS ASWE console), Intel information, Tactical memos, Bathythermograph data, Naval messages, Acoustic Performance Predications (PC-IMAT, SIMAS, STDA), SIPRnet, External communications (Chat, Voice radio), Internal communications (1JS (telephone) or IVCS net 14 (intercom)).

Fig. 2. Antisubmarine Warfare Evaluator (ASWE) persona

Multiple sources were referenced during the development of the persona draft versions including USW-DSS Build 1 user surveys, U.S. Navy-sponsored websites, and Naval Warfare Electronic Library (NWEL) documents. In order to ensure accuracy, the personas were then reviewed by subject matter experts (SMEs) and U.S. Navy fleet members.

Each persona includes the following information:

- Name of ASW role
- Location - e.g., surface, subsurface, shore, or air
- Operator Picture
- Quote
- Organizational Chart
- Description of operator's typical day
- Platform picture
- Goals
- Responsibilities
- Assigned assets
- Authority
- Titles designated to stand watch
- Ranks typically qualified to stand watch
- Location/room aboard the platform
- Knowledge, skills, and abilities
- Key Information inputs/sources
- Tools used today

In addition to user interface design, personas will be used to support training activities. Specifically, personas can be used to uncover potential training holes between curriculum and system capabilities. Since personas provide the knowledge, skills, and abilities (KSAs) of each user type, they can be used to find gaps in task allocation. This is critical for supporting command and control [6]. That is, providing a common tactical picture through distributing timely fused information to meet planning, execution, an assessment needs in air, surface, and subsurface.

4 Operational Concept Document

The Operational Concept Document (OCD) is a logical sequence of ASW operations supported by USW-DSS, which documents and examines the role and functionality of the operator in conjunction with all the software sub-systems. Beyond the interactive relationships internal to USW-DSS, the OCD also maps the ASW activities and operator's major tasks to the graphical user interface (GUI) screens and functional requirements. This feature lends itself to good design, not only to systems development but also test and evaluation with an operator-centered approach. Volumes of work have been published on this topic but often lack an operator-centric approach. Our OCD seeks to resolve this by providing a one-stop shop for: 1) a comprehensive set of ASW activities supported to produce the USW-DSS design, 2) lower level tasks supported by software or operator, 3) mapping of tasks to GUI and functional requirements.

As illustrated in Figure 3, the first column describes the ASW activities. The second column, entitled task name, decomposes the activity into lower level tasks mapped to the responsible actor (e.g. software configuration item, Crew, or Communications). The HCI column includes the need for and nature of the user interface (e.g. C- control, D- display, N- software only). The GUI column documents the location of the interface that supports the task. The requirements column documents the requirement fulfilled.

ASW Activity Description	Task Name	CI/Crew/Comms	HCI	GUI	Req #
Perform Initial Detect, Classify, and Localize (DCL)					
Manage Tracks					
19. **Fuse Multi-Sensor Data**. OSFCI performs background multi-sensor Integration data fusion on the received tracks when appropriate. (Note: Operator review of the fusion results is discussed in later Step X)	Fuse multi-sensor data	OSFCI	N	N	FDSS 4
20. **Update System Track Database**. TRCI updates the CTP database with system tracks. This includes the towed array, hull array, and sonobuoy tracks. This picture may also include any helo-processed tracks and contact classification from known threat and signature data.	Update system track database	CMCI TRCI	N	N	FDSS 20
21. **Update Common Tactical Picture (CTP)**. TDCI/CMCI continuously maintains the CTP display. This also includes maintaining ownship position, cooperating forces and all other reported tracks. The CTP supports drilldown and display of the supporting information and data.	Generate updates to CTP	TDCI/CMCI	N	N	FDSS 20
	Display updates to CTP	TDCI/CDCI	D	CTP	FDSS 8
22. **Update Non-Organic Assets via SIPRnet** All designated system tracks (what attributes) are passed to participants					
a. **Receive Non-Organic Link Tracks**. This is track data received via data link/SIPRnet from Cooperating Forces such as other surface ships, submarines, as well as other sources including, 89/SIPS, National assets, etc.	Receive tracks	TRCI	N	N	FDSS 11
b. **Transmit Tracks to Non-Organic Platforms** The CTP will provide the capability to select and transmit fused tracks selected from the CTP to external USWDSS platforms via the TRCI	Operator select and transmit Format and forward tracks	SCC/ASWE TRCI	C, D N	CTP	FDSS 11, 12
23. **Cue Operator.** Generate operator alerts for new and previously held tracks exhibiting characteristics of interest on operator specified criteria and doctrine.	Generate alert	CMCI	N	N	FDSS 24
	Display alert	TDCI, CDCI	D	CTP	FDSS 24, 62
	Acknowledge alert	SCC/ASWE	C	CTP	FDSS 24, 62

Fig. 3. Operational Concept Document example

The OCD emphasizes the consideration of human factors at the earliest stage of the design cycle. Equally important is documentation of an artifact in a quick, efficient, and verifiable manner that lends itself to use by the software developers. This is critical because too often human factors professionals develop products that are of little use or do not impact design.

Beyond its main objective of better supporting the development of a more effective system, the OCD has additional benefits. First, the OCD contains a comprehensive list of operator tasks and will support development of training curriculum. Secondly, it will support system testing and verification. [1] proposed a test for requirements completeness based on defining required system behavior under all conditions (e.g. all scenarios). The OCD is traced to functional requirements and can easily be modified to support different scenarios to support operator, software, and usability testing.

5 Usability Verification: Click Stream Task Analysis

In order to provide quantitative data that compared three build versions of the USW-DSS Mission Planning System (MPS), a usability testing technique called the click stream task analysis was conducted on one released version of the system (Build 2) and two proposed redesigns. The initial proposed design incorporated task flow processes used in NWP 5-01 [5]. The second proposed design incorporated feedback from a heuristic evaluation.

This task analysis method is similar to a keystroke level model (KLM) in that we compared the number of mouse clicks needed for the user to complete a specified task. However, we were not able to track the time to complete each user interaction because our evaluation was limited to screenshot display images. The efficiency of the user flow through the task was tracked (i.e. does the user flip back and forth through GUI screens). An additional benefit from analyzing display screens at the keystroke level is that it provided us with a way to fully engage with the information design and interaction design, which informed the heuristic evaluation and system redesign.

We documented an SCC's or ASWE's anticipated stream of clicks when creating a Course of Action (COA) and following it through as it becomes the mission plan ready for execution. For our analysis, we documented the task being completed (e.g. Prepare for mission, Determine mission parameters), the system object (e.g. button or pull-down menu name), the user action (e.g. click, type, select from pull-down menu), system location (e.g. Details tab, Generate Products tab, Navigation Tree), result (e.g. Populates section, Work area opens to default settings, Highlights object), and any design discussion notes. Design discussion notes included questions we had when working through the task, any unneeded functionality, and redesign ideas. Even though they were not included in the number of clicks, cognitive tasks during the COA creation were also noted to aid the development of another HCI artifact called the task diagram. If a task was not included in all three builds, it was removed from the click count total. In this way, we were able to make sure we were comparing apples to apples. This standardization was important to ensure we were comparing how many clicks it took to do the exact same set of tasks consistently across all of the builds.

Based on the three click stream task analyses, there were differences between each of the 3 builds. Build 1 required 197 clicks to create a COA while Build 2 needed 170 clicks. The JHU/APL proposed solution for Build 3 used 156 clicks to create the COA. As such, each system build decreased the number of steps needed to accomplish the same task.

6 Conclusion

ASW development challenges (e.g., reduced manning, integrating legacy tactical decision aids, command and control, etc.) led to the use of new HCI approaches to ensure value-added within the design process. Building upon earlier design work in Build 1, this approach developed HCI artifacts in a streamlined manner so that the products could support developers and thus design earlier in the cycle.

We have presented four work-centered design artifacts including the ASW scenario, persona, OCD, and usability verification click-stream task analysis. Using a consistent work-centered approach for all products ensures the ASW operator is implicitly the focus. By using a top-down approach it is possible to develop scenarios that extend the designers understanding of the domain and requirements. Equally critical is that this approach demonstrates the subsequent steps in the OCD support a complete and correct set of requirements with respect to the scenario in a language that both human factors and software developers can leverage. The process of creating the personas is a valuable experience. In addition to helping the SE acquire domain knowledge, the single-sheet personas are a quick reference for the software team to learn more and understand the customer for who they are designing the system. The click stream task analysis served as an effective quantitative analysis to compare different system builds. All together, these four HCI artifacts supported the execution of an end-to-end analysis merging the benefits of top-down systems engineering with a bottom-up approach.

Acknowledgments

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