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Final Report on Human Factors Research Conducted under the COMDAT Technology Demonstrator Project

by

Michael L. Matthews, Lisa Rehak, Humansystems® Incorporated.
Sharon McFadden, DRDC Toronto.

Humansystems® Incorporated
111 Farquhar St., 2nd floor
Guelph, ON N1H 3N4

Project Manager:
Ron Boothby
Humansystems® Incorporated
(519) 836 5911

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On behalf of
DEPARTMENT OF NATIONAL DEFENCE

as represented by
Defence Research and Development Canada – Toronto
1133 Sheppard Avenue West
Toronto, ON, M3K 2C9

DRDC Scientific Authority
Sharon McFadden
(416) 635-2189

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Project Director

Michael L. Matthews
Humansystems® Inc.

Approved by

Sharon McFadden
Human Systems Integration Section

Approved for release by

K.M. Sutton
Chair, Document Review and Library Committee

Abstract

The purpose of the COMmand Decision Aiding Technology (COMDAT) Technology Demonstrator Project (TDP) was to research and demonstrate multi-source data fusion (MSDF) technologies and carry out human factors (HF) studies to support upgrades to the Halifax Class Command and Control System (CCS), in the area of battle space awareness. Since the requisite HF knowledge to support this TDP did not exist, the HF component included the generation of the founding knowledge necessary for decision aid development in future projects. The major work items included

- the conduct of cognitive and functional task analyses to define the information requirements of the major Operations Room positions on Halifax Class ships;
- the development of human-in-the-loop measures of performance in order to evaluate strategies for conducting performance evaluations, define current performance in the Operations Room, and evaluate technologies including MSDF;
- recommendations for improvements to human computer interfaces in the existing CCS and the Technology Demonstrator (TD);
- the development of a concept of operations for user involvement in MSDF; and
- support for an evaluation of operator-system picture compilation performance using the final TD.

The detailed results of the HF work have been published in a series of reports over the course of the project which lasted from June 2000 to March 2007. This final report provides a summary of the reports along with related material that informed and supplemented this work, some lessons learned, and recommendations for future work. Overall, we have a better understanding of the usefulness of the methods that were investigated as well as considerably more knowledge about the information requirements and processes involved in building the tactical picture in the Halifax Class Operations Room. In addition, we have generated improved guidance for designing the interfaces needed to support operator goals and tasks as well as a better understanding of the research needed to build even more effective interfaces and decision support systems for naval command and control.

Résumé

Le projet de démonstration de la technologie (PDT) d'aide aux décisions de commandement (COMDAT) avait pour objet d'étudier les technologies de fusion de données multi-sources (MSDF) et d'en faire la démonstration ainsi que de mener des études des facteurs humains (FH) à l'appui de mises à niveau du système de commandement et de contrôle (C2) des navires de la classe Halifax, dans le domaine de la connaissance de l'espace de combat. Comme la connaissance des FH nécessaire pour appuyer ce PDT n'existait pas, la composante FH comprenait la génération des connaissances de base nécessaires à l'élaboration d'aides aux décisions dans des projets futurs. Les principales tâches de recherche comprenaient :

- l'exécution d'analyses des tâches cognitives et fonctionnelles pour définir les exigences d'information des postes principaux dans la salle des opérations des navires de la classe Halifax;
- l'élaboration de mesures de rendement avec un chaînon humain dans la boucle afin d'évaluer des stratégies d'évaluation du rendement, de définir le rendement actuel dans la salle des opérations et d'évaluer les technologies, y compris la MSDF;
- des recommandations d'amélioration des interfaces humain-ordinateur dans le système C2 existant et le démonstrateur de la technologie (DT);
- l'élaboration d'un concept des opérations en vue de la contribution des utilisateurs à la MSDF;
- le soutien d'une évaluation du rendement de compilation d'un tableau de l'interface opérateur-système au moyen du DT définitif.

Les résultats détaillés des travaux en FH ont été publiés dans une série de rapports tout au long du projet, qui a duré de juin 2000 à mars 2007. Le présent rapport final résume ces rapports de même que du matériel connexe qui soutenait et complétait ces travaux, certaines leçons apprises et des recommandations de recherches futures. Somme toute, nous avons une meilleure compréhension de l'utilité des méthodes étudiées, ainsi qu'une connaissance beaucoup plus complète de l'information requise et des processus nécessaires pour constituer le tableau tactique dans la salle des opérations des navires de la classe Halifax. De plus, nous avons élaboré des directives améliorées pour concevoir les interfaces nécessaires pour appuyer les objectifs et tâches des opérateurs et acquis une meilleure compréhension des recherches nécessaires pour construire des interfaces et des systèmes d'aide aux décisions encore plus efficaces pour le commandement et le contrôle navals.

Executive Summary

Introduction:

Advances in threat technology, the increasing tempo and diversity of littoral scenarios, and the volume and ambiguous nature of data to be processed under time-critical conditions pose significant challenges for Command and Control Systems (CCS) in Canadian ships as well as the operators who must use these systems to defend their ship and fulfil their mission. Consequently, since the early 1990's the Canadian Navy has assigned a high priority to research and development leading to enhanced command, control, and information system capabilities in data and information fusion and decision support to provide an accurate, and more timely, integrated Maritime Tactical Picture in order to provide the Command Team with as complete an understanding of the situation and threats as possible. The COMmand Decision Aiding Technology (COMDAT) Technology Demonstrator Project (TDP) was initiated to support that effort through research and development in multi-source data fusion (MSDF) technologies and related human factors (HF) studies. The purpose of the current report is to summarize the HF work carried out under COMDAT. Since the requisite HF knowledge to support this TDP did not exist, the HF component included the generation of the founding knowledge necessary for decision aid development in future projects.

Results:

This final report provides a summary of the HF work carried out under COMDAT along with related material that informed and supplemented this work, some lessons learned and recommendations for future work. The major HF outcomes of the TDP were improved methods, tools, and knowledge about

- cognitive and functional task analyses to define the information requirements of the major Operations Room positions on Halifax Class ships,
- the development of human-in-the-loop measures of performance to define the current performance in the Operations Room and evaluate technology including MSDF,
- the design of human computer interfaces in naval command and control systems,
- the design of a concept of operations for user involvement in MSDF, and
- the design and conduct of the evaluation of operator performance on existing and new technologies.

Significance:

The results of this work have already informed the mid-life upgrade of the Halifax Class Operations Room and are expected to define the HF involvement in future naval acquisition projects.

Future plans:

Some of the recommendations for further work are being undertaken in other TDPs such as INCOMMANDS and in naval applied research projects.

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Sommaire

Introduction:

Les progrès de la technologie de la menace, la cadence accélérée et la diversité croissante des scénarios sur les littoraux, ainsi que le volume et la nature ambiguë des données à traiter dans des délais critiques posent d'importants défis aux systèmes de commandement et de contrôle (C2) à bord de navires canadiens, ainsi qu'aux opérateurs qui doivent utiliser ces systèmes pour défendre leur navire et s'acquitter de leur mission. Par conséquent, depuis le début des années 1990, la Marine canadienne a accordé une haute priorité à la recherche et développement menant à des capacités améliorées du système de commandement, de contrôle et d'information à l'égard de la fusion des données et de l'information et de l'aide aux décisions afin de fournir un tableau tactique maritime intégré exact et plus opportun dans le but de fournir à l'équipe de commandement une compréhension de la situation et des menaces aussi complète que possible. Le projet de démonstration de la technologie (PDT) d'aide aux décisions de commandement (COMDAT) a été lancé pour appuyer cette initiative grâce à la recherche et développement en technologie de fusion de données multi-sources (MSDF) et à des études connexes des facteurs humains (FH). Le présent rapport a pour but de résumer les travaux en FH effectués dans le cadre de la COMDAT. Comme la connaissance des FH nécessaire pour appuyer ce PDT n'existait pas, la composante FH comprenait la génération des connaissances de base nécessaires à l'élaboration d'aides aux décisions dans des projets futurs.

Résultats:

Le présent rapport final résume les travaux en FH effectués dans le cadre de la COMDAT de même que le matériel connexe qui soutenait et complétait ces travaux, certaines leçons apprises et des recommandations de recherches futures. Les principaux résultats en termes de FH du PDT étaient des méthodes, outils et connaissances améliorés dans les domaines suivants :

- analyses des tâches cognitives et fonctionnelles pour définir les exigences d'information des postes principaux dans la salle des opérations des navires de la classe Halifax;
- élaboration de mesures de rendement avec un chaînon humain dans la boucle afin de définir le rendement actuel dans la salle des opérations et d'évaluer les technologies, y compris la MSDF;
- conception d'interfaces humain-ordinateur dans les systèmes de commandement et de contrôle navals,
- élaboration d'un concept des opérations en vue de la contribution des utilisateurs à la MSDF;
- conception et exécution de l'évaluation du rendement des opérateurs utilisant des technologies existantes et nouvelles.

Portée:

Les résultats de ces travaux ont déjà contribué à la formulation de la mise à niveau à demi-vie de la salle des opérations des navires de la classe Halifax, et l'on s'attend à ce qu'ils définissent la contribution des FH aux projets d'acquisition navals.

Recherches futures:

Certaines des recommandations de recherches futures sont mises en œuvre dans le cadre d'autres PDT tels qu'INCOMMANDS et de projets de recherche appliquée navale.

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1 Background

The current Halifax Class Command and Control System (CCS) is based on a concept of operations and technology that derive from the late 70's and early 80's. Advances in threat technology, the increasing tempo and diversity of littoral scenarios, along with the volume and ambiguous nature of data to be processed under time-critical conditions pose significant challenges for the CCS and the operators who use these systems to defend their ship and fulfil their mission. Consequently, since the 1990's the Canadian Navy has assigned a high priority to research and development leading to enhanced Command and Control (C2) capabilities in data fusion and decision support to provide an accurate integrated Maritime Tactical Picture (MTP) in order to provide the Command Team with as complete an understanding of the tactical situation as possible.

In response to this requirement, Defence Research and Development Canada (DRDC) established the Command Decision Support Working Group (CDS WG) to determine the Research and Development (R&D) required for improved decision support for the Command Team. Many of the recommendations of the CDS WG (McCann, Chalmers, Flowers, Hix, Paradis, Pigeau, and Turner 1998) centred on medium and long term research in human factors (HF) including Human-Computer Interaction (HCI) and method and measures for assessing human-system performance. In addition, there was a requirement for behavioural and cognitive analyses to support the development of effective decision support. They recommended the following R&D activities:

- cognitive task analysis of the Operations Room Officer (ORO) function,
- literature survey of technologies for and HF aspects of naval decision support, and
- Cognitive Work Analysis (CWA) and Operator Machine Interface (OMI) requirements for computer-based decision support tools for the ORO.

In response to this recommendation, DRDC Toronto carried out a cognitive task analysis of the ORO (Matthews, Webb, and Bryant 1999b) and a literature survey on HF issues related to decision support (Bryant and Webb 1999) and DRDC Valcartier conducted a proof of concept study on CWA (Chalmers, Burns, and Bryant 2001). The results of these studies, together with analyses of current deficiencies in the Halifax Class Operations Room, led to recommendations for further research and design concepts for improving the CCS.

To support the short term requirements for improved decision support, DRDC approved the Command Decision Aiding Technology (COMDAT) Technology Demonstrator Project (TDP) to transition existing research on Multi-Source Data Fusion (MSDF) into the Canadian Forces. Since the corresponding HF knowledge was not available, COMDAT included a large HF component to provide both direct support to the development of the Technology Demonstrator (TD) and the founding knowledge for decision aid development in future projects. The major HF work items were as follows:

- Conduct a function and task analysis of the Halifax Operations Room positions to more fully understand their information requirements and how the positions interact in order to evaluate the potential impact of MSDF and to define the HCI requirements for future decision support systems.
- Define Human-in-the-Loop (HIL) Measures of Performance (MOPs) and trial some selected MOPs.

- Evaluate performance on the existing CCS using the MOPs developed under the previous work item.
- Suggest improvements to the OMI of the existing CCS and the TD.
- Develop Concepts of Operations (CONOPS) for user involvement in MSDF.
- Support the conduct of an evaluation of operator performance on the final TD.

1.1 Goals of the HF program to support the COMDAT TD

The ultimate goal of the above work was to develop a body of HF knowledge that could be used to support the TD as well as provide the founding knowledge for decision aid development in future projects. Specific goals for the HF work included

- enhanced knowledge of which OMIs are feasible and operationally useful, and
- the required domain knowledge to establish the evaluation capabilities to conduct HF work in future TDPs.

It was anticipated that this information would be provided through a series of reports produced during the TDP including the current report.

1.2 Structure of report

Section 2 of the report provides a summary of the most relevant research that informed the HF work under COMDAT. Prior to COMDAT's start, DRDC Toronto was actively researching the development of improved HF methods and measures to support the acquisition of new systems in the Canadian Forces. In addition other nations, in particular the US, were engaged in related efforts to develop a human centered approach to the design of naval systems. DRDC had access to much of this work through its participation in The Technical Cooperation Programme (TTCP), Human Resources and Performance Group (HUM) Technical Panel 9 (TP9): Human Systems Integration for Naval Systems. A brief summary of the most relevant aspects of that work is also included.

Sections 3 through 8 summarize the work completed under each of the COMDAT HF work units. Each of these sections has the following structure:

- title of work unit,
- goals of the work,
- parties responsible for the work,
- list of reports produced, and
- overview of each report including
    - abstract (from the report),
    - summary of work conducted
    - discussion and commentary from the present authors.

The report concludes with a section which outlines some lessons learned from the process and identifies areas where additional research may be required.

2 Prior Work

2.1 Relevant human factor research at DRDC Toronto

2.1.1 A framework for evaluating military command and control systems

Before the start of the COMDAT TDP, DRDC Toronto was actively engaged in developing generic requirements and methodologies that would provide guidelines to demonstrate how HF issues could be systematically integrated within a R&D program. The most relevant work for the COMDAT TDP was the specification of an overall framework to guide the process of evaluating performance of C2 systems that reflected both the contributions of the system hardware and software as well as human operators.

One significant publication to come out of this effort was the report:

"Matthews, M. L., Webb, R. D. G., and McCann, C. (1997). A framework for evaluation of military command and control systems. (DCIEM No. 97-CR-24). Human*systems* Incorporated, Guelph, ON."

A major conclusion of this report was that measures of performance provide more diagnosticity when they focus on system processes than outcome effectiveness. Further, the latter class of measures are often difficult to obtain under the required operational conditions and may lack sufficient reliability and validity, because of lack of control of critical variables of influence.

Three different human-system domains were identified as key to the evaluation of system effectiveness:

- *Function Usability:* compliance of system features, the Operator Machine Interface (OMI) and system functionality with HF guidelines and evaluated largely in terms of ease of use and utility;
- *User Fit:* demonstrated ability of the system to support user needs in key areas such as
  - situation awareness,
  - communication effectiveness,
  - decision support,
  - mental workload,
  - physical layout and environmental factors;
- *Operational Impact:* overall ability of the system to support users, working under representative conditions, to meet mission goals and sub-goals.

To provide a basis for the systematic capture of MOPs for critical C2 tasks, it was proposed that standard scenarios be created. These would range in complexity from simple strings of tasks or sub-tasks to more complex mission representations in order to challenge the capability of the system to meet the needs of users, as they work to achieve mission goals at the individual or team level. Using such standard scenarios, the three human-system domains would be evaluated using three distinct configurations employing simulation fidelity appropriate to the stage of system development. The three evaluation configurations are

- *Story Board*: Early in system development, operational and HF Subject Matter Experts (SMEs) systematically would walk through task based scenarios using low fidelity part or whole representations of the system concept (mock ups or story boards). These SMEs would assess features and predicted functionality for each evaluation domain (including compliance with HF guidelines) in terms of projected usability, user fit, and operational impact. Concept acceptance would be based on the outcome of this evaluation.
- *Test bed:* This evaluation configuration evolves in fidelity over the course of system development:
    a. Level 1: low fidelity representation of console, screens, or floor layout,
    b. Level 2: static test screens representing basic system part task functions,
    c. Level 3: part system functionality with task strings performed interactively,
    d. Level 4: fully functional prototypes configured for typical team operation(s).
- *Field trial or full scale simulation*: In this configuration, the full system is evaluated in a typical operational context. This would normally occur after installation at the first operational site.

The methods used to capture MOP data would vary across the three evaluation configurations, although some methods, such as rating scales and questionnaires, apply over all three configurations. At the story board level, OMI aspects of individual system components would be assessed against HF guidelines and design recommendations and checklists and ratings completed by HF and operational SMEs would be employed to assess basic elements of feature usability. In the test bed and field trial configurations, measures of effectiveness would be based on how well and how quickly mission critical tasks and goals are accomplished using prepared scenarios with the most typical measures being task completion time and accuracy.

As part of the literature review conducted for this report, several other important issues concerning the application of HF to the system development process were noted:

- Integrate verification (*Did the developers do the right things?*) and validation (*Does the system perform effectively with users in the loop?*).
- Apply HF from the start of development including concept acceptance.
- Have the HF effort be independent of the development group.
- Apply scientific reliability and rigor consistently in the measurement process to ensure that evaluation results will predict likely operational outcomes with some degree of confidence.
- Account for the context of operations: for example work volume and pattern, organizational structure, team interaction, training of test participants, workspace layout, and secondary tasks performed in parallel with the primary tasks (e.g. operation of supplementary systems, supervision).

The report also provided sample MOPs and addressed logistical issues concerning the capture of performance data in real time.

This framework was used as the basis for the development of methods and measures of performance covered in Section 4 on the development of MOPS.

2.1.2 Cognitive task analysis of the Operations Room Officer in the Halifax Class frigate

One of the major recommendations of the CDS WG (McCann et al. 1998) was to conduct a Cognitive Task Analysis (CTA) of the ORO position in the Halifax Class frigate. It was required to better understand the cognitive aspects of C2 in the Operations Room (Ops Room) as a prelude to preparing evaluation measures to assess future C2 support systems. The ORO position was selected for analysis from among other Ops Room positions as being the position with the most comprehensive responsibilities, most likely to provide a broad insight into C2 functions and to generalise to other positions.

The reports produced under this work package were:

Matthews, M. L., Webb, R. D. G., and Bryant, D. J. (1999). Cognitive task analysis of the Halifax-class Operations Room officer. (DCIEM No. CR 1999-028). Humansystems Incorporated, Guelph, ON.

Matthews, M. L., Webb, R. D. G., and Bryant, D. J. (1999). Annexes to: Cognitive task analysis of the Halifax-class Operations Room officer: Data sheets. (DCIEM No. CR 1999-029). Humansystems Incorporated, Guelph, ON.

Matthews, M. L. and Webb, R. D. G. (2000). Validation of cognitive task analysis (CTA) for the Halifax-Class ORO. (DCIEM-CR-2000-066). Humansystems Incorporated, Guelph, ON.

The CTA (Matthews, Webb, and Bryant 1999a; Matthews et al. 1999b) was based on interviews with eight pairs of experienced OROs. Each interview session lasted two days and walked interviewees through an operational scenario, which was based on a training exercise from the Halifax Class land based training simulator. OROs were prompted to describe their cognitive activities based on experience with similar events to those in the scenario. The ORO position in question was in a Halifax Class vessel in the forward screen, with no Task Group (TG) warfare duties.

Although, conducted in the context of one position, as well as constrained by current technology and procedures, the objective was to identify functional goals and associated cognitive needs that were device independent. Based on a previous review of the literature for C2 systems, four key functional areas were used to focus the interviews and for development of evaluation measures. These were situation awareness, communication, decision making, and mental workload.

Selected observations arising from the interviews (and expanded in the report) include the following:

- OROs employ a variety of mental models to organise their cognitive demands. Mental models vary in terms of level of detail, domain, and abstraction; they may be modulated by career path, experience, other team members, mission planning, watch hand-over, and recent events.
- Information systems need to provide less data and more "information" i.e. pertinent data meaningfully integrated in terms of the users' mental model(s). This implies a need for functional support that can be readily adapted by "educated" users to individual, contextual, and mission related needs.
- Mission preparation plays a major role in establishing mental models that will be employed during the mission operation.

- The core ORO function is to *manage* the overall Ops Room team picture compilation and threat response activities, rather than to be directly involved in the details of executing these functions. However, the ORO does become involved in both of these functions when existing team resources are not able to fully manage multiple threats.
- In the case of situation awareness, major requirements include information acquisition and integration, cognitive fit of the available data to the mental model(s) of the user, regaining awareness after switches in attention between different areas of focus, and alerts for unattended areas.
- Background tasks such as handling text messages interact significantly with ongoing operational responsibilities and require the ORO frequently to switch mental models.
- Handling of multiple threats particularly in areas of high traffic density are likely to remain a difficult information processing challenge. This challenge is increased if the ship is assigned TG responsibility for a warfare area.

After the work was finished, there was some concern about the completeness and hence overall accuracy of the results including

- the completeness and accuracy of the scenario used during CTA interviews,
- the completeness and accuracy of goal related activities identified by CTA OROs,
- the taxonomy of mental models used by OROs to manage information, and
- the proposed measures of cognitive performance.

A validation (Matthews and Webb 2000) was conducted by reviewing the CTA scenario and results with four OROs who had not participated in the original CTA. OROs were interviewed in pairs and interviews lasted one day for each pair. CTA results were also compared with standards for evaluation of OROs during training and pertinent elements of the United States Universal Naval Task List.

It was concluded that the results of the CTA were largely accurate and, with a few changes in terminology, could probably be generalised to other naval missions beyond the initial scenario used. Exceptions or areas of uncertainty were the omission of certain aspects of an ORO's work in the CTA scenario rather than any distortion introduced by inaccuracies in the scenario. Further, the original CTA scenario was found to have insufficient emphasis on, or absence of the following:

- an overall mission objective (as opposed to reactions to individual threat events),
- ORO planning functions before and during a mission,
- ORO Task Group assignments such as warfare duties,
- ORO co-ordination or de-confliction of ship board activities from a mission perspective, and
- missions such as humanitarian aid involving interaction with organisations outside the Navy.

The structuring of the results of the CTA into background (Ops Room management) and foreground (threat response) goals was seen as potentially confusing and unable to cover all combinations of ORO responsibilities. However, proposed measures of performance were seen as appropriate and feasible and are already in use informally by individual instructors during assessments of the ORO and other positions.

The primary utility of these reports was to identify the critical situation awareness elements and associated C2 decisions from the perspective of the ORO. Of some surprise, the role of the ORO was seen as primarily that of a manager of Operations Room processes, rather than as a primary participant in tasks of picture building, threat and situation assessment, and response execution. Under normal circumstances, the ORO relies on each of the warfare teams to adequately build and assess the picture and make recommendations on Course of Action (COA). It is only when the workload associated with one of these activities exceeds a warfare team's capacity that the ORO will act as the primary information processor and assessor of tactical information, by taking over command responsibility for a warfare sector.

In evaluating the utility of these findings for the COMDAT TD, it was evident that the primary information needs of the ORO position were unlikely to be addressed by the level 1 or 2 fusion capabilities (Roy 2001) that were expected to be the focus of the TD. Consequently, it was recognised that many of the information requirements associated with tactical picture compilation and threat assessment were likely to be better addressed by considering MOPs that focussed on warfare team members more directly involved with those processes than the ORO.

One criticism of the analyses could be that they were based exclusively on concepts of situation awareness, decision making, communication, and workload derived from prior report recommendations on how to measure C2 processes. As such, the issue of situation analysis appears to have been overlooked as an important area of C2 activity. Further, the cognitive analyses were not tied to specific theoretical constructs such as work domain analysis or hierarchical goal analysis.

2.2 Relevant research from TTCP HUM TP9

HUM TP9 is responsible for conducting collaborative research, of mutual benefit to TTCP nations, aimed at integrating human factors into the design of safe, manpower efficient, and cost-effective systems for current and future naval platforms. Collaboration under TP-9 is carried out in three main areas:

- technology drivers: evaluating the application and implications of new technology for naval systems,
- acquisition process: the insertion of HF into the acquisition process for naval systems, and
- tools for optimising naval platform manning requirements.

Over the past several years, research conducted jointly and separately by member nations in each of these areas has been made available to all members. In particular, the research on technology drivers proved of immense value to COMDAT. The results supplemented and validated many of the results and recommendations arising out of the studies carried out under COMDAT.

One of the earliest collaborative outputs from HUM TP9 was a generic model of the Human Systems Integration (HSI) process. The model emphasises functional analysis, which is the key to HF application in systems design. In conjunction with operational scenarios and descriptions of the operators' experience, the functional analysis provides the context of use that is required for the development of the operator-machine interface.

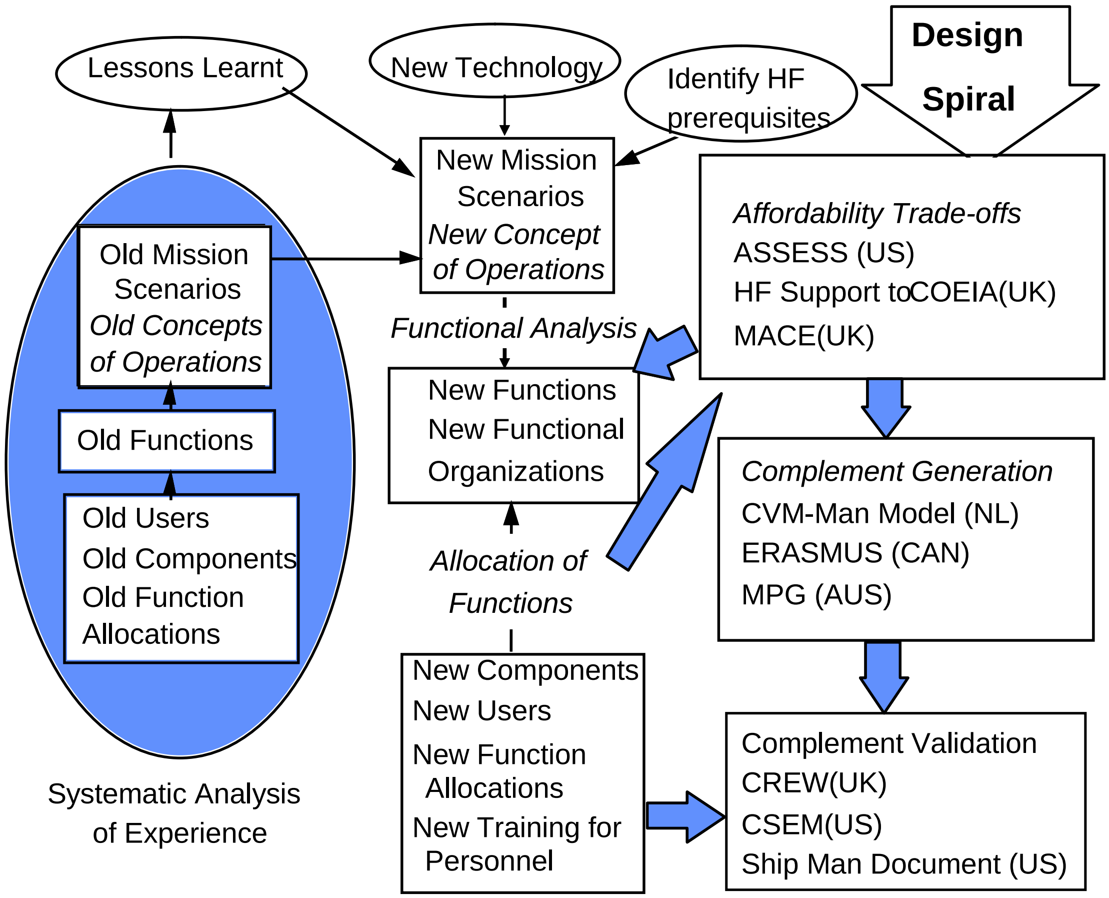

Figure 1: Generic model of the Human Systems Integration process

The development of the COMDAT HF work items did not follow this model completely, but the model's influence can be seen in the over all pattern of research. The requirements analysis was aimed at capturing the existing mission, functions, and concepts of operation as well as providing insight into new functions that would be required (Sections 3 and 7). Measures of performance were developed to support the evaluation of new decision support design concepts (Section 4) while the baseline analysis was necessary to do design trade-offs (Section 5). The HCI work unit (Section 6) was aimed at supporting the development of HF prerequisites. Finally, the design spiral was captured in the proposed HF evaluation of the Technology Demonstrator (Section 9).

The model was also used as part of a large US project on manning affordability[1]. This project's ultimate goal was to provide the processes, tools, interaction guidelines, and procedures required to optimize a combat systems environment for the warfighter at reduced manning levels. As with COMDAT, the project involved the development of human performance models and metrics, human-centered design tools, and OMI technologies, but on a much larger scale. Many of the OMI technologies were implemented and evaluated in the Multi Modal Watch Station (MMWS) and the Integrated Combat Environment (ICE). The former simulated a futuristic work station for a combat

[1] Details on this project which ran from 1996 to 2000 can be found at http://www.manningaffordability.com/S&tweb/Index_main.htm.

systems operator, while the latter simulated a possible Operations Room incorporating the MMWS. The results from this and related US projects have proven of immense value to COMDAT. For example, research on the development of methods and measures for assessing performance (Kellmeyer and Osga 2000) supported recommendations made under COMDAT for measuring human performance in the COMDAT TD. As well, evaluations of traditional and experimental symbol sets to support more effective information processing (Kirkpatrick, Dutra, Heasly, Granda, and Vingelis 1992a; Kirkpatrick, Dutra, Lyons, Osga, and Puggi 1992b; NAVSPAWARSYSCOM 1991) both informed and complemented the symbology studies carried out under COMDAT Finally, the Combat Systems Functional Allocation Board (CSFAB) Human-System Interaction (HSI) Style Guide (Osga and Kellmeyer 2000), provided under HUM TP9, was one of the sources for the COMDAT Style Guide. Annex A provides a detailed summary of the most relevant studies.

In addition to the specific knowledge acquired through the individual studies, the success of the manning affordability project supported the institutionalization of a human centered design process into the US Navy acquisition process. Through a series of HUM TP9 workshops, the Canadian Navy was made aware of the approach and outcomes of this project and as a result has instituted a more human-centered approach to acquisition. One recent example was the request for a more extended requirements analysis than originally planned for under COMDAT. Finally, many of the design concepts and OMI technologies evaluated under the manning affordability project are being considered by HMCCS.

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3 Requirements Analysis

3.1 Goals

The goals of this work were to perform a requirements analysis of the operators in the Operations Room of a Halifax Class frigate. As with any requirements analysis, the purpose is to document the existing functions and tasks performed in order to provide important information for system designers.

The positions of interest were the

- Commanding Officer (CO),
- Operations Room Office (ORO),
- Sensor Weapons Controller (SWC),
- Assistant Sensor Weapons Controller (ASWC),
- Information Management Director (IMD),
- Operations Room Supervisor (ORS),
- Warfare Officer,
- Track Supervisor (TS),
- Electronic Warfare Supervisor (EWS),
- Air Raid Reporting Operator (ARRO), and
- Anti Submarine Plotting Operator (ASPO).

3.2 Responsible parties:

The Multi Function Task Analysis (MFTA) and Hierarchical Goal Analysis (HGA) were contracted to CMC Electronics and the Cognitive Work Analysis (CWA) was contracted to Human*systems* Incorporated.

3.3 Reports Produced

Coates, C. and Kelleher, D. (2002). Task analysis of the Halifax Class Operations Room Officer (ORO) Sensor Weapons Controller (SWC) and Assistant Sensor Weapons Controller (ASC) positions: Mission, function and task analysis report. (DRDC Toronto CR 2002-219). CMC Electronics Ltd, Ottawa, ON.

Langille, R. and Kelleher, D. (2002). Task analysis of the Halifax Class Sensor Weapons Controller (SWC) and Assistant Sensor Weapons Controller (ASWC) positions: Mission, function and task analysis report. (DRDC Toronto CR 2002-024). CMC Electronics Ltd., Ottawa, ON.

Coates, C. and Kelleher, D. (2002). Task analysis of the Halifax Class Operations Room Officer (ORO) Sensor Weapons Controller (SWC) and Assistant Sensor Weapons Controller

(ASC) positions: Information flow and processing analysis report. (DRDC Toronto CR 2002-220). CMC Electronics Ltd, Ottawa, ON.

Coates, C. (2006). Human factors analyses of operator positions in the Operations Room of the HALIFAX Class frigate. (DRDC Toronto CR 2006-117). CMC Electronics Ltd., Ottawa, ON.

Matthews, M. L., Keeble, A.R and Bruyn Martin, L. (2007). Analysis of the role of Dempster-Shafer algorithms to support recognition of surface and air contacts by Halifax Class Operations Room operators. (DRDC Atlantic CR 2007-091). Human*systems* Inc., Guelph, ON.

Matthews, M.L., Keeble, A.R and Sartori, J. (2007) Decision Ladder modelling of the recognition and identification processes for surface and air contacts on the Halifax Class frigate. (DRDC Atlantic CR 2007-093). Human*systems* Inc., Guelph, ON.

3.4 Summary of reports

The different requirements analyses of various positions in the Halifax Class Operations Room (Ops Room), conducted prior to and under COMDAT, covered a very broad spectrum of approaches to documenting the processes in building the tactical picture. The following summary provides the reader with a very general understanding of what each methodology provided:

- *Cognitive Task Analysis (CTA)*: provided a higher level view of the cognitive demands at the ORO position. The need for management of the Ops Room was identified together with the problem of the ORO constantly having to switch task and operational focus while still maintaining both tactical and management situation awareness as well the lack of current systems to support such activities (Matthews et al. 1999a; Matthews et al. 1999b).
- *Mission Function Task Analysis (MFTA)*: provided a detailed description of the tasks as they are currently performed by the SWC, ASWC and ORO. Critical tasks were identified. The task set comprised both picture compilation and ship response activities. The results identified critical tasks that could be re-assigned from operator to machine. The level of detail of the approach did not extend to a fine grain analysis of the tasks that would inform specific design solutions for specific operators (Coates and Kelleher 2002b; Langille and Kelleher 2002).
- *Information flow and processing analysis*: provides operational sequence diagrams and identified the critical information flow between the ORO, SWC and ASWC and from these positions to other operators and external agencies (Coates and Kelleher 2002a).
- *Hierarchical Goal Analysis (HGA)*: provided, for each operator position, the goals associated with what the system needed to achieve in different operational contexts. Stability analysis revealed potential sources of instability and suggested design solutions. Information flow analysis (upwards only) showed information bottlenecks and the overload on the auditory communication channel (Coates 2006).
- *Analysis of the role of Dempster-Schafer (D-S) and decision ladder modelling*: provided a finer-grain account of the detailed sequential activities involved in contact recognition and identification by the Above Water Warfare (AWW) team. Specific operational contexts where D-S may assist the operators were identified. The specific information used by operators at each stage of the process was identified together with the source and type of

data provided (Matthews, Keeble, and Bruyn Martin 2007a; Matthews, Keeble, and Sartori 2007c).

3.4.1 Task analysis of the Halifax Class Sensor Weapons Controller (SWC) and Assistant Sensor Weapons Controller (ASWC) positions: Mission, function and task analysis report.

Task analysis of the Halifax Class Operations Room Officer (ORO) Sensor Weapons Controller (SWC) and Assistance Sensor Weapons Controller (ASWC) positions: Mission, function and task analysis report.

Excerpt from executive summaries (no abstracts)

CMC completed a traditional MFTA of the SWC and ASWC positions, representing activities through the range of missions carried out by those positions in the HALIFAX Class frigate during peacetime, transition to war and wartime operations. The aim of the MFTA was to identify the critical tasks performed by the SWC and ASWC, and to quantify the frequency of interaction and methods of interaction between the SWC/ASWC and the ORO. CMC then updated all work items of the SWC/ASWC MFTA to identify the critical tasks performed by the ORO and the interaction between the ORO and higher Command.

The MFTA of the SWC/ASWC positions produced a task inventory of 1155 tasks. When the ORO position was added this number grew to over 2600. The tasks rated as critical (33%) were subjected to a further analysis. These analyses of the ORO, SWC and ASWC positions establish a baseline database of the process conducted by the Ops Room team and therefore provide the basis for assisting future system re-design efforts.

3.4.1.1 Summary

Introduction

The aim of these reports was to document the methodology and results of the MFTA. Tasks related to decision making and the transfer of information, particularly within the Ops Room, were the primary focus of the analysis.

Analysis methodology

There were 4 stages to the analysis:

- Mission analysis,
- Function analysis,
- Task analysis, and
- Critical task analysis.

SMEs were used to augment the domain knowledge available within CMC.

Mission analysis results

The mission analysis started at a high level looking at missions that have been conducted by the Canadian Maritime Forces (peacetime operations, operations other than war, and wartime operations). Then, the mission analysis looked at the Halifax Class frigate (weapons, sensors, and organizational structure). Next, the focused shifted to the Ops Room and its systems, missions, personnel, and organization. Subsequently, details on the SWC/ASWC and ORO's responsibilities were outlined. Finally, a composite scenario was created that focused on the critical mission segments performed by the SWC and ASWC.

Function analysis

A function analysis identified the sequence of functions that must be performed by the system through a series of function flow diagrams. The detailed analysis was included in an Annex.

Task analysis

A task analysis was then performed. An Annex contains the detailed analysis which included the following information for each task identified:

- task number and description;
- initiating conditions;
- action, feedback, information and communication requirements;
- information available;
- decision component and requirements;
- frequency;
- accuracy required;
- interaction with ORO;
- Interaction with Command (in second report only);
- Task criticality rating; and
- Criticality rationale (addresses if human performance limits are being approached; whether or not the analysts feel that further analysis may or may not result in improvements).

Critical task analysis

The critical task analysis highlighted the critical tasks relative to five performance indicators (safety, mission effectiveness, efficiency, system reliability and cost). 28% of the tasks were deemed 'critical' in the original report that focused only on the SWC/ASWC. When the ORO was added in the second report the critical tasks increased to 33%. In the critical task analysis each tasks current function allocation (operator or machine) and risk mitigation was added to the task analysis.

Critical task reallocation

The current function allocation was further analyzed, and reallocation from operator performing the task to machine performing the task was suggested for purposes of risk mitigation. From the first report there were seven tasks outlined for transfer:

1. Conduct IFF interrogation.
2. Recognize radar jamming.
3. Identify chaff.

4. Assess acoustic data.
5. Initiate symbology on contact.
6. Input harpoon target calculations for firing.
7. Determine harpoon panel calculations for launching harpoon.

After the critical task analysis was completed with the addition of the ORO, 8 tasks were added that if automated would reduce risk:

8. Check ASW interfaces.
9. Select optimum sensor.
10. Determine location.
11. Assess radar data.
12. Assess effects of radar jamming.
13. Recognize air contact.
14. Establish position of contact passively.
15. Resolve towed array bearing ambiguities.

Concluding material

All objectives of the mission, function and task analysis of the ORO, SWC and ASWC positions were achieved. A number of conclusions and recommendations were made, including the identification of a pool of SMEs that are maintained throughout the study for project continuity (only in the first report) and further work to analyse the tasks and interactions of the Commanding Officer (only in the second report).

3.4.1.2 Discussion

These reports outlined a baseline list of tasks that must be performed by the ORO, SWC, and ASWC. A scenario was also chronologically outlined which may prove useful for further analysis or evaluation activities. The 15 specific tasks, that if re-allocated from operator to machine could reduce risk of mission failure, may provide a logical starting place for design, especially since they have already been validated by Navy SMEs.

The analysis method chosen (MFTA) is inherently detailed oriented. Thus, the design suggestions that arose were at a low level. A similar criticality analysis of higher level tasks may provide design suggestions for other aspects of the system.

The treatment of the SWC and ASWC as a single position until the lowest level of tasks shows the similarity between the two positions. However, it does not easily lead to any suggestions concerning the re-organization of responsibilities between the two operators. The level of decomposition of the tasks does not go down to a level of detail that would inform system designers on how a MSDF capability could be mapped onto the specific tasks of detection, recognition and standard identification at the operator level. As well, it would not allow specific recommendations to be drawn on useful approaches to OMI design or required changes in the Concept of Operations (CONOPS).

3.4.2 Task Analysis of the Halifax Class Operations Room Officer (ORO) Sensor Weapons Controller (SWC) and Assistant Sensor Weapons Controller (ASWC) positions: Information flow and processing analysis report.

Excerpt from Executive Summary (no abstract)

Following the results of the MFTA of the ORO, SWC and ASWC, an Information Flow and Processing Analysis was conducted all three positions. This report documents the methodology and results of the Information Flow and Cognitive Processing Analysis. It includes the Operational Sequence Diagrams (**OSD**s), which graphically depict mission segments against a timeline, and an analysis of the information and decision-making requirements of identified critical task sequences. Eight OSDs were generated, depicting elements from all three top-level functions or missions performed by the HALIFAX Class frigate, Conduct of Transit Operations, Conduct of Peacetime Operations and the Conduct of Wartime Operations. From these OSDs, 15 critical task sequences were identified, examining the information flow between the ORO, SWC and ASWC, as well as between these positions and other operators in the Operations Room, other departments within the ship, and external agencies.

Summary

Introduction

Three objectives were outlined: (1) develop network models; (2) identify critical task sequences; and (3) conduct information Flow and Processing Analysis for the identified task sequences. There are 6 sections to the report, not including Annexes.

Analysis methodology

A network simulation tool within IPME was used to develop a model of the functions performed by humans in conducting mission segments from the composite scenario (created during the MFTA). The network model consisted of 3 Operational Sequence Diagrams (OSDs). A performance prediction analysis was also carried out. Design symbology for the OSD was also outlined in this section along with the methodology used for the information flow and processing analysis.

Network model

The roles and responsibilities of the participants of the network model (ORO, SWC, ASWC) were described. The use of external agencies for the network modelling was explained, followed by explanations on the development of the OSDs. The network model was only used on mission segments that were determined likely to lead to the identification of decision-making and information flow issues and requirements for the Ops Room team. Annex B of the report contains the 8 OSDs covering 3 different mission types:

- OSDs involved with ‘Conduct transit operation’,
- an OSD outlining ‘Conduct peacetime operations’, and
- OSDs associated with ‘Conduct warfare operations’.

Information flow and cognitive processing analysis results

The information flow requirements and decision making process requirements to accomplish mission objectives were analysed in 15 critical task sequences. These 15 task sequences were selected based on a subjective assessment of their importance to the mission segment and the likelihood of identifying requirements/issues. Each task has an associated ‘Summary of findings’ that lists recommendations and general conclusions specific to the task sequence.

Concluding material

Conclusions were made based on the information flow analysis and observations made by the CMC team during this phase of the project. Additionally, there were 7 recommendations that are summarized below:

- Complete an information flow analysis of all Ops Room personnel (at minimum CO, Officer of the Watch (OOW), ORS).
- Carry out a quantitative performance analysis of key Ops Room personnel.
- Include the HALIFAX Class frigate employed as a Command ship in future analysis.
- Include SMEs serving on the West Coast in further analysis.
- Investigate the feasibility of developing a detailed checklist/handbook for each position in the Ops Room (Canadian Forces Naval Operations School (CFNOS) suggested to create).
- Conduct Maritime Interdiction Operations/Information Operations modelling.
- Examine the physical layout of the Ops Room and operator positioning for optimization.

Discussion

This report adds to the baseline information already collected concerning Ops Room personnel tasks. Though the final conclusions/recommendations included in the main body of the report do not outline suggestions on changes to the current Ops Room, the actual analysis contained in Annex C (Information Flow and Operational Sequence Analysis) does provide a number of specific suggestions to optimize performance of the Ops Room. Most of the changes are small, but collectively they could provide significant improvements.

3.4.3 Human factors analyses of operator positions in the Operations Room of the HALIFAX Class frigate.

Abstract

Results are provided for the analyses of eleven operator positions in the Halifax Class frigate Operations Room using the Hierarchical Goal Analysis (**HGA**) approach. Following mission analyses, a hierarchy of goals assigned to different operators was produced. Two follow-on analyses were conducted to identify potential instabilities in the system and requirements for upward information flow between operators. Operational Sequence Diagrams (**OSD**s) were produced for five critical task sequences and the corresponding task networks were implemented and tested in the Integrated Performance Modeling Environment (**IPME**). The final product of the project was the generation of a list of critical Operations Room activities supported by proposed solutions. The report concludes HGA and IPME are suitable tools to support the analyses of complex predominantly 'cognitive' systems.

Summary

Analysis methodology

Four different analyses were conducted (with assistance from SMEs) on 11 operator positions in the Halifax Class frigate:

1. *Hierarchical Goal Analysis (HGA)*: models a cognitive system consisting of one or more operators by identifying goals, at various levels of abstraction, which the system needs to achieve. Goals are desired states to which current states are compared.
2. I*nformation Processing/Perceptual Control Theory (IP/PCT) Model*: represents the operator's allocation of attention and human memory together with a framework for tracking the load on the operator's information processing system. The model was implemented in IPME. The IP/PCT data was then used to generate the upward information flow analysis (there is a need for information flow when one operator controls a goal that supports a goal controlled by another operator) and stability analysis (looking to see if more than one operator controls the same external variable).
3. *Task networks:* The IPME model requires a chronological set of events in order to run the program and identify periods of operator loading. The networks represented five critical task sequences.
4. *Critical activities:* A modified Cooper-Harper Scale was used to rate goals using criteria for safety, mission effectiveness, and human performance capability. The goals with higher values in any of the rating criteria were then further analyzed to provide potential solutions.

After a detailed description of each type of analysis, the report included a brief description of the analysts' interaction with SMEs as well as an environmental analysis that summarized the environment in which the Halifax Class frigate is required to operate.

Hierarchical Goal Analysis

There were a total of 562 goals outlined. Complete listings of the top level, first, and second level goals are included in the main body of the report. Goal allocation and usage are included in the Annex. The report notes that a 'bottom-up' review of the goal decomposition should be conducted to validate the top-down process used by the analysts in the HGA.

Junior operators tend to repeat goals more frequently in their day-to-day activities, so while they are as occupied or as busy as the senior operators, they are allocated fewer unique goals. The SWC has the most goals because as a director he/she is responsible for surface and air picture compilation and warfare. In a general-purpose frigate this effectively doubles the SWC's responsibilities in comparison to the ASWC, who is only responsible for subsurface picture compilation and warfare.

IP/PCT

For each of the 562 goals, a Perceptual Control Theory (PCT) table was created. Completing the PCT analysis was challenging; especially the resolution of the internal, external and controlled variables. The technical authority was used in place of SMEs for review of the tables due to their volume and the corresponding time required to fully review them. In the end, the PCT data proved extremely useful for subsequent analyses.

Stability analysis

Given the large and complex nature of the Halifax Class frigate, the number of external variables identified as being controlled/influenced by more than one operator (13 variables) is low. A detailed discussion is included that outlines additional potential sources of instability (e.g. shared responsibilities, conflicting goals, etc.) and suggests solutions. For example

- Limit access to equipment controls to the primary and secondary owner of the goal responsible for those specific settings.
- Implement shared situation awareness displays.
- Ensure visibility of the (ideally electronic) stateboard to all operators who require information.
- Lock out non-critical users from CCS.
- Include a greater capacity for overlays, including the ability to preview the screen to visualize a planned overlay.
- Increase use of real time text based communications.

The report also noted that a complete list of instabilities was not included due to demand on the operators and future complex organizational analyses should include all operators that support the completion of a goal in the instability analysis.

Upward information flow analysis

Different presentation methods for the upward information flow were tested throughout the project and resulted in the development of an interactive viewer that optimized data display. This display was presented to the SMEs, and observations recorded. A major observation was that the volume of verbal reports puts an overwhelming demand on the auditory channel, while the visual stimuli are quite limited. A limitation noted in the report is that only an upward information flow analysis was conducted, but lateral and downward communications should be added to provide a complete link analysis.

Task networks

OSDs were developed on a goal by goal basis and provided representations of the critical operational sequences to SMEs. After validation, the tasks were run through IPME where many technical glitches were discovered – mostly related to the IPME scheduler – and a full system implementation was not possible. Single runs and multi-threat scenarios were successfully conducted, and the results presented. For SME validation, the IPME outputs were not as useful as desired. A lack of OSDs of the entire network, no straightforward ways to combine outputs from different runs, and novel terminology/concepts all made SME validation of IPME outputs difficult.

Critical activities

No single operator or group of operators had a monopoly on critical activities. The CO had the highest percentage of activities considered critical, followed by the ASPO and EWS respectively. In discussions with SMEs, 63% of activities were considered for proposed solutions. The majority of solutions recommended automating displays and data entry, as well as the integration of tactical command decision aids.

Conclusions/recommendations

The analysis methodologies were found to be applicable to the complexities of the Halifax Class Ops Room. As such, the information collected during this project was useful for the OMI specifications for the upgrade to the Ops Room and was applied to the redesign of the operator workstations, operator interface, and Ops Room layout.

Discussion

This report provides a large number of practical and specific suggestions concerning the advancement of the current Ops Room on a HALIFAX Class frigate. The stability analysis, upward information flow analysis, task networks, and critical activities analysis all resulted in functional change suggestions. The extent to which the specific suggestions are effective cannot be shown yet; however, the issues identified are based on a thorough analysis validated by SMEs. It should be noted that none of the listed solutions mention how, or if, multi-sensor data fusion would be advantageous.

The SMEs' difficulty in using IPME output to validate the model was noted which points to the need to make such output more usable to the operational community.

The OSDs included in the annexes provide a detailed understanding of the actions the different operators are required to perform, including the recognition/identification process. Communications between different operators are clearly shown. Analysts wanting a better understanding of the Ops Room are encouraged to review the material. The level of decomposition and analysis for the conduct of recognition and identification process is probably insufficient to inform design aids for these processes at the individual operator level. Readers should consult Matthews, Keeble and Bruyn (2007) and Matthews, Keeble and Sartori (2007) for this kind of detail.

3.4.4 Analysis of the role of Dempster-Shafer algorithms to support recognition of surface and air contacts by Halifax Class Operations Room operators

Abstract

This report integrates thirteen work items completed under the COMmand Decision Aid Technology Demonstration Project (COMDAT). The goal of these work items was to document the existing recognition and identification processes for air and surface contacts performed by the Above-Water Warfare (AWW) team of the HALIFAX Class frigate. The report provides an analysis of the potential role that Dempster-Shafer (D-S) algorithms for evidential reasoning might play to support contact recognition and identification. Finally, potential air and surface scenario events where D-S may assist the team were devised.

Summary

This work addresses the requirement to investigate and develop a concept of use that would potentially allow D-S functionality for evidential reasoning to be deployed in the CCS to provide effective support to Ops Room operators in the conduct of recognition and standard identification of air and surface contacts. The investigation included operator roles, information flows, operator-automated system interaction schemes, and interface design.

The report provides a detailed analysis of the recognition and identification processes as they are currently conducted for air and surface contacts based on the ship's current sensor suite and off-board data sources as well as its current information acquisition and integration procedures.

The phases of the work included the development of a technical plan, interviews with Navy SMEs, analysis of the results, graphing and tabulation of information flow sequences, and evaluating the role that might be played by D-S algorithms to support evidential reasoning by the ship's team.

Within the constraints on the existing analyses, the data did not reveal operational situations involving detection, identification, and recognition where D-S functionality (as it was considered to be implemented in the TD) could be seen to have a role in enhancing the normative processes involved. There are some circumstances, where crew attention is elsewhere, or there are high rates of contacts, that may point to a limited role whereby D-S recommendations could enhance situation awareness and decision making.

The analyses suggest that the major processes of evidential reasoning, which prove challenging for the crew, are in the association of EW information with radar data, and the assessment of contextual information. Therefore, it was suggested that it was these aspects of analysis and decision making that could be fruitfully explored in the context of a more generic MSDF capability that embraces broader information usage than currently implemented in the TD.

The report also identified a potentially important role in recognition for D-S and MSDF with more generic capabilities than were implemented in the TD. Such a role has been outlined in some detail in Keeble, Matthews, Lamoureux, Berger, and Zobarich (2007).

Finally, the circumstances of twelve surface and twelve air events were documented that could give rise to the useful application of MSDF and/or D-S technology. The events were created through a "brainstorming" process but are based to some extent on SME experience and interview data. Two

of the events were then selected to show in detail how MSDF and D-S functionality could be implemented to support team recognition.

Discussion

These studies provide a very detailed account of the recognition and identification of air and surface contacts by the Ops Room Command Team using a timeline analysis. The level of detail in describing these processes and the granularity of analysis are finer than with other analyses produced under the COMDAT TDP. The analysis showed somewhat surprisingly that there was not much evidence to show that D-S algorithms that incorporated level 0 and level 1 fusion concepts (Roy 2001) would support the typical evidential reasoning undertaken by operators on single contacts. When evidential reasoning is used, it tends to involve the use of information based upon context and behavioural characteristics of contacts, or involves decisions concerning the association of EW information with platform tracks. Thus in order for D-S algorithms to have a useful role in contact recognition, some form of level two evidential reasoning would need to be incorporated, as well as an ability for algorithms to have access to information that is available to the team but does not come through MSDF sensor sources.

However in spite of this finding, the study goes on to show some recognition situations where D-S based evidential reasoning algorithms could assist a team that was inattentive or otherwise overloaded. The twelve specific air and surface situations identified could represent some interesting test cases to evaluate the performance of any future evolution of the HALIFAX Class CCS for its ability to support the recognition process.

3.4.5 Decision Ladder modelling of the recognition and identification processes for surface and air contacts on the HALIFAX Class frigate.

Abstract

This report presents results of an analysis of the surface and air picture compilation processes by the Operations Room personnel of a HALIFAX Class frigate using a decision ladder modelling approach. The analysis focused on the Recognition and Standard Identification of a single air and surface contact and the management of these processes. The goal of the analysis was to identify the information-processing activities operators need to perform in recognition and standard identification, the major short-cuts between these processing activities, and the knowledge states that result from these activities. This was done to inform future design considerations to support the integration of multi-sensor data fusion technologies into future enhancements to the HALIFAX Class Command and Control System.

Summary

This project focussed on the picture compilation process for air and surface targets using a Decision Ladder (DL) analysis methodology to uncover the primary processing activities and knowledge states. The DL analysis examined specifically the recognition of a single air or surface contact and the management of these processes.

The DL approach requires an organisation of the material into a ladder structure as indicated in the standard template for a DL representation in the figure below. An important part of the DL analysis is the identification of "leaps" and "shunts", which represent short-cuts that are taken by skilled and experienced operators.

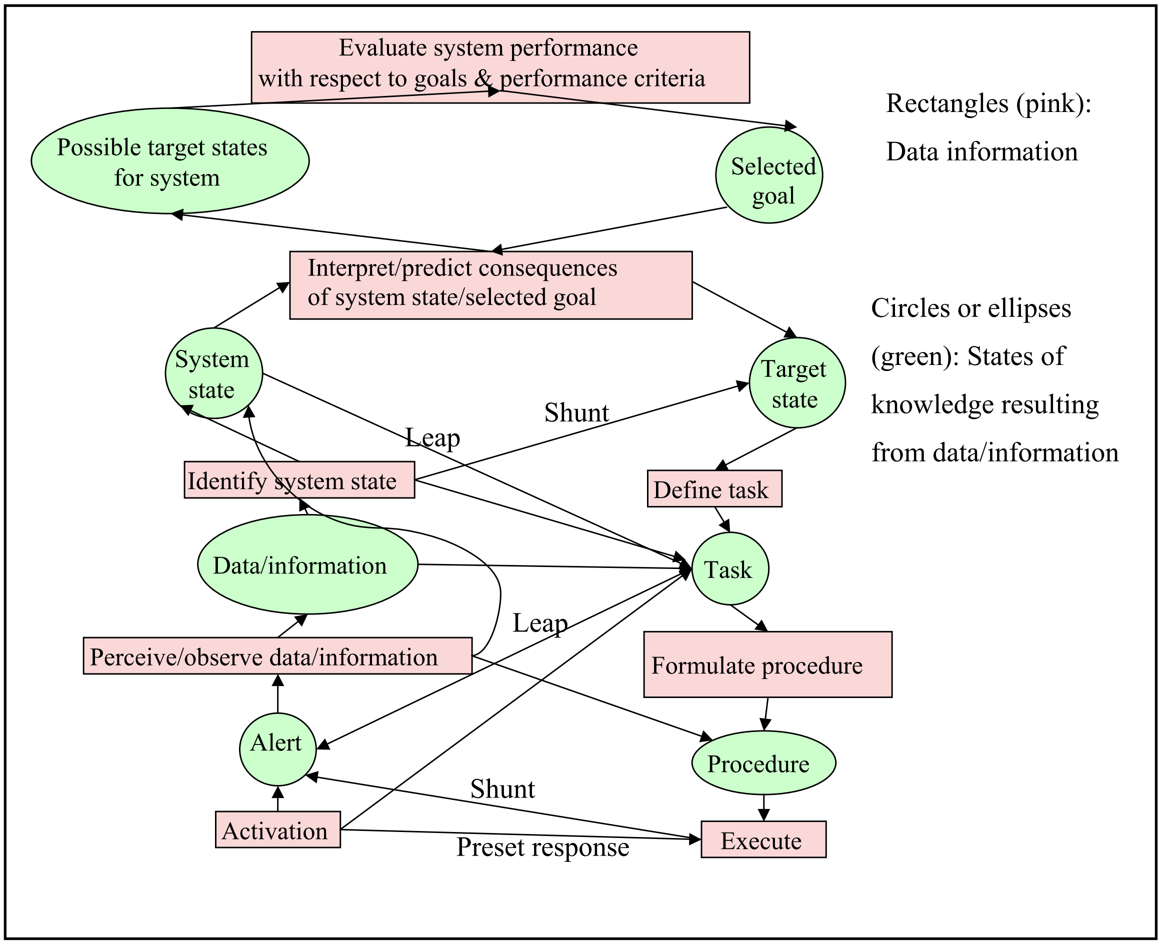

Figure 2: Representational template for a generic Decision Ladder

The analysis also provided

- a description of the "system",
- the goals, and
- performance metrics for evaluating system states, goals, and performance and resolving competing goals.

In addition, the detailed descriptions of each processing activity included information on its

- purpose,
- information used, and
- a priori information used

Direction from the Scientific Authority indicated that the approach to be taken was a formative description, rather than a serial analysis of the sequential process steps. In particular, one goal of the analysis was to identify short-cuts in the process that might identify opportunities for future design improvements to the CCS to integrate MSDF and D-S capabilities.

The information used to conduct the analyses was based on interviews with Navy SMEs, other analyses conducted in support of COMDAT, and relevant Navy documentation.

The first step in the analysis involved creating a detailed inventory of the information sources; this involved providing details on the following:

- source information
- recognition, identification and derived information
- significance of context and lack of information, and
- presentation format

Following this initial step, the decision ladders for recognition and identification of an air contact were evolved. These formed the basis for developing a similar representation for a surface contact. Finally, the DL for the management process was created, a task made simpler by the prior creation of the other DLs.

The analyses revealed a number of short-cuts in every DL, typically between the system state and tasks or procedures. This outcome reflected the fact that the process involved highly trained and experienced personnel, who could quickly go from an awareness of the state of the system to the required action demanded by that awareness. However, some aspects of the management process did require an evaluation of options and a weighing of action alternatives, thereby involving more nodes in the DL. For all of the analyses, the step of formulating a procedure was typically not seen to be an integral component of the behaviour of experienced personnel.

Discussion

This report provides a highly detailed account of the processes and knowledge states that support recognition and standard identification of an air and surface contact. The strengths of the analyses are

1. They provide in one place a very coherent description of what is done in the recognition and standard identification processes, and what specific information is used at each step of the processes, together with the source(s) of that information. Therefore, the analysis provides some value-added over traditional methods.
2. The information source inventory provides a valuable reference for those wishing to understand what information is provided by a specific source that contributes to recognition and identification including the limitations and value of that information.
3. The analyses show in a generic sense what processes are required and what can be skipped over (shortcuts) in the conduct of recognition and standard identification.
4. The formative nature of the analyses allows for an understanding of what generic support could be provided in the future to enhance the Halifax Class CCS.

The major limitations of the analysis are

1. Because the analyses provide a generic description of what is done, they cannot inform the support requirements for a specific operator doing a particular task at a fixed point in time in recognition or identification.
2. It is also not clear how the DL approach allows for a simple representation of the links between functions. Within each function there are multiple tasks and processes, each of which may possibly link to a task or process in another function.
3. In view of the multiple prior analyses, it is not clear what new information was provided by the DL approach. While the DL method has resulted in a tight integration and documentation of the processes performed, the knowledge states and information used and its sources, it is not at all obvious what insights have been gained as a result of this re-mapping. For example, even the identification of shortcuts was pre-empted by some of the results of the more serial analyses using information-flow or process sequence methods discussed previously.

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4 Development and evaluation of measures of performance

4.1 Goals

The goals of this work were

- to use the outcomes of existing cognitive and other task analyses to identify useful MOPS to evaluate critical C2 processes, centred on the ORO;
- to evaluate methodologies and environments that would be suitable for creating reliable and valid MOP data; and
- to conduct feasibility and proof-of-concept assessments of the suitability of methodologies and environments identified as potential approaches to MOP data collection.

4.2 Responsible parties

All of this work was contracted to Human*systems*® Incorporated.

4.3 Reports Produced

Matthews, M. L., Webb, R. D. G., Stager, P., and Keeble, R. (2001). Evaluation of potential test environments for assessing the impact of multi-sensor data fusion on command and control operations in the Halifax Class frigate. (DCIEM No. CR 2001-071). Human*systems* Incorporated, Guelph, ON.

Matthews, M. L., Webb, R. D. G., Keeble, A. R., and Lamoureux, T. M. (2004). Development of measures of performance for evaluating the COMDAT technology demonstrator: Potential use of the Naval Combat Operator Trainer (NCOT) for data collection. (DRDC Toronto CR 2004-009). Human*systems* Incorporated, Guelph, ON.

Matthews, M. L., Webb, R. D. G., Keeble, A. R., and Lamoureux, T. M. (2004). Development of measures of performance for evaluating the COMDAT technology demonstrator: Potential use of training records from the Operations Room Team Trainer (ORTT). (DRDC Toronto CR 2004-010). Human*systems* Incorporated, Guelph, ON.

4.4 Summary of reports

4.4.1 Evaluation of potential test environments for assessing the impact of multi-sensor data fusion on command and control operations in the Halifax Class frigate.

Abstract

This report reviewed five training simulator facilities in the Canadian Navy for their suitability in conducting test and evaluation (T&E) in support of the COMDAT multi-sensor data fusion (MSDF) initiative. The facilities were the Operations Room Team Trainer (ORTT), the Naval Combat Operator Trainer (NCOT), the Combat Systems Training Centre (CSTC) and Halifax Class Operations Room at harbourside or at sea.

It was concluded that the NCOT would be the most suitable facility for conducting T&E using single operators performing simple operational functions such as detecting and tracking radar contacts.

For more complex functions in the Ops Room, including tasks involving interactions between complete warfare teams, interactions between warfare directors and the ORO, and between the ORO, CO and the entire Ops Room team, the report found that the ORTT represents a more suitable environment for conducting T&E activities.

Summary

A systematic evaluation was conducted of potential trial environments suitable for the execution of COMDAT related T&E trials with a goal of collecting real-time, human-in-the loop (HIL) performance data. A set of detailed capabilities requirements for conducting T&E was developed under the four major categories of: logistics, experimental control, data collection and storage, and analysis. Each of the potential facilities was reviewed and evaluated against these requirements and the results tabulated. The review took into account earlier work developing a framework for evaluating military information systems (Matthews, Webb, and McCann 1997) as well as data fusion levels (Roy 2001). This framework considered the need to conduct iterative evaluations of human performance during development in terms of part, whole, and team tasks at several levels of prototype design under mock up, test bed or simulator, and sea trial conditions. Existing Navy systems used for collecting performance data were also reviewed. The capabilities of each facility were then assessed for their suitability for conducting the expected range of T&E activities.

It was concluded that the NCOT would be the most suitable facility for conducting T&E using single operators performing simple operational functions such as detecting and tracking radar contacts. While more limited in its simulation fidelity than the ORTT, the NCOT facility appeared to be the most versatile to configure and the most economical to operate. NCOT allowed the collection of T&E data for several operators performing the same task in parallel. NCOT also appeared suitable for assessing performance of small teams of 2-4 individuals performing more complex, interacting functions. This assessment was based upon the expectation that the contractor responsible for NCOT would deliver software that supports this level of functionality within the next year.

For more complex functions in the Ops Room, including tasks involving interactions between complete warfare teams, interactions between warfare directors and the ORO, and between the ORO, CO and the entire Ops Room team, the ORTT represented the preferred environment for conducting T&E activities. A range of scenarios has been developed for team training in the ORTT, which could be adaptable for T&E purposes.

Severe constraints on the availability of the ORTT (and possibly the NCOT) were noted, due to ongoing training demands from the Navy. Further, the necessary personnel infrastructure to support trials, (e.g. game players, controllers and communicators) in the ORTT is high and is constrained by personnel availability. Such limitations may preclude the possibility of conducting dedicated T&E trials in the ORTT.

Discussion

The assumption behind these investigations of potential test environments was that they could be made available for T&E purposes to evaluate the impact of COMDAT technology on real-time human-system performance in the conduct of critical C2 tasks. Of the various options that seemed feasible for such purposes, it was recommended that proof of concept trials be conducted in both NCOT and the ORTT to assess their actual capability and limitations using a scenario-based approach. In particular, there would be a need to demonstrate a capability to reliably, accurately and effectively capture MOP data of interest.

Limitations

There is very little discussion of the possibility of inserting the COMDAT Technology Demonstrator into these environments. In part this was due to a lack of a good understanding of what the COMDAT TD would look like and be capable of doing at the time the report was prepared. In addition, the report would have benefited from a general discussion of what form of human centred T&E might be conducted in the different facilities given that the required capabilities did not exist.

4.4.2 Development of measures of performance for evaluating the COMDAT technology demonstrator: Potential use of the Naval Combat Operator Trainer (NCOT) for data collection.

Abstract

This report compiles the information contained in five other reports and Technical Memoranda pertaining to the development of Measures of Performance (MOPs) for Multi-Sensor Data Fusion technology. The report evaluates the logistics and the utility of the Naval Combat Operator Trainer (NCOT) to gather these MOPs. The report recounts the development of specific MOPs, the conduct of a proof-of-concept trial at NCOT (with attendant identification of potential system improvements), the outcome of discussions with the contractor responsible for the maintenance and operation of NCOT regarding enhancements, and the investigation of one potential commercial-of-the-shelf solution for some of the improvements described. As a result of identifying these potential improvements, it was recommended that team records created during Navy team training in Operations Room Team Trainer (ORTT) be considered as a better source for deriving MOPs.

Summary

A series of studies was conducted to evaluate the NCOT environment as a suitable candidate for gathering MOPs to evaluate the COMDAT technology against baseline performance. The first study (also published as Matthews, Webb, and Keeble (2002)) developed a set of MOPs based on the cognitive task analysis outlined in Section 2 (Matthews et al. 1999b) and a comprehensive plan for evaluating the impact of future command decision aid technologies on human and operational performance in the Halifax Class Ops Room. The plan outlined an incremental approach to T&E to generate reliable and valid performance data for a range of critical tasks performed by the Ops Room team, with a general focus on the role of ORO.

A series of data collection trials were proposed that would match the developmental sequence of MSDF and other technologies that formed the basis of the COMDAT TD. This sequence was to involve (i) an initial concentration on the integration of above water warfare (AWW) sensors and Link 11, followed successively by (ii) integration of surface aspects of AWW sensors and Link 11, (iii) integration of all UWW sensors, and (iv) all of the former integrated with the wide area picture (WAP).

For each trial a detailed description was provided of the logistics (personnel, software support and facilities) that would be required to prepare, conduct and analyse the trial. Trials would be scenario-based, with the scenario content largely focussed on the warfare area that the TDP was designed to support. The trial sequence would involve the initial collection of baseline performance data using existing technologies to serve as a subsequent comparison for the same operational tasks aided by the COMDAT technology. Requirements for the test scenario were provided in detail including the geographical, environmental, political and military contexts, the game entities and their dynamics, and the sequence and number of events. It was recommended that these initial trials be conducted in the NCOT facility, which appeared to provide many of the requirements for the first stage of evaluating the most immediately emerging TDP functionality, while minimising the logistical overhead to support the trial.

The initial effort focused on MOPs for AWW as well as the generic situation awareness needs of the ORO in assessing threats and building the tactical picture. It also provided details of the research design in terms of the number of data trials and test participants that would be needed to achieve the required sensitivity to detect effects of interest.

The second study involved an initial assessment of the capability of NCOT to support real-time data collection using intact Ops Room teams performing tasks of picture compilation and threat assessment. The outcome of this assessment led to a third report which provided specific recommendations for software enhancements to the NCOT facility that would be required in order to allow reliable and effective data collection and efficient analysis. One limitation of the NCOT environment from the perspective of T&E was the lack of an adequate capability for playback, review and analysis of team behaviours during a test scenario. Consequently, the fourth report evaluated COTS products to provide the required playback/analysis capability and recommended that it be integrated into the NCOT environment, if future T&E were to be considered in this facility. The final report outlined discussions with the contractor for the NCOT software on changes that would be required in the functionality of the existing software to meet the needs of future T&E trials.

Discussion

The report provides a good set of initial MOPs that could potentially be used to evaluate the utility of the COMDAT TD. The proposed strategy for conducting T&E and the detailed plan provide a useful model for any one interested in conducting human centred T&E. It identified many risks that are often not considered until too late in the process. These included

- the ability of the NCOT facility to support team-based scenarios and capture the required T&E data,
- the availability of an adequate number of Navy personnel to act as test participants,
- the exact manner in which the TDP will be implemented and how it can be interfaced with the test environment,
- the possibility that operational realism may have to be traded against the requirement to capture reliable and valid data, and
- the generalisability of the findings to broader mission contexts.

The remaining sections, while valid at the time, are of less long term value. In the end, the capabilities of the NCOT facility were not sufficient to support the requirements for full scale T&E trials. With the additions recommended in Sections 3 through 5 of the report, it could be usefully employed for evaluations of OMI functionality and design concepts at the single operator level, for which the minimal overhead and logistics requirements would provide for an effective and efficient test environment.

4.4.3 Development of measures of performance for evaluating the COMDAT technology demonstrator: Potential use of training records from the Operations Room Team Trainer (ORTT).

Abstract

This report compiles the information contained in three Technical Memoranda pertaining to the development of Measures of Performance (MOP) for Multi-Sensor Data Fusion (MSDF) technology, and evaluates logistics and the utility of the Operations Room Team Trainer (ORTT) to gather these MOPs. The report outlines the development of a strategy for collection of MOPs, the conduct of a proof-of-concept trial at ORTT (with attendant identification of potential improvements to the data collection strategy), and the investigation of methods to reduce the logistical and availability problems associated with obtaining access to Subject Matter Experts. The major conclusion of the report was to recommend against the conduct of real time trials dedicated exclusively to the collection of COMDAT TD relevant MOPs. Instead, it was proposed that MOPs be derived from the archived records of existing, intact ship's teams undergoing evaluations and exercises in the ORTT. As a result, a full-scale, investigation of the ability of the archived ORTT training records data to provide performance data for the COMDAT TDP was initiated.

Summary

All thinking in the previous studies (Matthews, Webb, Stager, and Keeble 2001); (Matthews, Webb, Keeble, and Lamoureux 2004a) about the methods by which baseline and TD enhanced MOPs could be collected had centred upon the conduct of live trials dedicated specifically to T&E requirements. However, detailed exploration of the logistical requirements to support such trials, indicated that such an approach was unlikely to be implemented given the availability of the ORTT, supporting logistical personnel, and ships' teams.

The first section of this report, therefore, outlines an alternative method for gathering MOP data to support the COMDAT TDP. This method involved analysing archived performance data collected during ship work-ups and training, therefore requiring less logistical coordination and control over the ORTT. The report provides an initial assessment of using ORTT training records as a potential source of COMDAT relevant MOPs, based on the observation of an actual team training exercise and evaluation of the real-time data record.

Several merits to the proposed approach were identified:

- No additional burden on the Navy for T&E trials with support personnel and trial participants.
- Data collected from a wide range of Navy personnel, thereby improving reliability and generalisability of MOP data collected.
- Ongoing use of the ORTT for training provides many opportunities for collecting T&E data.
- A large ORTT database of exercise records representing Navy personnel operating under quasi-operational conditions from which performance data can be extracted.
- Detailed data from T&E assessments using intact teams could provide important insights to the Navy about team performance issues not readily ascertained when the team is assessed during training.

Using pre-recorded scenario data from the ORTT was also seen to have some disadvantages:

- No direct T&E control over the trial, for example to vary circumstances in a systematic manner or to inject situational awareness "probes" into the information stream.
- Scenarios could not be repeated precisely because training exercise controllers introduce events depending upon how the team under observation was performing.
- T&E could not request a "SITREP" to assess situational awareness of any team member at a particular point in time.

Overall, the initial assessment indicated that there was merit to pursuing this approach and recommended that a "proof-of-concept" trial be conducted to make a final determination as to whether this would be a suitable approach for efficiently collecting valid and reliable data.

The second, and major, section of the report outlines the conduct and outcome of the proof-of-concept trial. For COMDAT, the practical goal of any trial was to evaluate the operational impact of MSDF technology on critical Ops Room tasks. The technology impacted most directly on the picture compilation component of the overall detect-to-engage process. Therefore, it was recommended that the technology could best be assessed by measuring key processes in the detect-

to-resolve cycle using appropriate MOPs. These MOPs were expressed in quantitative terms such as percent accuracy, percent errors, time to perform certain tasks, total time spent in associated communications and percent communication errors.

The specific goals of the ORTT POC trial were as follows:

- Observe a training scenario in action and note areas of interest to the T&E team for potential MOP extraction.
- Assess the practicality of inserting T&E "tags" into the scenario record during scenario execution to assist in subsequent MOP analysis.
- Develop a methodology for analysis and recording of the captured data.
- Analyse the digital video and audio record (using ORTT Debrief software) to build the ongoing team picture and communications for selected events.
- Analyse the supplementary video and audio record (using a standard VCR) to build the ongoing team picture and communications for selected events.
- Derive quantifiable MOPs from the previous analyses.
- Determine range of potential MOPs that could be assessed using the methodology.
- Make recommendations for the specific subset of MOPs that would be most suitable for assessing the impact of MSDF technology in future trials.
- Comment upon the effectiveness and efficiency of the data extraction and analysis methodology and its implications for logistical and other support in future trials.

Data extraction

For the purpose of the pilot study, it was decided that relevant data would be extracted from the scenario record for scenario segments that focussed on air, surface, and subsurface picture building. Scenario playback, and therefore data extraction, for each event started just prior to initial registration of the air, surface and subsurface contact on the CCS. Scenario playback and data extraction for each scenario event ended at the point of resolution or at the end of threat engagement for the air, surface and subsurface contact. In total, it took approximately 12 hours of initial data extraction by 3 persons to capture 75 minutes of the scenario.

The following data, extracted from video (CCS display) and audio playback of scenario events were logged directly into a spreadsheet by the T & E team:

- Network communications including the specific network over which the communication occurred (e.g. C & C, TG Command), the identity of the person sending the communication, the identity of the person receiving the communication and the content of the communication.
- Local picture information, such as range scale, at critical points in the scenario playback (printouts of the CCS display provided this information as well).
- Hooked tracks at critical points in the scenario playback.
- Time of occurrence for each network communication, local picture change, keystroke, or significant event logged.

- Additional comments noted by the experimenter for future reference. For example, an Ops Room Team member might have been on a different network channel and therefore missed an attempted communication from another Ops Room Team member. This represents important information that would not be captured by the above data extraction methods.

The results of the analysis produced sixty potential MOPs across air, surface and sub-surface warfare areas that could be extracted from the records. Of these, concrete examples and data were provided for nineteen and a further eleven were identified as being feasible to extract, given appropriate scenario circumstances and/or time for more in-depth analysis. The trial clearly demonstrated that the ORTT data record provides a capability to capture a number of MOPs that relate to the critical processes of the detect-to-resolve cycle and picture compilation and associated communications. The report provides a recommendation for the preferred subset of MOPs that would be most suitable for assessing the impact of MSDF.

The final section of the report, which dealt with an unrelated issue, but which was of interest to DRDC, addresses how to get access to Subject Matter Experts for blocks of time to participate in trials or to meet with contractors to explain operational procedures and processes. This brief report addresses problems in obtaining this access and outlines ways to lessen demand and administrative burden whilst still providing the required SMEs to contractors.

Discussion

The major contribution of this work was to show the viability of analysing data from existing ORTT training records to support the requirements of the COMDAT T&E program in terms of providing baseline metrics for existing system performance with respect to above water warfare tactical picture compilation. The primary drawback to the approach is that it is currently limited to the existing CCS. The scenarios are designed to support training requirements and would not necessarily be optimum for establishing baseline performance of tasks relevant to specific Technology Demonstrator Projects.

5 Baseline Performance of the Halifax Class Operations Room

5.1 Goals

The primary purpose of this work thrust was to provide data for selected MOPs that would describe HIL performance on the existing Halifax Class CCS on key tasks relevant to the potential future application of MSDF technology. The MOPS selected were derived from previous report recommendations as outlined in Section 4 above. The approach taken was based directly upon the work described in 4.4.3 in which ORTT records captured during team work-ups were subsequently analysed and metric data extracted.

5.2 Responsible parties

All of this work was contracted to Human*systems*® Incorporated.

5.3 Reports produced

Matthews, M. L., Keeble, A. R., Bruyn Martin, L., and Sartori, J. (2007). Baseline performance measures of the detect-to-recognize and identify process in anti-air and anti-surface warfare: Analysis of Operations Room Team Trainer (ORTT) training records. (DRDC Toronto CR 2007-029). Human*systems* Incorporated, Guelph, ON.

5.4 Summary of reports

5.4.1 Baseline performance measures of the detect to identify process in anti-air and anti-surface warfare. Analysis of Operations Room Team Trainer (ORTT) Training Records.

Abstract

The goal of this project was to create a baseline data set that would represent typical performance of the processes of air and surface contact detection, recognition and identification by the Operations Room team of HALIFAX Class frigates. Archived data from the Operations Room Team Trainer (ORTT) Navy training records were analysed to yield metric data for a number of measures of performance (MOPs) for critical tasks that had been identified from prior Human Factors analyses. The detailed analysis of the resulting data set is provided in a classified Annex. Summaries of the contact types, data trends and broad findings are reported below. Limitations in the data and their utility for baseline comparison for future technology enhancements are discussed.

Summary

As part of the HF thrust of the COMDAT project, it was determined that an effort should be made to quantify and measure any performance increments that might accrue through future enhancements to the Ops Room systems of the Halifax Class frigates in support of picture compilation. To support this effort, several HF analyses were conducted of the "detect- to-identify" process and MOPs were developed that focused on a wide range of operator tasks and operator positions.

Following the development of MOPs, an evaluation was performed of several possible Navy environments that would support the requirements for conducting T&E trials (Matthews et al. 2001; Matthews et al. 2004a)

As a result of this assessment, it was determined that the logistical requirements for implementing full T&E trials were too difficult to surmount. As a result, it was decided to explore the possibility of using Navy training data that had been archived in the ORTT as a means of creating baseline performance metrics for critical tasks, against which future technology enhancements could be evaluated (Matthews, Webb, Keeble, and Lamoureux 2004b).

Proof of concept trials were conducted to assess the feasibility of this approach. Following the successful outcome of these trials, a more sustained effort was undertaken to capture a range of performance data from available, archived data sets. This effort is the subject of this report.

The project proceeded in two phases: initially, only air warfare was analysed; subsequently, the analysis focused on surface warfare. The air analysis examined four data sets which represented different teams participating in an Operations Team Training 2 (OTT2) assessment (the final assessment that "certifies" that they are fully operational and ready). Forty four air contact events (fifteen-assumed friend; one-suspect; twenty six-hostile and two-neutral) were analysed from the data sets and task time data were extracted for the following primary metrics:

- initiate and complete resolve,
- first and subsequent identification (ID) states, and
- associate Electronic Support Measures (ESM).

The full analysis and details of the MOPs data are provided in a separate classified report. It includes data on task performance time and performance errors. It was concluded that the majority of the errors could have been ameliorated if decision aids based on MSDF were available.

In the case of surface picture compilation, five data sets were analysed from ORTT trials, yielding a total of ninety seven surface contacts that were recognized and identified. Again, the results of these analyses were provided in a separate classified report. Surface recognition times ranged widely and frequently reflected the time required to deploy assets closer to contacts of interest in order to gain further recognition data. The majority of contacts were recognized to "*poss(ible) high type*", followed by "*prob(able) class*". The primary information used for recognition assessments came from human judgment of contact behaviour rather than from sensor data in itself. Again, several errors were identified and in each case, the availability of MSDF decision support may have mitigated the situation.

The report concludes with a discussion on the reliability and generalisability of the data and makes several recommendations for future work.

Discussion

This work appears to have met the requirement to provide a quantitative, baseline data set that represents the time required for critical tasks in air and surface recognition and identification. The data accurately represent the performance of the current system, as reflected by the effort of experienced teams working with complex scenarios that are designed to evaluate and "certify" their operational readiness. There was sufficient data available to allow many of the important time-based metrics to be assessed. However, in order to reduce some of the variance in the data, some additional data sets should be analysed.

Limitations

The major limitation of the obtained data reflects constraints within the training scenarios with respect to the number of simultaneous contacts that a team is expected to be successful in dealing with, and the rate at which contacts are presented. In general the contact level and rates are such that a competent team, working efficiently, does not fall behind in the recognition and identification process. However, it has been frequently suggested that MSDF technology may be most beneficial in those circumstances where the operating environment is characterised by high air and surface contact rates, with a heterogeneous mix of contact types. Under such conditions, MSDF would increase the overall system performance envelop by working in the background to process all contacts and compliment the work of the team. Therefore, the very kinds of conditions (high load and high contact rate) where one would like to assess the incremental performance due to MSDF are not represented in the baseline data collected in the ORTT. The report recommends one approach to solving this problem by using the baseline performance data to build an accurate task network model to simulate the identification and recognition processes, and then to vary the input.

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6 Suggestions for improvement to the Operator Machine Interface for the Halifax Class CCS

6.1 Goals

The goals for this work were to

- Review the state of knowledge with respect to OMI guidelines relevant to the CCS.
- Provide system designers with a COMDAT style guide that would contain clear guidelines on the design of screen elements and interfaces in the development of new displays for future C2 systems and upgrades.
- Review the TD for compliance with the style guide.
- Conduct an analysis of methods for representing contact data certainty on tactical displays, obtain operator feedback on display design options, and recommend a preferred OMI.
- Conduct experiments in areas where additional information would be required to support the development of the COMDAT OMI.

6.2 Responsible Parties

The first 4 goals were contracted to Unger Campbell and Associates**.** The last goal was completed by DRDC Toronto**.**

6.3 Reports produced

Unger Campbell, G. (2001). Command Decision Aiding Technology (COMDAT) Operator Machine Interface (OMI) study: Version 1.0. (DCIEM CR 2001-172). Unger Campbell and Associates, Delta, B.C.

Unger Campbell, G. (2001). Command Decision Aiding Technology (COMDAT) Operator-Machine Interface (OMI) style guide: Version 1.0. (DCIEM CR 2001-151). Unger Campbell and Associates, Delta, B.C.

Unger Campbell, G. and Baker, K. (2003). Command Decision Aiding Technology (COMDAT) symbology and design study. (DRDC Toronto CR 2003-036). Unger Campbell and Associates, Langley, BC.

Unger Campbell, G. (2004). Command Decision Aiding Technology (COMDAT) Technology Demonstrator (TD) Operator Machine Interface (OMI) Style Guide Compliance and Enhancement. (DRDC Toronto CR 2004-129). Unger Campbell and Associates, Lynnwood, Washington, USA.

Unger Campbell, G. (2004). Command Decision Aiding Technology (COMDAT) Operator-Machine Interface (OMI) style guide: Version 2.0. Unger Campbell and Associates, Langley, B.C.

McFadden, S.M., Li, A. and Trinh, K. (2007) Representing data quality on naval tactical displays. (DRDC Toronto TR 2007-032). Defence R&D Canada - Toronto, Toronto, ON.

McFadden, S.M., Jeon, J., Li, A., and Minniti, A. (2007) Evaluation of symbol sets for naval tactical displays (DRDC Toronto TR 2007-046). Defence R&D Canada - Toronto, Toronto, ON.

6.4 Summary of reports

6.4.1 Command Decision Aiding Technology (COMDAT) Operator Machine Interface (OMI) study: Version 1.0

Abstract

This report provides supplemental and background material related to the development of the COMDAT OMI Style Guide for Navy Command and Control operations. The material is presented in five chapters. Three chapters comprise background materials as follows: the purpose and outline of the COMDAT OMI Style Guide, a literature review, and a discussion of making the documents available on the World Wide Web. The remaining two chapters present respectively a discussion of Naval symbology and a discussion of identified Human Factors and Usability issues in specific command and control functions of a Halifax-Class Canadian Patrol Frigate (CPF).

Summary

Purpose of the style guide

The purpose of creating a COMDAT style guide was to provide design guidance for the OMI of the COMDAT technology demonstrator. The intended users of the style guide were, in the short term, those Defence R & D Canada personnel who are involved in the development of the COMDAT Technology Demonstrator. The ultimate users of the technology will be the fleet personnel, although they will not use the style guide per se.

In the long term, the COMDAT OMI Style Guide should apply to new technology that will be deployed in the fleet. Accordingly, the style guide was designed to incorporate each of the following requirements:

- Adhere to current forms of doing business (to take advantage of the current fleet knowledge base).
- Address current HF knowledge and practices to provide enhancements using new information.
- Provide for growth (to permit integration of new technology and techniques).

Literature review

This comprised a comprehensive review of published reports on a wide range of OMI issues for C2 from a variety of operational domains. The majority of these reports were published in the last ten years. The annotation indicates which reports provided material for inclusion into recommendations for the style guide.

One of the major recommendations to emerge from the style guide was to shift from a traditional Open Source Format (OSF)/Motif style to a Microsoft (MS) Window style. The report clearly identifies those aspects of the latter style which would not be appropriate for application in a Navy Halifax Class C2 context.

Symbology

The recommendations focus on the symbology needed to support the information requirements of the back row Command Team of a Halifax Class Ops Room. They cover the tactical display symbology for these operators and the symbology required to support MSDF. Issues considered include the information needs of the team, representation of MSDF contacts and contact certainty, and representations of quantitative and qualitative data.

Identification of HF and usability issues in the Halifax Class Ops Room.

This section provides information to developers on sources of information for implementing COMDAT applications or for upgrading the current CCS. Recommended sources are observations conducted during a sea trial, administered questionnaires, and relevant reports produced during the COMDAT TD program.

Publication of documents on the World Wide Web (WWW)

Some high level recommendations are provided concerning format, links, graphics, and usability.

Discussion

This report provides a useful overview of the process used in compiling the final OMI Style Guide and provides some initial recommendations. The literature review represents a timely summary of recent relevant work on OMI design for a variety of C2 application environments. Many of the recommendations are at a very general level and somewhat preliminary. They become refined in later reports.

6.4.2 Command Decision Aiding Technology (COMDAT) Symbology and Design Study

Abstract

The report includes a description of three Human Factors efforts carried out to support the upgrade of the Halifax Class Command and Control System (CCS) in the area of battlespace awareness. The first section is comprised of a report on an evaluation of symbology developed to convey the certainty of Multi-Source Data Fusion displays. The remaining sections are comprised of annotated illustrations of COMDAT Operator-Machine Interface (OMI) Style Guide compliant displays.

Summary

MSDF certainty symbology evaluation

A fundamental issue surrounding the development of MSDF technology is how to represent fused information. In current operations, the outputs from different sources are presented on dedicated screens; the operators have information about the certainty of the data because of the information available on the screen on which it appears. If contacts from a variety of new sources were integrated into a single display the issue arises as to whether there is a need for symbology that informs the operators about the quality of the information and if so, how should it be optimally presented. Heretofore there have been several attempts to develop certainty symbology within a variety of defence applications without particular success.

Three symbology options for presenting certainty information were evaluated. The SMEs comprised a range of ranks from a Halifax Class Ops Room. The evaluation involved both performance and preference measures including ratings of the meaningfulness, level of certainty represented, and perceived usefulness in the context of a radar tactical display. A group discussion of the candidates and other alternatives generated some design concepts that were considered to be desirable for representing certainty information.

The preferred option was the "slider" or "draining bucket" symbol set which was designed to indicate the time that the report was received. In this symbol set the more full the "bucket" appeared the more recent the report and hence the more certain the contact.

Of interest, the SMEs all resisted the concept that the MSDF would be useful to them at the CCS level. In the discussion group that followed the structured evaluation, 100% of the participants stated that they did not find the concept of certainty symbology to be useful for the CCS except perhaps to help with situation awareness when an operator first comes on shift. The SMEs indicted that the concept would be more useful in a planning display rather than in real time on the tactical display. Arguments made by the SMEs included the following:

- Any contact that was not clear would be examined in detail by the operator via the tabular displays. The SMEs suggest that interpreting the certainty measure would produce a distraction rather than help.
- Identification is not an issue at the CCS level. The identities of contacts represented on the CCS have already been confirmed elsewhere.
- Track quality is already identified by a number. These SMEs were quite clear that the main concern of the operators is whether the track quality is good enough; the quality is either good enough to engage or it is not. Levels of information about the track quality when it is anything less than "Good to Go" are less critical. It is not clear whether the less critical information is used at all. Additional detail, other than "Good to Go" or "Not Good to Go" in certainty displays is perceived by the operators to be a hindrance rather than help during a real-time CCS task.

Notwithstanding these comments, which largely address the perceived utility of such a display, the report makes some suggestions for an enhanced symbology design to facilitate recognition and reduce certainty. Readers should refer to the original report for an illustration of this.

OMI design illustrations

Section two of the report provides specific examples of symbology, graphics, and OMI elements that would amplify the first version of the COMDAT OMI Style Guide. These enhancements were subsequently captured into the final version of the Guide.

CCS look and feel upgrade

The third section of the report provides extensive examples for an upgrade to the CCS OMI to conform to the proposed style guide, largely based upon the report authors' HF Engineering experience and knowledge of display design for C2 environments. These were later incorporated into the final version of the style guide (Unger Campbell 2004a).

Discussion

In as far as it goes, this report provides some valuable information concerning how track certainty information might be represented in a future MSDF display. Given that different types of certainty were considered (time, position, identification, source), the report could have gone further in considering the saliency of these different types of certainty for operational contexts and considering the specific design-representation requirements separately for each.

The report recommends the use of the slider format for representing certainty; yet, the data appear to indicate that SMEs preferred the dot format.

The report clearly identifies important considerations for the specific design of MSDF certainty symbology, reflecting concerns of clutter and unobtrusiveness by the SMEs. However, some of the design recommendations may be too vague for implementation by future system designers for example: "symbology must be small and unobtrusive", "MSDF symbols….. must be as compact as possible".

In general, this report provides a useful starting point for considering how certainty information may be best represented in future displays. The report opens the door to many questions which will need to be addressed before specific and comprehensive recommendations can be made with a level of assurance. Some of these issues are

- What are the operation decisions where representation of certainty would be of value?
- What is the type of certainty that needs to be considered for the above?
- Are the needs of operators to reduce uncertainty about information different at differing phases of building situation awareness in a tactical environment?
- Are there preferred methods for representing the level of certainty for different types of certainty (time, position, source etc) – or should a common method be used?

Given the complexity of this issue, the small sample set and limited validation by the operational community, the results and recommendations of this report are probably best taken as suggestive and pointing to the requirement for further research and analysis, rather than providing a definitive answer that could be immediately incorporated into requirements for future upgrades of the CCS.

6.4.3 Command Decision Aiding Technology (COMDAT) Technology Demonstrator (TD) Operator Machine Interface (OMI) style guide compliance and enhancement

Abstract

This report describes the results of a review of the prototype COMDAT TD OMI and describes its compliance with the COMDAT OMI Style Guide. The review is presented in three parts. Part one, a compliance matrix, identifies over 120 design elements of the COMDAT TD OMI that are not compliant with the COMDAT OMI Style Guide. Each of the non-compliant elements is described in the compliance matrix. The relevant paragraph (and paragraph number) from the COMDAT OMI Style Guide is identified for each non-compliant design element. Part two identifies 24 new items that will be added to the COMDAT OMI Style Guide as a result of the review. Part three covers other usability issues, identified during the review, that are not directly related to style guide items. The review notes include specific style guidance as well as other usability observations from the COMDAT TD review.

Summary

Background

As part of the TD development, new design concepts were being developed and implemented by Lockheed-Martin to (a) incorporate the output from MSDF processes into the current CCS tactical picture and (b) integrate the wide area picture as provided by GCCS-M and Link-11 with the Ownship tactical picture. The new functionality allowed operators to access and manipulate this additional information. Thus, the initial design of the OMI for the COMDAT TD deviates substantially from the current CCS tactical display.

An initial review of the design concepts developed during the second build of the COMDAT TD, and the OMI itself, showed that they were not completely consistent with the COMDAT OMI Style Guide or with good HF practice. Therefore, as a precursor to specifying additional enhancements to the OMI, it was necessary to conduct a formal review of the current COMDAT TD OMI.

The intent of the review was to identify inconsistencies between the COMDAT TD OMI and the COMDAT OMI Style Guide so that these inconsistencies could be addressed. The ultimate goal was to recommend an interface that was consistent with the COMDAT OMI Style Guide and with good HF practice.

COMDAT OMI review process

The author conducted an initial walkthrough of the COMDAT TD OMI, followed by a detailed analysis of the compliance of the OMI with Version 1 of the OMI style guide. This review appears to have been conducted by the report author alone. The two outputs of the review process were a compliance matrix and some general observations**.**

Compliance with the style guide

Specific elements of the COMDAT TD design that were not compliant with the COMDAT OMI Style Guide were identified and were recorded in a compliance matrix. It identified 123 areas where the COMDAT TD could benefit by re-design so as to be compliant with the COMDAT OMI Style Guide.

Since, the COMDAT TD development was part of the Naval Tactical Display (NTD), and was limited in scope by requirements to retain some aspects of the NTD displays, the compliance matrix took into account these limitations in scope but was not restricted to those design features that were solely part of the new TD.

Only those elements of the style guide relevant to the current build of the COMDAT TD OMI were included in the compliance matrix.

The non-compliant components were found to cover a wide range of different OMI issues, which are summarised below:

- format of displays (fonts, symbology, organisation, appearance, formatting of text, colour coding),
- display navigation,
- windows management,
- match to user requirements and needs,
- input controls and data entry,
- error handling,
- consistency with MS Windows,
- overlays and tools,
- hooking tracks,
- track coding, and
- representation of certainty

Revisions to the style guide

As a result of the review, a number of issues arose that required either the addition or removal of items from the first version of the style guide. Such changes were then incorporated into what became the final version.

Author's general impressions of the OMI

The primary and overwhelming impression was that the controls and displays were too complex for operational use. The impression was of a system that was designed to reflect and provide access to the underlying technology, rather than to enhance the ability of the operators to complete their missions successfully.

The MSDF displays appeared to reflect the research community's requirements rather than the operator's requirements. While the displays and controls did permit the tasks to be completed, the designs were not focused on the operators' tasks or missions. In an operational environment, the effectiveness of the MSDF would benefit significantly, and be very useful to the operational effectiveness of the ship, with modifications to the display concept that were consistent with good HF principles within the operational context.

Discussion

This report provides a very thorough review of the prototype TD OMI and makes a number of critical and useful recommendations to enhance the utility and usability of the system functionality.

For system developers, it would have been useful to provide some indication within the compliance matrix of the severity of the consequences of non-compliance, thereby allowing some prioritisation of remedies. (For example, "minor" issues such as misaligned text or tab fields are not differentiated from more operationally significant problems such as difficult to navigate screens). In particular some of the recommendations concerning issues that impact upon critical tasks and operations are not given sufficient weight or highlighting in the report. These issues include track numbering by MSDF, which has significant operational consequences for track management and contact recognition, representation of certainty in the MSDF contact, operator access to underlying sensor data for MSDF tracks, and access to the MSDF tactical display screen.

The following limitations and points should be considered when assessing the value of the information provided:

- The recommendations appear to be the opinion of one HF qualified person alone. They have not been validated by a second HF SME and, in particular, recommendations that reflect operational requirements do not appear to have been validated by Navy SMEs.
- Statements such as "text is not legible" are not informative for system redesign purposes. It would have been better to have expressed this along the lines of "text height was …x min at the operator preferred viewing distance of …cm; this does not conform to guideline .., which states that text must have a minimum visual angle of …. Therefore increase the height of this text to …mm". Similar comments apply to statements such as "The hooked track should itself become brighter or larger in order to confirm that it is indeed the hooked track."

6.4.4 Command Decision Aiding Technology (COMDAT) Operator- Machine Interface (OMI) style guide: Version 1.0.

Command Decision Aiding Technology (COMDAT) Operator- Machine Interface (OMI) style guide: Version 2.0.

Abstract

This document provides an Operator-Machine Interface (OMI) style guide for the Canadian Command Decision Aiding Technology (COMDAT) project. This COMDAT OMI Style Guide has been created to support development in Command Decision Aids for Halifax-Class Canadian Patrol Frigates (CPFs). The objective is to provide guidance to create a common look and feel that is compatible with existing systems, yet accommodates new developments and knowledge.

Summary

The initial version of the style guide was published as a DRDC report (Unger Campbell 2001a). Under later contracts, it was implemented as an HTML document (Unger Campbell 2004a) and upgraded to include the OMI design illustration discussed in Section 6.4.2 (Unger Campbell and

Baker 2003) and the modifications and additions arising out of the evaluation of the COMDAT TD (Unger Campbell 2004b). The summary and discussion apply to the final version of the style guide.

Introduction

The COMDAT OMI Style Guide provides design guidance, design rules and a framework for the OMI design rule development process. There are 4 overall objectives of the style guide:

- compatibility with the current Halifax Class CCS,
- employment of an interface style with which the operators are familiar,
- compatibility with existing military OMI style guides, and
- ability to accommodate new features and functionality.

It was hoped that this guide would lead to OMI's that are consistent, interoperable and usable.

A major change from the existing CCS is a recommendation to adopt the Microsoft Windows style as a template for the look, feel and functionality of new systems.

Design filters

The expected end-users of the style guide will be developers of technology for Maritime CCS operational personnel. Developers need to design for the lowest anticipated operator skill set, while ensuring support for high level operators. The physical environment of CCS operators (i.e. shipboard Ops Room) must also be taken into account in the design.

Source documents

Thirteen source documents are cited throughout the style guide.

Input devices

Input devices for the COMDAT CCS include, at minimum, a keyboard and a pointing device. Touch screens are suitable for infrequent operator tasks, but voice-activated controls are not suitable (at this time) for Maritime C2 function. Specific pointer shapes and function are outlined, along with expected functioning of the input devices.

Windows

There are 3 different types of windows outlined: system (or root) windows, primary windows and secondary windows. Characteristics of each type of window are described with specific attention paid to 'status bar' and other information bars that are required on each window.

Design guidance

A variety of issues that designers would need to address are discussed; notably:

- consistency,
- arranging information,
- three levels of window modality,
- widget selection,
- coding critical information, and
- window navigation and selection.

The report provides detail on how input devices attain window focus and control objects, specifically using a pointer device and keyboard. The thorough discussion of object control outlines four methods of transferring objects, feedback operations, error detection, and undo capability. Additionally, a chart provides specific maximum system response times for certain system inputs (e.g. response time for the appearance of a character after a key is pressed should be less than 0.2 seconds).

Controls

The 'Controls' section of the report lists characteristics and actions that the controls in any CCS system should have. Different rules are outlined between controls associated with very frequent and/or safety critical tasks (e.g. hooking tracks or changing the range in the tactical display) and controls for more generic tasks. Also, design rules are outlined for the currently used Quick Access Buttons to increase their visual affordance[2]. Finally, each of the different types of controls (e.g. push buttons, radio buttons, and checkboxes) is discussed with a view to providing guidance on streamlining their implementation.

Menus

Menu hierarchy structures are reviewed, including the advantages (e.g. decreased cognitive requirements) and disadvantages (e.g. slower for experienced operators); the elements and operations of menus are thoroughly laid out.

Window states

The report notes that windows along with their associated menus and title bars must have consistent functionality to ensure the operators do not waste time searching for the information they need. A detailed description of windows is included.

Security and simulation

Security login and logout procedures are specified. Simulation data must be easily distinguishable from real data, and during any simulation real data must be protected.

Data display and entry

Rules for data entry include navigation, pointer activity, and data manipulation for both alpha and numeric characters. The data display rules similarly define use and organization of both alpha and numeric characters. Special attention is paid to error correction.

Special functions and formats

Except for critical situations, the report recommends that audible alerts not be implemented. Date/time and latitude/longitude need to be consistently displayed and messages need to be consistently handled. Additionally, the spell check, printing, and imagery manipulation functionality are described.

Graph display

The characteristics of line graphs, bar graphs and histograms are outlined to expedite efficiency in readability and comparisons across graphs.

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[2] Within the HF community, affordance is defined as those action possibilities which are readily perceivable by an actor.

Tactical graphics

The usability of tactical graphics is central to operator effectiveness. Issues that are specifically discussed include optimizing the use of colour, shapes, and size for differentiability.

Maps and situation displays

The usability of the tactical display is also central to operator effectiveness. General tools to manipulate the display and characteristics of the display are discussed. The specific CCS functioning of hooking is also included.

Colour

The final section of the report outlines general rules for the use of colour. The report provides detailed guidelines on how colour is to be implemented on displays depending on the working environments ambient lighting (e.g. dark adaptation versus normal lighting). Readers of this information will require familiarity with colour space specification metrics in order to fully comprehend the recommendations.

Annex 1: Highlights of the COMDAT OMI Style Guide

Annex 1 includes a high level overview of the style guide and draws particular attention to map controls, display area layout, operator actions and the COMDAT status bar.

Annex 2: Illustrations of a style guide compliant CCS

Annex 2 provides a static re-design of the current Halifax Class CCS functionality and layout along with an explanation of the changes that have been implemented. The upgraded design was created to illustrate the application of the COMDAT OMI Style Guide to the current CCS.

Discussion

The style guide provides a large amount of detailed information to system designers looking to implement evolutionary technology for Maritime CCS. The majority of the report describes in considerable detail Microsoft Windows styles features and operation. The few sections that address operationally specific support requirements, stress the continued reliance on the current display functionality in order to minimize transfer effects and training costs, which, as a result, may limit more drastic changes in design.

The HTML implementation of the style guide provides a highly usable approach for locating information.

The body of the style guide provides very little *higher level* information concerning overall flow, style, and usability of the CCS system. While Annex 1 does contain this type of information, a greater number of high level summaries in each section would be beneficial for those looking to contribute to designs of the system but who are not responsible for implementation (and therefore do not require the detailed information). More pictures and figures to enhance the comprehensibility of some design concepts would have been useful.

A logical next step is to create a software package with frames and widgets consistent with Microsoft Windows Styles in a programming language that works with the current CCS system. This would greatly ease the required work for designers who are looking to test and implement additions/changes to the current system. The software package could be similar to how ‘Microsoft Visual Basic’ automatically creates certain functionality (e.g. by default, every window frame has 3 buttons in the upper left corner for minimizing, maximizing, and closing) and provides global functionality to be similar across programs (e.g. access to directories and folders through input windows like 'Save As' and 'Open'). This type of package would ensure a faster implementation of Windows-like designs by programmers who would otherwise delay programming the details associated with Windows styles in order to expediently implement their additions/changes.

Limitations

One of the major areas not addressed in the style guide concerns how to provide functionality at each work station that addresses the specific operational needs of the user for different phases of operations (e.g. picture compilation, threat assessment, response and response management). While this may not have been the mandate for the contracted work, there will be a need for future systems to provide context- relevant, operational information tuned to the needs of different team members. That is, while the style guide provides detailed guidance for the display of data, it does not address the higher cognitive requirements of the team in terms of information display.

6.4.5 Representing data quality on naval tactical displays

Abstract

Multi-Source Data Fusion (MSDF), as developed under COMDAT, provides an assessment of the reliability of the estimate of the fused track's attributes and position. Part of the human factors work under COMDAT has been to investigate methods of representing the quality of the MSDF-generated tracks to the operator. The research reported in this paper is concerned with the potential impact of different representations of data quality or uncertainty on the visibility of tactical symbols and the intuitiveness of the different representations. Three methods of representing data quality were investigated: a variably filled bar presented beside the tactical symbols, different diameter rings that encompassed the tactical symbols, and varying the saturation of the tactical symbols. In Experiment 1, a visual search task was used to compare the accuracy and speed with which participants could locate multiple instances of each of the tactical symbols without any representation of data quality and when each of the three methods tested were added. Experiment 2 examined the ability of participants to quickly and consistently interpret the quality of the data, represented by the tactical symbol, using the three different methods. The results indicated that the bar interfered least with people's ability to locate the tactical symbols, but the saturation method was most consistently interpreted. A second set of experiments looked at applying the saturation coding to the bars and rings instead of the tactical symbol. Redundant saturation coding of the bars and rings had no effect on tactical symbol visibility and did not improve the consistency of interpretation of data quality. The basic recommendation was that a small independent symbol, such as the bar, was the preferred method for representing data quality. However, operators should have the option of turning it off if the display appears too cluttered. If a different symbol shape is chosen, its intuitiveness should be assessed prior to implementation. Further research is required to improve our understanding of the number of levels of data quality operators can use effectively.

Summary

This report examines how to represent the data quality of MSDF tracks to the operator. This is an important issue, since knowledge of the reliability of the track data could be of potential benefit to operators concerning action to take on the contact. Also, since operators raised concern about display clutter in the Unger Campbell study, design approaches needed to be found to overcome this, while still allowing for the representation of data quality.

The report reviews some of the existing methods for representing information certainty and concludes that the evidence suggests that symbology which incorporates certainty information, or putting certainty information directly on a tactical display, appear to be a better option than standalone certainty displays. However, the implications of putting such information directly on displays raises the issue of clutter and this does not appear to have been empirically investigated. Further, the research on how to represent different levels of certainty has not addressed the question of how a specific level of certainty can be mapped onto symbology in order that an operator can understand and interpret it unambiguously.

The report provides a good summary overview of recent work on the representation of certainty and notes the deficiencies in many studies to date.

As a consequence of a lack of definitive answers in the literature, the study had the goal of examining graphical methods and specific symbology as a way to represent recognisable certainty levels by measuring performance on criterion tasks.

In the first two experiments, the stimuli were based on the Naval Tactical Data Set (NTDS) and equivalent symbols from Mil-Std 2525B; each symbol was annotated with a bar (to the right of the symbol) or ring (surrounding the symbol) or the saturation was varied. Three levels of data quality were indicated by the proportion of the bar filled in, the size of the ring, or the degree of saturation.

Operator tasks were to either count the number of target symbols on the display as quickly and accurately as possible or search for a specific symbol and indicate the data quality.

The results of the counting task were somewhat complex but generally showed that performance with the saturation coding was generally poorer than with the remaining methods and that performance with the ring coding was poorer than the control condition. For the classification task, only the saturation coding condition showed a consistent use of the 5 point rating scale by all subjects; however, the bar coding showed a trend for significantly different ratings for each level.

The conclusion from the first two experiments was that none of the methods were entirely satisfactory for representing data quality. The saturation method resulted in the most consistent response, but it severely impacted the response time and accuracy with which the tactical symbols were located. The bar method had the least impact on response time and accuracy, but there was some inconsistency in the participants' interpretation of the different levels of fill. The range rings were the least successful. They were not consistently interpreted across participants and accuracy and response time for counting the symbols was significantly poorer.

Accordingly, a second pair of experiments was conducted in which saturation (the preferred coding method) was combined with a secondary symbol (bar or ring); it was predicted that performance would be superior to a monochrome condition. The second experiment was conducted with the NTDS symbology.

The results for the counting task were somewhat similar to the first experiment, but there was no significant performance improvement resulting from the redundant coding of data quality. For the classification task, the bar method was again found to be superior to the ring method for coding quality.

Overall, the results showed that the addition of a bar representation had a relatively small impact on response time for locating specific symbols. Paradoxically, while saturation coding of data quality was more readily interpreted, it resulted in symbols that took longer to count.

In conclusion, the authors raise the important point that certainty in tactical displays may be manifested in more than one dimension of a contact (e.g. track location, time lateness, platform and ID) and that it would be unworkable to try and represent certainty for each of these because of the impact on display clutter. Therefore, it was concluded that a symbol should provide only general information about the overall quality of data in order to avoid potential clutter and increased operator information load.

Discussion

This report addresses an important issue concerning how to represent data quality to operators using symbology that is readily interpreted but does not clutter displays and allows symbols to be quickly located. The experiments conducted provide some useful information concerning a potential way ahead for such representations and clearly show what types of methods are less successful. In particular, the experiments show the difficulty of trying to incorporate iconic information about a contact into the contact symbology. The results, however, are suggestive of future directions rather than being able to provide definitive, immediate solutions that would translate directly into either guidelines or deployable design concepts (which was not the intent of the study). The results clearly indicate that more empirical work is necessary before the important variables are identified that influence how to code for data quality in tactical displays.

Limitations

The report does not discuss the issue of how to trade-off detailed information on data quality with issues of clutter, particularly as operators range out.

6.4.6 Evaluation of symbol sets for naval tactical displays

Abstract

The four experiments reported in this paper were conducted in support of the COMmand Decision Aiding Technology (COMDAT) (11bg) Technology Demonstrator Project (TDP) and the Halifax Class Modernization Command and Control System (HMCCS) programme. The first experiment assessed the relative visibility of the basic Naval Tactical Data System (NTDS) and MIL-STD-2525B (2525B) tactical symbols. Performance with the colour-coded versions of the two symbol sets was not significantly different. However, the air and subsurface symbols were less discriminable than the surface symbols. Recommendations for improving the discrimination of the different warfare area symbols are included.

One potential advantage of the 2525B symbols is the possibility of adding additional information about the track platform to the basic symbol shape. The remaining experiments assessed the visibility of the basic symbols with iconic information added and the visibility of the icons themselves. Adding iconic information did not have a large effect on the efficiency with which the basic symbols were located except when the icon shape replaced the symbol shape. Performance in locating and recognizing individual icons depended on their complexity and their uniqueness. It was recommended that only a small number of highly discriminable icons be used at any one time. The use of icons without the symbol frame should be restricted to non tactical information and such icons should probably not be colour coded. Further research is required to determine how to implement these recommendations.

Summary

The laboratory experiments reported in this paper were all designed to address issues concerning the development of improved OMI guidelines to support naval tactical picture compilation. A critical first step in this process is the ability of operators to quickly and accurately discriminate contact symbols of interest from among other contacts in the tactical picture, as well as discriminate contact symbology from complex backgrounds that may contain a map or other graphical information (e.g. a water space management box). Therefore, the design of symbols to support this requirement becomes an important issue that cannot be left to software designers; hence, guidelines have been proposed to constrain and inform the design implementation.

The experiments reported provide a much needed empirical evaluation of the effectiveness of two existing guidelines in promoting symbology that supports the tactical requirements of operators. The two guidelines are the NTDS symbol set currently used on tactical displays in the Halifax Class frigates and MIL-STD-2525B (2525). The results of these experiments will be used to provide recommendation to the Navy on the selection of suitable symbology for naval tactical displays.

The introduction section of the paper provides a fairly detailed overview of the historical background research and analysis in the development of military symbology in the last two decades. This is a period in which there have been significant technological advances in coloured display capabilities. There was clearly a need to re-evaluate the NTDS symbols against other candidates to determine whether the design concepts were still valid, since they were developed in the early days of electronic display in operations centres. Over the same period, there were considerations that symbology could be augmented through the additions of iconic information to complement the shape and colour coding of the NTDS symbol set. The set was also expanded to

include symbols for “assumed friend” and neutral tracks. A North Atlantic Treaty Organization (NATO) committee evolved a new set of symbols from the NTDS set, but these were never formally ratified.

In summarising the data from prior studies, the paper notes that some of the findings showing superiority for the NATO over the NTDS set were only obtained when the two symbol sets were presented against different backgrounds, and that in general no conclusive evidence could be drawn over which set was better. Therefore, the motivation for the experimental work was to provide a clearer understanding of the relative strengths and weaknesses of the NTDS and 2525 symbol sets in order to recommend improvements to the design concepts laid out in MIL-STD-2525B.

The methodology required subjects (non operators) to search a simulation of a naval tactical display on a coloured CRT display and locate specific target symbols in a context of other symbols and against a plain grey or more complex map background. Essentially this required subjects to count the number of a specified symbol type present in the display. Primary measures were the time required to locate targets and performance accuracy. Four experiments were reported; each addressed significant issues for the design of symbology.

The first experiment examined the ability to locate prescribed symbols in a complex background as a function of the target set type (NTDS v 2525) and the confusability among symbols. The comparison set of symbols was based upon the nine basic NTDS symbol types. The results showed that performance was typically better with a colour coded target set and that the NTDS symbols produced better performance than the 2525. However, there were distinctive patterns of results for different contact symbols, for which the reader should consult the original report.

Experiment two examined the effect of background type and symbol complexity (by adding icons which indicated platform type) on performance with the 2525 symbol set. The results showed that adding an icon to a symbol had no effect on performance for air symbols, but degraded performance for the surface and underwater symbols. Without the icons, the surface symbols tended to be more detectable than the air and underwater symbols. When the icons were added this was no longer the case. Further, performance on these two categories of symbols was also degraded by the addition of background information.

The third experiment examined the ability to count the number of occurrences of a specific icon representing a “warfighting object” located inside one of the three hostile symbol shapes (air, surface, sub-surface) in a cluttered display. In general, it took longer to locate a specific icon in a symbol shape than to find the same shape without an internal icon.

The fourth experiment examined the ability to identify the platform associated with the icon inside the shape in the context of the basic search task. All subjects were initially trained to identify the icons to a level of 95% accuracy. Overall, there was no significant difference in performance across the individual icon types, although some took longer to identify (air symbols with rotary and fixed wing icons and subsurface symbols with the sub, mine, and decoy) than others.

The following conclusions can be drawn from these experiments:

- Overall performance was very similar on the colour coded NTDS and 2525 symbols sets. Thus, when the symbols were presented on the same background, and the recommended form for the NTDS symbols was used, the 2525 symbols showed no advantage over NTDS symbols. The use of the same background and thicker lines probably contributed to the visibility of the NTDS symbols.

- Both symbols sets have problems that were not identified in previous comparisons of the NTDS and NATO symbols. When all nine symbols are presented simultaneously, performance with the air and underwater symbols is considerably poorer than with the surface symbols.
- The use of colour coding improves the detectability of the symbols. A comparison of the monochrome and colour coded solutions indicates that colour coding reduces confusion across the different shapes. This is especially true for the 2525 symbols.
- As the number of icons increases they become progressively less discriminable. If icons are to be used they should be restricted to a few classes only and reserved for special cases (e.g. critical platform types).
- The visibility of the 2525 symbols relative to the NTDS symbols is also affected by the fact that all the 2525 symbols are effectively the same size. The larger size of the NTDS surface symbols contributes substantially to their visibility and reduces the likelihood that they will be confused with an air or underwater symbol – thus contributing to the visibility of those symbols. Unfortunately, reducing the size of some of the 2525 symbols would make them less suitable for adding icons.

The report makes several recommendations on how to increase the visibility of air and underwater symbols and provides direction for further studies that will be required before definitive recommendations can be made concerning improvements to existing recommendations and guidelines for symbol design.

Discussion

This study provides an important review and critique of the considerations that shape the design of symbols for naval tactical displays. The historical review and analysis of previous work provides a clearer understanding of the strength and weaknesses of current recommendations.

The experiments conducted provide valuable empirical data which show that adoption of emerging ideas on symbol design and the implementation of iconic information into symbols are complex matters that can lead to design solutions which result in performance decrements, as well as increments.

The results clearly point out the need for a significant level of effort to be expended for future empirical investigations of symbol design alternatives before valid and robust recommendations can be confidently made to designers of symbol sets to be used in new generations of naval tactical displays. The results also point to the need for a greater understanding of the information priorities of operators in order to prescribe important candidate contact types for which enhanced contact information should be provided to complement the basic symbology.

Limitations

There are a number of critical variables that are likely to influence the performance with tactical symbology that were beyond the scope of these studies. Factors such as ambient lighting (and range of lighting), off-axis viewing, different display technologies, backgrounds and overlays, scalability under different range settings are all important issues. They will need to be explored in a parametric and systematic manner in order to produce comprehensive guidelines that can be unambiguously interpreted by future system designers.

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7 Development of Concepts of Operation for the integration of automation for decision support

7.1 Goals

The overarching goal of this work was to generate knowledge on how MSDF functionality could be practically implemented for future system upgrades to the Halifax Class C2 system. The sub-goals were as follows:

- to identify the types of decision support that could be provided by MSDF functionality to support selected tasks in tactical picture compilation and track management,
- to provide sample CONOPS for the proposed support functionality, and
- to provide illustrative examples of the OMI support functionality.

7.2 Responsible parties

This work was contracted to Humansystems® Incorporated.

7.3 Reports produced

Keeble, A. R., Matthews, M. L., Lamoureux, T.M. Berger, N. and Zobarich, R. (2007). Concept of Operations (CONOPS) for Recognition, Standard Identification and Track Management and Recommendations for Interface Design for an MSDF Enhanced System. (DRDC Toronto No. CR-2007-056), Humansystems® Incorporated, Guelph, ON.

7.4 Summary of reports

7.4.1 Concept of Operations (CONOPS) for recognition, standard identification and track management and recommendations for interface design for an MSDF enhanced system

Abstract

The goal of this work was to develop a Concept of Operations (CONOPS) and prototype Operator Machine Interface (OMI) for the provision of a semi-automated and automated decision support capability based upon multi-source data fusion (MSDF) and evidential reasoning algorithms to assist the processes of contact detection, recognition and identification performed by the Halifax Class frigate. The report starts by documenting the existing, baseline CONOPS for air and surface picture compilation and then maps onto this opportunities where MSDF could play a role. Based upon such opportunities, a CONOPS for MSDF enhanced decision support was developed and an experimental OMI was prototyped. The CONOPS and OMI were then validated with Navy Subject Matter Experts (SMEs) and positive support to the proposals was obtained. The proposed OMI and CONOPS provides enhanced support to overall contact management, improved situation awareness for contacts of interest, collated evidence and recommendations for recognition and alerts for potential recognition errors. An interactive PowerPoint demonstration of the proposed OMI was delivered.

Summary

The initial phase of this project involved an analysis of the existing CONOPS for the conduct of recognition, standard identification and track management for air and surface contacts. The analysis was based upon information collated from interviews with Navy SMEs, the experience of one Navy SME attached to the project (former sea trainer and ORO) and reports of HF analyses conducted under the COMDAT TD program. The following major functions that could be impacted by MSDF technology were identified:

- equipment set-up;
- radar track initiation;
- contact localisation and tracking (single and multiple ships);
- track correlation;
- association of EW to vehicular tracks (single and multi-ship);
- the recognition process: considerations of speed, ESM, Identification Friend or Foe (IFF), visual information;
- the recognition process: considerations of LINK 11, Primary ID (PRI ID), ID amplification (ID AMP), Global Command and Control System (GCCS)- platform and Electronic Intelligence (ELINT) tracks;
- recognition confidence levels and decision making;
- the Standard Identification process: definition and assignment;

- the Standard Identification process: ID amplification, LINK 11, PRI ID and ID AMP;
- track numbering; and
- team situation awareness.

The second step involved a consideration of how MSDF functionality could support the above operations. For the purpose of the analysis, this consideration was not constrained by the actual functionality in the TD prototype but was based on a reasonable extension to what MSDF could be capable of within the bounds of known technology. The scoping of this functionality involved discussion with and feedback from the Scientific Authority.

As a result of this analysis, a number of MSDF support functions were identified and the operator information needs to make use of such functions were prescribed. This information was then fed into design seeds for system functions and a CONOPS to support MSDF.

The philosophy was adopted to use decision support conservatively in order to maximise operator trust and acceptance and to provide an evolutionary change in the C2 CONOPS (as opposed to an aggressive application that took operators out of the loop and gave decision making entirely to MSDF). The recommendations for a conservative integration of MSDF functionality assumed no change in the existing command authority to make decisions and recommendations. The proposed CONOPS was designed to function within a multi-ship formation where not all ships would necessarily be equipped with COMDAT decision support. As an evolutionary system, the existing authority structures for assessments of Standard ID and recognition were retained. Any automation regarding ID or recognition was limited and specifically selected by the operators in their particular context.

The following assumptions were made concerning the MSDF functionality:

- a database of all air and surface vessels,
- MSDF data fusion algorithms that accurately combine sensor information,
- recognition propositions based upon combined sensor information and evaluated by evidential reasoning algorithms,
- an accurate and independent database of all ongoing information amassed within the MSDF system, and
- a capability for the MSDF data fusion algorithms to accept operator input and use the data in a similar manner to sensor sources.

The following principles were adopted as a high level CONOPS:

- Operators will typically use the MSDF functionality to consolidate evidence for assessments which they will continue to make themselves (apart from those instances where the MSDF decision aid takes ID or recognition action automatically).
- Depending on the authority, or the operator in question and the authority structure in force for the operation, the operator may just review the evidence provided by the aid and take action independently to accept the propositions and send them to the CCS Global Database (GDB).

* Operators may use the evidence to make an assessment report up the authority chain, sending proposition reports through to the CCS as appropriate after feedback from the higher authority.

Several assumptions were made concerning the relationship between the MSDF and CCS systems:

* MSDF will be integral to the CCS, not a stand-alone system.
* Certain data fields in the CCS GDB will be fed real time from the MSDF algorithms (course and speed of a contact being tracked locally by a MSDF ship as determined directly by the MSDF tracking algorithms).
* Others data fields will not have this direct link. (ID, PRI AMP and ID AMP).

Central to the proposed CONOPS is the notion of Operator-As-Input to provide data to the MSDF algorithms that are held by the team but not available to MSDF through other means. The CONOPS relies heavily on the ability of operators to interact with recognition propositions presented by the system, or even with recognition possibilities not presented by the system but resident in the MSDF database, to enhance the relevance and usefulness of the system. This interaction would be purposeful and undertaken within an authority structure such that the interaction should almost always result in an improvement in the data and thus the output from the aid. The functionality for an operator to review the results of an interaction and then "undo" it allows them to troubleshoot or "what if" as they work through the recognition challenge.

An important element of this interaction is the continued parallel processing of all data being fed into the MSDF system without operator interaction, which facilitates the identification and presentation of disconfirming information to the assessments being made by the operators. Allowing MSDF to continue processing its organic data (all data except the operator initiated data) after an operator has interacted with the propositions allows for disconfirming evidence to be presented, so that if the aid is clearly assessing an ID or recognition differently from the one in the Operator-As-Input process, an operator can review the evidence.

The following operational functions were identified as being the most likely to benefit by the proposed MSDF decision support capability:

* improved situation awareness of the tactical picture,
* improved situation awareness for priority contacts,
* integration of all relevant data on a contact,
* enhanced capability under overload conditions,
* improved association of EW to platforms, and
* validation of recognition assessments.

On the basis of this overall philosophy concerning the application of decision support, the proposed CONOPS and the identification of operator information requirements, a demonstration OMI was developed based on the design seeds. The design team consulted guidelines developed for C2 OMI as part of the COMDAT TD program, reviewed recent literature on new developments in design concepts and consulted other relevant HF guidelines in shaping the proposed OMI design.

The report then provides details of the major functionality and OMI design details by presenting figures and a narrative text to describe what the functionality does and how it is to be used by operators. Essentially, the functionality comprises four components:

1. Setup page for configuring the system.
2. Interactive data pages through which the operator compiles the picture and conducts recognition assessments.
3. Alerts: these are operator configured to provide improved situation awareness under prescribed conditions.
4. A track symbol and data block (tactical display).

The proposed functionality went through two validation processes with Navy SMEs. An initial validation after the design philosophy had been developed, and a final, more in depth validation, in which the actual OMI and functions were systematically reviewed and analysed by a representative cross section of Ops Room operators. This final validation of the proposed functionality received moderate to strong endorsement from the SMEs and minor suggestions for improvement were identified and incorporated into a subsequent design revision.

In addition to the report, an interactive PowerPoint demonstration was delivered which provides a tutorial-like package that illustrates how the functionality would work and how operators would use it.

Discussion

This work provides an important step in translating how an MSDF and evidential reasoning support system might be integrated in a very practical way into a future re-design of the Halifax Class C2 system. The proposed evolutionary approach to the system design makes good sense and would allow for an incremental assignment of decision making to automated functions if operational experience were to warrant it.

The proposed design makes some interesting recommendations for system alerts and improved situation awareness (which are not necessarily tied to an MSDF capability), which may merit further consideration as HMCCS evolves.

The analyses of the existing CONOPS in this report would be of use for future system (re)designers in understanding how the Ops Room team currently conducts the processes of surface and air contact recognition and standard identification.

One significant limitation is that the underlying MSDF functionality to support the proposed CONOPS does not currently exist within the COMDAT TD.

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8 Support to DRDC Atlantic for land and sea trials

8.1 Goals

The goals of this work were to

- Provide a trial plan to enable the conduct of real-time, HIL trials to evaluate the performance of the TD.
- Identify scenarios that would be used in HIL trials that would be suitable for exercising the MSDF TD capability.
- Support the conduct of a HIL trial to assess MSDF functionality.

The third goal was never met because of a change in emphasis of the TDP.

8.2 Responsible parties

This work was contracted to Human*systems*® Incorporated.

8.3 Reports produced

Matthews, M. L. and Keeble, A. R. (2004). Towards a trial plan for evaluating the COMDAT TD: Final report. (DRDC Toronto No. CR2004-053). Human*systems* Incorporated, Guelph, ON.

8.4 Summary of reports

8.4.1 Towards a trial plan for evaluating the COMDAT TD: Final report

Abstract

This report outlines a series of evaluations and analyses of the COMDAT TD with a view to conducting future trials to evaluate its potential impact upon operator performance in the Operations Room of the Halifax Class frigate. Specific issues commented upon include the operator-machine interface, the logistics of integrating the TD into a suitable trial environment, the availability of existing scenario elements to provide a suitable evaluation context, the types of performance measures that could be feasibly implemented and options for the format and location of future trials.

Summary

The report covers the following major areas:

- an outline of aspects of system usability, functionality and operational performance to be assessed in planned sea and land-based trials;
- comments upon the existing TD functionality and its implications for an evaluation trial;
- assessment of the availability of existing scenarios to be used in future trials to evaluate the TD;
- provision of an overall trial plan for evaluating the TD;
- identification of requirements for data capture and OMI enhancements in order to conduct a future evaluation trial; and
- recommendations for the next steps to be taken in the overall trial plan.

The trial plan proposed an incremental approach to T&E with each step designed to evaluate some aspect of the TD. Step 1 would involve an initial proof of capability assessment that would involve a systematic test of the TD functionality in which simple, but representative, operational events are used to stimulate the TD algorithms, using mini scenarios that can be readily and quickly constructed. It would also establish the limits and capabilities of the TD and define an operating envelop within which to assess the specific functionality. The second step would involve SME evaluation of the functional utility of the system and development of a CONOPS. The process recommended would be a scenario, or event-based, cognitive walkthrough. The third step would be full HIL trials in which system functionality would be assessed with complete teams working through a predetermined scenario in real time with concurrent capture of MOP data. For each component of the trial plan, the report provides details on logistical requirements, the MOPs to be collected, and the methods for collecting MOP data.

The report identifies several existing scenarios that are used for ORTT training that would provide a suitable context for conducting HIL trials. These scenarios provide the required event characteristics to assess a wide range of the TD functionality and its impact on operational performance. It also identifies a number of logistical problems that would be faced in integrating the TD into potential test environments, such as the ORTT. These include issues of OMI consistency, integration of MSDF tracks with CCS tracks as well as technical issues concerning interactions among the underlying software systems.

Discussion

The proposed plan represents a standard approach to conducting a HF evaluation of a prototype system. The use of an incremental approach allows design flaws to be identified early in the evaluation process prior to substantive investment in resources. Since the evaluation was never carried out, it is not possible to say if this approach works for systems such as the COMDAT TD.

9 General Discussion

This section provides an overall appreciation of the relevance of the HF work conducted under COMDAT, lessons learned, and areas for future research. As stated in the introduction, a great deal of the HF work under COMDAT was not necessarily directly related to the development and evaluation of the TD. Its goal was to increase DRDC and industry capability to provide HF support to R&D projects such as COMDAT through the development of improved tools and methods. Under the TDP, methods for conducting requirements analysis, measuring human performance in complex systems, and providing design guidance were explored. As a result, we now have a better understanding of the utility of the methods that were investigated as well as considerably more knowledge about the information requirements and processes involved in building the tactical picture in a naval C2 system. In addition, we have generated improved guidance for designing the interfaces needed to present the required information and support these processes. As is usually the case with R&D, we also have a better understanding of what research still needs to be done to allow us to build more effective interfaces and decision support systems for naval C2.

9.1 Requirements analyses

9.1.1 Utility of the different methods

As shown in Section 3, each of the analyses provided useful and in many cases similar information about the goals, tasks, information requirements and processes used by operators in the Halifax Class Ops Room. Although the analyses varied in their coverage, the overlap does provide unique insight into the utility of the different methods for this type of application. Each method has strengths and weaknesses that might make it the method of choice under specific conditions, but any of the methods, if used properly by trained personnel, would probably be suitable. However, it is clear that both cognitive and task requirements should be included and that it is important to identify the higher level system goals as well as the specific goals of the individual operators and to understand the communication links amongst the various members.

9.1.2 Representation of information from analyses

There is a continuing challenge of how to make the extensive results of the HF analyses conducted under the TD amenable to the needs of those responsible for system re-design and requirements specification. While this report provides an overall summary of the analyses, it is structured in terms of what was done under the different contracts rather than providing a user-oriented document. The latter would focus more on questions that a user of the information might be expected to ask. While the answer to such questions will certainly be found in the report, there needs to be a mapping to allow more direct access to the information based upon a query-oriented architecture.

9.1.3 Tools

Although the methods for conducting a requirements analysis are reasonably well defined, the conduct of these analyses still tend to be extremely labour intensive. There is a need for better tools to support data collection, data representation, and the transformation of the information from data collection tools such as Task Architect to simulation tools such as IPME.

9.1.4 Further analysis work

Although the analyses were extensive, there were several areas that were not fully investigated by any of the analyses and should be pursued further. Most of these have been noted in the specific reports and/or Section 3. They include

- *Communications:* While several analyses noted the overload on the auditory channel, bottlenecks at several operator positions, and communication errors, no systematic analysis has been conducted at a sufficient level of detail to understand the extent and nature of the communication problems. There is a need to conduct both a lateral and downward flow analysis to complement the upward flow analysis in the HGA. The most direct and valid method for analysing the communication process would be to examine the communication records obtained during ORTT training. These records contain a very detailed log of all communications by all team members for all stages of picture compilation and threat response which would provide a quantitative basis for specifying the type and frequency of communication bottlenecks and communication errors by task and operator position.
- *Goal analysis:* There needs to be a greater understanding of goal conflict particularly as it relates to management of the picture compilation process. The information requirements to provide decision support to help resolve goal conflict need to be identified. There is also a need to decompose the goal analysis to a finer grain to allow a better understanding of the goals associated with the compilation of the tactical picture.

9.2 Measuring human performance in complex systems

As the cost and complexity of new systems increase and examples of unacceptable systems proliferate, there is a growing demand that developers prove that their systems will actually improve overall performance. Thus, a significant portion of the HF work under COMDAT was directed at improving our capability to conduct HIL studies. The results of this work are summarized in Sections 4, 5, and 8. Prior to COMDAT, there had been a substantive effort to develop a process for conducting HF evaluations of C2 systems (Matthews et al. 1997). COMDAT was one of the first opportunities to apply this process. The experience indicated that lack of human resources and suitable facilities make it unlikely that, in the near term, we will to able to conduct the type and quality of evaluation that HF specialist would traditionally favour in order to collect robust, reliable, and valid data. However, we have improved our ability to define measures of performance and validate them. We also have a better understanding of what are the barriers and potential alternatives to traditional HF research paradigms.

9.2.1 Measures of performance

The most successful part of this project was the development and validation of the MOPS (Matthews et al. 2004a; b). As a result, developers have a clear process for how to develop MOPs and a proven method for validating them. The first step is to ensure that MOPS and a potential method of assessing each are developed as part of the requirements analysis. Beyond the time and effort saved in having to go back to SMEs at a later stage, this process ensures that the MOPs and evaluation methods are available early in the development process prior to building a prototype/TD. Hopefully this will lead to the necessary measurement capability being an integral part of the TD and not an afterthought.

Since the MOPs reflect current goals and tasks, it should be feasible to validate them using the process followed in the studies reported in Section 5 (Matthews, Keeble, Bruyn Martin, and Sartori 2007b). This approach provides information on which MOPs are likely to be measurable and relevant data on performance on the current system. Moreover, the results show the “actual” practice in operation as opposed to the “theoretical” process identified in the requirements analyses (which are based on SME accounts and analyses of documentation). Thus, the operational data often reveal short cuts and the potential for errors in the process. This information can often lead to insight for the design of new technology.

9.2.2 Test and evaluation- lessons taught

One key objective of the TD was to conduct an empirical evaluation of the effectiveness of the MSDF functionality in the context of operational tasks and user requirements (Matthews and Keeble 2004). To this end, appropriate MOPS were developed with the ultimate goal of utilising these in a full scale evaluation in a simulated operational context. The evaluation trial was conceived of as being a close approximation to the team and individual tasks involved in target detection and recognition. It would be conducted in a test environment that was of sufficient operational fidelity that operators could access the TD functionality in a manner that was integrated into their standard operating environment.

The desired objective of conducting a full scale evaluation with operators produced many challenges at the technical, engineering, logistic, and personnel levels. For example, at the engineering level there were considerations of how to display MSDF tracks and integrate them into the existing CCS tactical picture while maintaining track numbering integrity. There were also issues of the choice of symbology and the representation of certainty information. There was a further difficulty in being able integrate the TDP functionality in a transparent manner into the aging infrastructure of the existing CCS. Another issue was that the TDP, which was designed to implement and demonstrate a particular technological concept, did not have the features required to meet the requirements of HIL T&E; it lacked the necessary data capture capability and ability to flexibly change system parameters to allow manipulation of variables of interest for T&E purposes. At the logistical level, there were difficulties in finding a suitable T&E environment, configuring that environment, creating scenarios and finding available, experienced Ops Room personnel to participate in a trial, or series of trials. At the personnel level, there were issues concerning the need for a CONOPS for the new functionality, the training in such a CONOPS and how this would mesh with existing operational procedures and practices.

Given such challenges to conducting evaluations of fully evolved systems in operational or quasi-operational contexts (which are likely to be found in other situations where new military systems are being developed), alternate, and more practical and cost-effective approaches will need to be considered. In this respect, the approaches suggested by Matthews (1997), Osga (1995), and Kellmeyer and Osga (2000) may have some merit.

Based on the approach of Matthews et al. (1997) and integrating the lessons learned from more recent experiences in this and other projects, it is recommended that the general approach to T&E should focus on the following aspects of a C2 system:

- Utility (the usefulness of the system functions for critical operational tasks; support for communication, situation awareness, situation analysis, decision making).
- User fit (meets operator requirements for usability, OMI design, configurable to different operator roles, positions and teams, training and suitable workload).
- Operator-system performance (on critical tasks).
- Operational capability (team based critical tasks in an operational context; workload; trust in automation).
- Overall system capability (performance envelope; resource requirements).

With these evaluation dimensions in mind, the approach advocated is to conduct much of the basic evaluation for utility and user fit (particularly usability) at a very early stage in development using storyboards and very simple mockups. This approach is a cost effective way of getting early feedback on whether basic operator requirements are being met, and avoids too much effort being placed on developing a fully interactive prototype to essentially obtain the same outcome (Kellmeyer and Osga 2000). In the case of the TD, storyboards were used for evaluating concepts for representing uncertainty (Unger Campbell and Baker 2003) as well as for the CONOPS design concepts to support MSDF functionality (Keeble et al. 2007).

With such feedback integrated into the development cycle, the next stage of testing would be to validate the ensuing design solutions with functional prototypes and to conduct operator-system performance testing on critical tasks using appropriate performance metrics (both of which have been identified by prior HF analyses). The approach to this phase of testing would be to use the simplest and most basic interactive functionality to gather the required information. This evaluation would eventually be extended to include sequential task strings that replicate core operational procedures by individuals and, possibly, teams.

Using such an approach would mean that cost risk is mitigated for the developer and the match to operational requirements for performance and user fit is mitigated for the operational community. It would be anticipated that 90-95% of the HF issues concerning the new system could be addressed in this way, leaving a small number of issues concerning operational fit to be addressed once a deliverable, functional system is fielded to the operational environment. Some of the critical issues that may only be validly evaluated in an operational environment include trust in automation, workload, and task management. Essentially, this general approach can be though of as a sophisticated implementation of “build a little-test a little”.

It should be noted that even with such an approach, it may still not be possible to fully evaluate the overall system capability or bandwidth because of logistical or other constraints in the typical testing or operational environment. For example, if there was a need to look at performance when there is a mass attack and a high number of tracks to be processed (a scenario for which MSDF capability has been advocated as providing a benefit), this could not be done with existing scenario capabilities and would be limited by the existing procedures and training standards of personnel. Also, if there was a desire to empirically evaluate the effects of manpower reductions in the Ops Room, or a change in responsibilities or procedures, this would be very difficult to implement in a HIL trial. In such cases, modelling and simulation provide an additional T&E approach that could successfully address these and other similar issues. Such an approach should be seriously considered in the development of complex systems in which there is a desire to obtain sound evidence on the degree to which the system will improve operational performance and how all of the system elements (human, hardware, and software) can be fine tuned and manipulated to maximise the operational gain.

A summary of the sequential stages of evaluation are outlined in the following table.

T&E requirements	Approach	Example
Requirements; system analysis	Prior to system development	Work, function, cognitive, task and Hierarchical Goal Analyses; OMI Guidelines
Utility, usability; OMI design	Storyboards, mock-ups, table top evaluation, cognitive walkthroughs	Symbology; display of MSDF data; integration with CCS tracks; alerts; representing certainty
Performance evaluation- core functionality-single tasks; dynamic usability	Appropriate MOPS for conducting simple critical tasks; screen prototypes, interactive, dynamic displays	Single contact recognition and identification
Operational procedures: individuals and teams	Interactive functionality to support performance of task strings; CONOPS	Tactical picture compilation, individual situational awareness, prioritisation of targets
Operational capability	Interactive scenarios using team based activities for tactical picture compilation	Validation of full MSDF functionality in a more dynamic and realistic environment; team situation awareness; time required for contact recognition; trust in MSDF automation
Overall system capability-performance envelop	Modeling and simulation	Impact of MSDF with high contact rates; reduced manning; operator overload

To summarise, the logistical and other requirements to support a full scale trial dedicated to T&E were shown over the course of the TD to be almost insurmountable given the many constraints identified. However, the training environment of the ORTT was found to provide an opportunity to collect the required operationally valid data (and has been demonstrated for the existing processes of air and surface contact detection, recognition and identification) (Matthews et al. 2007b). For the future, an ability to integrate new C2 functionality into the ORTT system would represent an effective strategy for evaluating that functionality at a high level of fidelity and with complex tasks.

For the evaluation of the utility and usability of new system functions, a more practical and cost-effective approach is recommended using cognitive walkthroughs of early design concepts and simple prototypes of system functions. Subsequently, this would be followed by an approach that employed dynamic displays with limited functionality to allow operator interaction for the conduct of core critical tasks.

Overall, the goal of the T&E strategy must be to optimize the method and approach to evaluation by using just enough technology to address the issues of interest. Fundamentally, this means that there is a need to develop *a priori* a detailed T&E plan to identify these issues and to identify the appropriate approach and logistics for an incremental process of evaluation. The risks of relying solely on a final evaluation of a completed system to accomplish the various needs of T&E are high, and even if they can be mitigated through a careful analysis of the logistics and practicality of such an approach, represent a high investment in effort with a low probability of successfully achieving the required level of comprehensiveness, validity and quality in the evaluation data obtained.

9.3 System design/re-design

9.3.1 Use of a style guide

In recent years, many style guides have been developed (Unger Campbell 2001b). They are seen as a way of avoiding the development of incompatible interfaces across multiple systems in complex environments such as an Ops Room. Although it proved relatively straightforward to develop the COMDAT OMI Style Guide and the concept was readily accepted by the Navy, it was never actually used in the development of the interface for the TD. Instead, the designers based their interface on the existing CCS with all its known flaws. Thus, it is not possible to assess the actual utility of the document.

The review of the TD interface by the developer of the style guide (Unger Campbell 2004b) indicated that it did contain most of the necessary guidance needed to evaluate the interface. However, the developer was familiar with the content and the format. Thus, a naïve user might have had greater difficulty. Ideally, the guide would be used during the development phase. As indicated in the discussion in Section 6, the guide may be less useful for that purpose because it lacked higher level guidance and sufficient relevant examples. Possibly even more critical is the lack of a supporting software package which would allow the designer to easily generate compliant windows, menus, etc. This type of tool allows the designer to focus on the overall design and automatically ensures a more consistent and compliant look and feel.

9.3.2 Interface improvements

The COMDAT reports contain a large number of recommendations for improving the current interface and for designing an interface for a CCS with MSDF. Unfortunately, none of these were implemented. However, all of the recommendations were based on accepted HF knowledge, were conceptually validated by SMEs, or arose out of the requirements analyses. They include

- Reduce auditory communication load (particularly at ORO and SWC positions).
- Provide visual aids for improved situation awareness and attention switching at all positions.
- Provide visual aids for improved management of the Ops Rooms (ORO).
- Integrate all tabular information on a contact in a single place available to all positions (including: track number, bearing + trend, range + trend, course + change, speed + change, length (if ship), time held, current ID, recognition (TG, ship and local), evidence supporting recognition assessment.
- Provide critical contact data for a track on the situation display (e.g. right click or hover brings up track data block).
- Provide a visual aid that presents information concerning potential associations between EW and platform tracks (e.g. association matrix).
- Provide visual aids for management of tracks and the tactical picture (ORO, SWC) – including a single source to see all relevant information on all tracks, with sorting and prioritisation capability.

- Provide the ability to predefine contacts, areas and conditions of interest so that "automated" processes can provide alerts or indicators when conditions are met.
- Provide visual aids on track data displays to allow operators to quickly observe the status of pre-defined alerts to conditions or contacts/tracks of interest.
- Provide a consistent and common OMI design for all displays that is consistent with operators' existing mental models for computer systems (e.g. "MS-Windows" functionality).

It should be noted that implementation of many of these will have the side benefit of reducing the auditory communication load.

Examples of possible implementations of some of the above recommendations are provided in Keeble et. al. (2007)

9.4 Unanswered questions and future research

9.4.1 Symbology for tactical displays

The research reviewed in Annex A along with that carried out by DRDC-Toronto (McFadden, Jeon, Li, and Minniti 2007a) point out some fundamental problems with existing and proposed standards for symbology. Further research is required to better understand (a) what critical elements of the tactical picture need to be represented on tactical displays, and (b) what tactically critical contact attributes need to be represented in symbology and (c) what form of encoding and representation is best for displaying such information (taking into account tactical context, overlays and clutter).

9.4.2 Alerts and indicators

Although the project did not specifically examine the issue of the design of alerts and indicators, there were several instances when this issue was raised by operators during the course of interviews concerning tactical picture compilation and situation awareness. Based upon such comments and informal heuristic evaluations of the present CCS design, we believe that empirical studies need to be conducted on the best way to implement alerts and other situation awareness aids and indicators. In particular, the planning of the alert/indicator hierarchical scheme needs to be done in a disciplined manner to avoid replicating existing alert problems with the CCS. Attention needs to be given as to how alerts should be divided (or replicated) between data and tactical windows. The proposed scheme for indicators and alerts in Keeble et al. (2007) is but one possibility among many which should be empirically evaluated.

9.4.3 Representation of certainty and other information

In the context of MSDF and decision support algorithms, the system maintains internally a significant level of detail on contact attributes and generates propositions concerning recognition state (and possibly identity). The issue of how much of this underlying information (and in what format) should be presented to the operator has been touched upon in this project, but requires further analysis and investigation. In particular, further research is needed to determine the best approach to representing confidence of information (used for decision support) in a manner that is intuitive to operators and contextually relevant. Some of the preliminary ideas developed under COMDAT (McFadden, Li, and Trinh 2007b; Unger Campbell and Baker 2003) require further exploration and empirical assessment.

10 Conclusions

This report has provided a summary of the HF work carried out under COMDAT along with related material that informed and supplemented this work, some lessons learned, and recommendations for future work. The major HF outcomes of the TDP were improved methods, tools, and knowledge about:

- cognitive and functional task analyses to defined the information requirements of the major Ops Room positions on Halifax Class ships,
- the development of human-in-the-loop measures of performance to define the current performance in the Ops Room and evaluate new technology including MSDF,
- the design of human computer interfaces in naval command and control systems to better meet the goals, information requirements, situation awareness and decision making of individual operators,
- the design of a concept of operations for the implementation of MSDF into tactical picture compilation, and
- the design and conduct of the evaluation of operator performance on existing and new technologies.

The output from the COMDAT TDP has already informed the mid-life upgrade of the Halifax Class Ops Room and is expected to define the HF involvement in future naval acquisition projects. The results and the recommendations for further work are also being passed on to other TDPs and naval applied research projects.

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ANNEX A – Human factors studies of relevance to COMDAT

The Technical Cooperation Programme (TTCP), Human Resources and Performance Group (HUM) Technical Panel 9 (TP9): Human Systems Integration for Naval Systems is responsible for conducting collaborative research of mutual benefit to TTCP nations aimed at integrating human factors into the design of safe, manpower efficient and cost-effective systems for current and future naval platforms. Collaboration under TP9 is carried out in three main areas:

- Technology drivers: evaluating the application and implications of new technology for naval systems;
- Acquisition process: the insertion of HF into the acquisition process for naval systems;
- Tools for optimising naval platform manning requirements.

Over the past several years, research conducted jointly and separately by member nations in each of these areas has been made available to all members. In particular, the research on technology drivers, especially the research carried out under the manning affordability project, proved of immense value to COMDAT. In order to provide a better understanding of the conclusions and recommendation put forward in the various COMDAT reports, this Annex provides a summary of the most relevant research provided under the auspices of HUM TP9 and its relevance.

A.1 Operator Machine Interface (OMI) studies

The requirement in COMDAT to consider human factors issues in the design of the OMI for the Halifax Class Command and Control System (CCS) echoed similar requirements in other TTCP nations. In fact, the United States had already conducted a series of studies aimed at producing OMI design guidelines to support the development of a more effective and efficient interface for the Aegis Combat Information Center (CIC) (Osga 1995). To a large extent the goals for the OMI work under COMDAT were similar, although more modest, to those of the Aegis project. However, the Aegis project followed a more systematic human factors process starting with an analysis of the operator's tasks. The individual tasks were further analysed to determine generic OMI procedures and the steps required to carry out these procedures. This knowledge was used to develop design concepts that supported efficient completion of these procedures. Many of the concepts reflect good human factors practice, but they are especially critical for the efficient execution of time-critical tasks carried out in an Operations Room. They include:

- minimize cursor movement,
- eliminate or reduce unnecessary visual shifts between alternate displays,
- reduce nonproductive shifts between input devices,
- efficiently use left and right hands while resting arms comfortably,
- use a broad and shallow menu structure,
- increase information density and segmentation per display,

- promote “automatic” performance and sensory modality sharing,
- provide constant visual feedback on task progress,
- reduce redundant information on separate displays and co-locate related information on a display,
- use “pop-up” or “dialog” windows to allow task completion on a single display,
- design flexibility to account for users with varying system experience.

For more detailed discussion on each of these design concepts, the reader is referred to Osga, (1995). Many of them are consistent with the COMDAT OMI Style Guide.

To evaluate their utility, the Aegis CIC console was redesigned to be consistent with these concepts and task completion times on the original and redesigned consoles were compared using a Micro-Saint model (Osga 1989). The model was populated with actual response times for the actions required to complete procedures on the existing console and estimated times for the actions required to complete the same procedures on the redesigned console. On average, they found a 62% reduction in completion times with the redesigned console. Since, the model did not assume improvements in times to absorb information because the presentation format was improved, this finding was probably conservative.

In order to evaluate specific technologies for implementing the design concepts, a part task simulator, the Navy Advanced Information Management Evaluation System (NAIMES), was developed. Initially the simulator was used to evaluate different input devices, menu configurations, and console layouts. With it, operators could carry out typical tasks such as hooking tracks, adding tactical symbols to the display, and carrying out a multitask sequence that included hooking tracks, accessing menus, and executing functions. Details of the results can be found in Osga (1995). The specific findings are probably of limited relevance, since they involved 1990’s technology, but the analyses of the suitability of different types of input devices, menu formats, and console layouts for a CCS type display remain relevant. The work also illustrates the potential of using a relatively simple simulation to evaluate OMI concepts instead of a full scale prototype. Such an approach ensures that most OMI design issues are handled early in the design process and reduces the likelihood that evaluation of a final prototype will be negatively impacted by simple OMI design errors.

A.1.1 Studies on symbology

The results of these initial evaluations were used to provide short term recommendations for improving the OMI of the Aegis CIC. Following the completion of this work, NAIMES was redesigned to allow the investigation of more innovative technologies that could be introduced in the medium to long term. A major part of this work was the development of an improved symbology set. As with the current Halifax Class CCS, the Aegis CIC consoles employed the Navy Tactical Data System (NTDS) symbols set. In the case of the Aegis console, only monochrome NTDS symbols were used. In addition to the lack of colour coding, the NTDS symbols provided operators with minimal information about the track other than position, warfare area, and standard identification. Thus, a series of studies were conducted to evaluate an alternative symbol set that was being developed by a North Atlantic Treaty Organisation (NATO) working group (North Atlantic Treaty Organisation 1992). In general the results of these studies supported the use of solid colour coded shapes that could be annotated with icons that provided supplemental platform information about tracks (Kirkpatrick et al. 1992a; Kirkpatrick et al. 1992b; NAVSPAWARSYSCOM 1991). These studies, which focused primarily on air and surface symbology, formed the basis for the symbology studies carried out under COMDAT (McFadden et al. 2007a). A more detailed summary of the results and their implications for the design of HALIFAX Class tactical displays are available in that paper.

The availability of multiple symbol sets in the NAIMES environment supported the evaluation of an innovative method for reducing clutter and supporting information processing - variable coded symbology (Osga and Keating 1994). The idea was to use different symbol sets (and other concepts), in association with user defined filters, to increase the salience of task relevant tracks and decrease the salience of other tracks. Osga and Keating provided operators with access to six different symbol sets – the standard NATO symbology, the basic NATO symbology (no annotation), colour-coded NTDS symbols, white NTDS symbols, grey NTDS symbols, coloured, and black dots. Operators associated the different types of tracks that met the criterion of their filters with the different symbol sets. They could also select amplifying information for specific types of tracks For example, they could have two sets of tracks (hostile fighters and warships) coded NATO full and have one with leaders and one without. The initial study looked at the number of filters and levels within a filter that operators would generate. Typically, operators created between 2 and 4 filters with between 2 and 17 levels for each. Overall, 23 unique filters were created. Next, participants used their filters in monitoring a dynamic scenario. On the whole, the response was positive. Operators liked the concept and thought it had merit for reducing the complexity of a tactical display. Unfortunately, there were no comparisons of performance or situation awareness across the different sets of filters. One concern is that this type of manipulation could lead to lower awareness of new tracks.

The absence of performance assessment was partially overcome with two later studies by Nugent (1996) and Van Orden, Nugent, La Fleur, and Moncho (1999). Both studies compared performance with variable coded symbology (VCS) and conventional symbology on a visual search task. Three symbols sets, monochrome and colour coded NTDS symbols and colour filled NATO tactical symbols, were used in the variable coded symbology condition and colour-coded NTDS symbols were used in the control or conventional display condition. There were three VCS conditions – (1) colour NTDS for prominent and monochrome NTDS for receded, (2) NATO symbols for prominent and colour NTDS for receded, and (3) NATO for high, colour NTDS for moderate, and monochrome NTDS for low prominence targets. The operator’s task was to locate, select, and enter as many target symbols on a simulated tactical display as possible. The Nugent study used throughput (a combination of accuracy and response time) and confirmation time as the measures of performance. The second study (Van Orden et al. 1999) used response time per target. The results were similar in both studies. Overall, the use of variable coded symbology did not have either a positive or negative impact on performance. Instead, performance within each condition tended to be a function of the target’s symbol set. In particular, performance was poorest when participants had to search for targets coded using monochrome NTDS symbols in VCS 1 and best when the target symbol was coded using the NATO symbology in VCS3. The difference in results could not be attributed to the number of symbols displayed in each symbol set. The Van Orden et al (1999) study also collected eye movement data recording the number of fixations per target. That data indicated that poor performance was linked to the presence of both white and grey symbols on the same display. Thus, they recommended that variable coding combinations should not include both grey and colour-coded NTDS symbols. These results support the need for more systematic study of the factors that affect discrimination of symbols in complex displays (McFadden et al. 2007a).

One of the potential limitations of using filled symbols is that some tracks are more likely to be partially or totally obscured on cluttered displays. Nugent (1994) and Nugent, Keating, and Campbell (1995) investigated this possibility along with two potential tools for overcoming it. The two tools were a pop-up window that listed all tracks in a small area surrounding the coordinate position selected on the display and a click tool that brought each symbol in the group to the forefront on successive mouse clicks in the area containing a cluster of symbols. The NATO symbol set was compared against a colour-coded NTDS symbols set that had been amplified to provide a similar level of information to the annotated NATO symbols. Operators searched for target symbols under a no overlap, partial overlap, total overlap and an "on top" condition. In the latter, the target symbol was always positioned on top of two or more adjacent symbols. They were expected to search for the target symbol, using the selection tool and hook potential targets symbols. Performance was faster and more accurate with the NATO symbols in the no, partial and "on top" overlap conditions, but there were fewer time-outs with the NTDS symbols (failure to find all the targets in a two minute period). Moreover, a more detailed analysis indicated that the superiority of the NATO symbols occurred primarily in the "on top condition. In the total overlap condition, performance was more accurate with the NATO symbols, but it was significantly faster and there was less use of the selection tools with the NTDS symbols. The faster response time was primarily due to the larger number of time-outs with the NATO symbols. There was no difference in performance between the tools except that operators using the click tool made less use of it and had twice as many time-outs. This difference was attributed to the ability to review all symbols in a group simultaneously with the pop-up tool.

The results of the above studies formed the basis for the initial interface for the Multi Modal Work Station (MMWS) which was developed to explore more advanced concepts in interface design in support of the manning affordability project.

A.1.2 Support for the management of tasks

In a complex environment such as an operations room, operators must complete a wide range of tasks and task sequences accurately and quickly. There can be a heavy workload associated with the planning and time management of these tasks. In an attempt to reduce this type of workload, concepts to support task management were investigated as part of the MMWS project. Initially, a set of task characteristics and the design requirements for these characteristics were defined. For example if a characteristic of a task is that it has defined schedule then that schedule should be made available to the operator (Osga 2000). Design requirements were associated with these characteristics and in turn these were matched with a variety of user-interface aids to support tasks with those characteristics. Thus, the system might provide a display showing a summary of the steps associated with the task of prosecuting a hostile target and by monitoring the system status alert the operator when the next step needed to be carried out. Tasks were looked at from the perspective of their impact on cognitive performance. Tasks that were skill- or rule-based were good candidates for automation as were information seeking tasks.

The utility of one possible type of task management display was evaluated empirically by St. John and Osga (St. John and Osga 1999) using a generic task. A simulation was developed in which participants supervised a group of friends (tasks) getting ready for a trip to a shopping mall. The supervisor had to monitor six concurrent tasks and evaluate the effect of problems that arose on deadlines. They were provided with a display that listed a set of tasks and subtasks, including their start time and completion time, that needed to be completed in order for the supervisor to meet his/her goal. A simple Gantt chart layout was used that mapped the tasks and subtasks against timelines. The supervisor received alerts about the tasks. The goal of the experiment was to see if the task manager display could improve the evaluation of alert messages. A second experiment added a decision support tool that ranked the alerts into one of four priorities and informed the supervisor in one of two ways about the priority of the alert. In general, the results showed the value of simple displays that reduce memory load associated with remembering the spatial-temporal order of tasks and, in the second experiment, that reduce the workload associated with determining which of multiple tasks need to be addressed first.

An important issue in the design of task management support is how to integrate it into the overall interface. User evaluation of a prototype task management display implemented in the MMWS suggested that the use of time and display scrolling were not beneficial (Osga 2000).

A.1.3 Evaluation of 3-dimensional display concepts

Advances in graphic engines have led to the development and investigation of more advanced concepts in symbology such as the use of 3-dimensional (3-D) displays and icons (Smallman, Schiller, and Mitchell 1999; Smallman, Oonk, St. John, and Cowan 2000a; Smallman, Schiller, and Cowen 2000b; Smallman, St. John, Oonk, and Cowen 2000c; Smallman, Oonk, St. John, and Cowen 2001a). An initial study (Smallman et al. 1999) looked at the utility of a 3-D display for improving rapid situation awareness (SA), where SA was defined as the percentage of correctly answered questions about specific display attributes. Participants monitored a tactical scenario presented as a 3-D display with realistic icons, a 2-dimensional (2-D) display with realistic icons, or a 2-D display with conventional symbols. In this case, MIL-STD-2525B symbology (Department of Defense 1999) was used. Every thirty seconds, participants were probed about the spatial and identity attributes of four of the targets. Initially SA was best with the 2-D display with conventional symbols, but over time, it increased in the other two conditions until it was similar in all three conditions. In terms of the individual attributes, spatial attributes, especially altitude and attitude, were recalled better with the 3-D icons in the 3-D display while identity and platform information was more accurate with the 2-D symbols.

One problem with 3-D perspective displays is the inherent ambiguities of perspective projection and the lack of depth cues making it difficult to accurately identify the position of tracks. Smallman, Schiller, and Cowan (2000b) investigated three techniques for overcoming this problem – drop lines (a line that extended from the centre of the icon to the ground plane) and drop shadows (a shadow of the icon appears directly under the symbol on the ground plane) and scaling of track symbol size. The first two techniques are designed to unambiguously locate the position of the icon. In addition the length of the line and the distance between the icon and its shadow provides an estimate of altitude. Participants were shown seven versions of a tactical picture: six 3-D views and one 2-D view. In three of the 3-D views, the icons were all the same size and in the other three they varied continuously with distance. Within each set of three, one scene used drop lines, a second used drop shadows and a third used nothing. Participants were asked to reconstruct each display by placing pins on a colour printout of the background topography where they thought the track icons appeared on the display. Misalignment was significantly less with the use of both drop lines and drop shadows. However, changing aircraft size as a function of distance was only beneficial when it was the only depth cue. There was no benefit to using the combined cues. In fact, misalignments were significantly greater with the use of size change and drop lines.

Other studies by the same group, (Smallman et al. 2000a; Smallman et al. 2000c; Smallman et al. 2001a) focused on the relative advantage of 3-D icons and 2-D symbols for representing track attribute information. Initially (Smallman et al. 2000a; Smallman et al. 2000c), participants were shown the icons or symbols one at a time and asked to name them (i.e. the platform) as quickly as possible. Platform identification performance was consistently better with the 2-D symbols than with the 3-D icons. The authors attributed this finding to the fact that 2-D symbols can be created with high discriminability. With the realistic 3-D icons, it is often necessary for operators to discriminate subtly different looking platforms.

The final study (Smallman et al. 2001a) examined a broader range of attributes, represented by 3-D icons, 2-D icons, or 2-D symbols, using a visual search task. The symbols and icons were presented on either a 2-D or 3-D display. In general, tracks with the specified attribute (e.g. platform, altitude heading), were located faster when symbols were used rather than icons and with a 2-D display as opposed to a 3-D display. However, there were exceptions. Searching for heading and speed was faster with 3-D icons, but only on the 2-D display. The reason for the latter is that heading (direction) and attitude (ascending etc) are confounded with 3-D icons seen in a 3-D perspective view. The heading advantage for icons was attributed to the fact that the icon itself indicated direction. With the symbols, the symbol heading does not change but a short line (called a leader) attached to the symbol indicates heading. The speed advantage was attributed to the fact that speed was linked to platform category (air versus surface/subsurface) and these two categories were more discriminable when imaged as icons than as symbols. The overall conclusion of the authors was that realistic coding (3-D icons in a 3-D perspective view display) puts an extremely high burden on the visual attribute of shape. With symbols, it is possible to map attributes onto different dimensions of the symbol and to make differences along a dimension highly discriminable.

A.1.4 Representation of track heading

In an attempt to improve the discrimination of category and heading with symbols, Smallman, St. John, Oonk, and Cowen (2001b) proposed a set of hybrid symbols, which they called "Symbicons". These were simplified versions of a plane and boat and the direction the Symbicon pointed indicated the direction the track was moving. Using the same visual search task described in the previous paragraph, they found that performance with the Symbicons was equal to or better than performance with the symbols on affiliation and platform and to the icons on heading and platform category. Thus, Symbicons successfully combined the best characteristics of symbols and icons.

A follow-on study (Keillor, Thompson, Smallman, and Cowen 2003) supported the use of Symbicons for detecting a change in heading. In it, participants search for a change in heading on a tactical display where track attributes were imaged using either Symbicons or 2525B symbology. Participants located the heading change more quickly when Symbicons were used.

This study used a change-blindness paradigm. Change blindness refer to the phenomenon that humans are often unable to detect major changes in objects in two successively presented scenes (DiVita and Nugent 2000). Typically, two images of a scene that differ only in one aspect, (e.g. the heading of a specific track) are alternated. A blank screen is presented briefly after each presentation of one of the scene images. These three images are presented continuously until the participant locates the change. DiVita and Nugent (2000) investigated the use of change-blindness for evaluating graphical interfaces and showed that it occurred even in relatively low workload conditions when people are focused on monitoring a display for change. The Symbicon study by Keillor et al (2003) demonstrated that the paradigm could be used successfully to evaluate design concepts. It has the added advantage, unlike most visual search tasks, that participants are not searching for a specified object which is closer to the actual task of operators monitoring tactical displays.

One potential limitation of Symbicons, in respect to their use in a Halifax class Ops Room, was that the same shape was used for both surface and underwater tracks. Another possible limitation is that there is no redundant coding of affiliation and shape. However, our own research suggests that the blocky shapes used in MIL-STD 2525B are not particularly discriminable (unless redundantly colour coded) (McFadden et al. 2007a). Another issue is the broader impact of rotating the whole symbol. While rotating the shape improves recognition of heading, it could reduce recognition of the platform category in a more complex environment with a large number of unique shapes. In general these studies show the potential value and limitations of symbology for encoding information and point to the need for more systematic research on design concepts for multidimensional symbols on complex display.

A.1.5 Situation awareness for changes in the tactical picture

Another approach to ameliorating the effects of change blindness has been explored by Smallman and St John (2003) in their investigation of a tool that they called CHEX (Change History Explicit). The tool monitored the output of a simulated tactical display and logged significant changes in critical tracks in a reconfigurable table displayed beside the tactical display. Entries in the table were dynamically linked to the tracks on the tactical display. They found that CHEX was very helpful in maintaining situation awareness when monitoring the display and for recovering situation awareness after an interruption especially as track density increased. Performance with CHEX was compared against conditions with no support, a static, unlinked table, and the static table with the critical tracks circled in red. A second experiment compared CHEX with the ability to replay interrupted periods at high speed. Again, the CHEX tool proved superior. Further research would be required to determine the overall efficacy of such a tool in an operational setting, since many operators are loathed to take their eyes off the tactical screen. On the other hand, some operators may focus more on the output of the tool instead of the tactical display. This could affect their comprehension of the overall tactical picture.

A.1.6 Automation

Tools such as CHEX reflect the use of underlying automation to carry out monitoring tasks that humans are known to be notoriously poor at (Parasuraman 1986). Human use of automation has been extensively studied particularly in the cockpit. A common finding is that human-system performance in systems with extensive automation tends to be sub-optimal. People are either over reliant on automation or ignore it (Endsley 1996). Since the MMWS included substantive automation, one study (St. John, Oonk, and Osga 2000) examined the impact of reducing the reliability of the automation that prioritized alerts in a task management system such as the one implemented in the MMWS. The experiment compared 100% accuracy against 75% accuracy. The reduction in accuracy was due to a switching in priority of two of the tasks. In one case, the human was informed that the automation had not been informed of the switch and in the other they were just told that the reliability of the automation had been reduced. There were also two manual conditions, one with the original priority and one in which the priority was switched. In the informed and manual conditions, the participants were informed verbally that the priority had switched but the display was not updated. In the uninformed condition, the new priority was shown on the display. The two tasks, whose priority was switched, did not occur until half way through the scenario. Thus, in the first half of the scenario the automation worked perfectly. However, the performance of the informed group was still poorer than that of the 100% reliable condition although it was better than the uniformed condition in terms of number of errors. In the second half, all groups except the reliable automation group performed similarly. Of interest is the fact that, in the informed group, 8 of the 11 participants relied on the automation and the others handled the task manually during the first half. The results suggest that being aware of the conditions under which automation is likely to fail can lead to more effective use of it, but not uniformly. Also some people appear to be able to make use of unreliable automation even when they do not know why it might fail.

The results of this study are typical of studies on human use of automation. Since future naval systems will include substantial automation, it is important to understand how to design systems employing automation in order to optimize human-system performance. As well as providing useful information, this work illustrates the use of part task experiments to evaluate specific design concepts. Such studies allow the collection of larger and more rigorous data sets than would be possible using existing systems and Navy SMEs while still providing directly relevant knowledge that can be used in the design of a prototype system.

A.2 Performance measurement

A key aspect of the research conducted in support of the MMWS was the development of improved methods and measures for assessing performance in both part tasks and for evaluation of prototypes and existing systems. As with the previous two sections, the research discussed below has supported and supplemented the research on MOPs conducted under COMDAT and provided significant insight into possible methodologies for measuring performance in complex naval systems.

A.2.1 Workload

One of the most common measures of performance used in assessing prototype systems is workload. It is often assessed using subjective methods such as rating scales that are presented during a scenario (task) or after its completion (Gopher and Donchin 1986). One commonly used scale for that purpose is the NASA TLX (Hart and Staveland 1988). While the evaluation of workload using such scales has been reasonably successful, like all subjective methods, it can interfere with the tasks being carried out, and is subject to participant bias. Other methods, that do not have these limitations, include physiological and performance tests. However, they also have limitations (Gopher and Donchin 1986). The MMWS attempted to avoid the limitations of individual measures by including a real-time workload measurement capability (Van Orden 2000) that integrated a whole range of measures designed to assess operator activity, environmental (task) characteristics, and the psychophysiological state of the operator. The overall system was to be composed of multiple modules each of which collected a specific measure. The output of each module was fed into an integrator that produced an overall assessment. Unfortunately, it was not possible to implement all of the modules as some of the methods required substantial development to turn them into real-time estimates. Van Orden (2000) described one system to predict drowsiness and high visual workload using monitoring of several measures of eye activity. He compared eye activity in a boring monotonous task over time and also in tasks involving contact density and found a reasonable correlation between contact density and eye activity at the high end. However, with low contact density, there was evidence of additional activity probably associated with other visual activity. This problem became more evident when he tried to use this measure in complex search and selection tasks. Other modules that have been investigated include speaking rate and button pushing rate. The paper also included a discussion of initial efforts to correlate some of the workload measures with task activity. The general conclusion was that it will probably be difficult to accurately estimate operator workload in any simple way. It is necessary to take into account modulation factors such as operator experience and system state. The conclusion was that a model that captures the relative importance of different workload measures is likely to be individual and system specific. This suggests that developing a practical real-time capability for monitoring workload is unlikely unless it includes a learning component.

A.2.2 Evaluating new technology

As with the COMDAT TDP, the manning affordability project included the development of methods and measures of performance for assessing the impact of the new technology developed under it and implemented in the Integrated Combat Environment (ICE) and the MMWS (Freeman, Campbell, and Hildebrand 2000). The goal was to develop measures that could be used in evaluating whether the advanced command and control watchstation, as represented by the MMWS in the ICE laboratory, could be manned successfully by fewer operators than a traditional combat information centre. The approach they used was to developed a scenario designed to allow certain behaviours to emerge and then measured those behaviours. The MOPs centred on the detect-to-engage cycle and included a combination of subjective and objective measures. Specific MOPs included:

- timeliness and accuracy in the detection and response to tracks,
- communication level and content,
- situation awareness, and
- workload.

The results reported by Freeman et al. (2000) were restricted to data collected using an imbedded training system in the Aegis Combat Information Center using the anti-air warfare component of a standard watchstanding team. They did compare operator and observer estimates of workload over high and low workload parts of the scenario and found that workload varied as a function of the scenario and that the two estimates were similar. A subsequent paper (Osga, Van Orden, Kellmeyer, and Campbell 2001) includes some comparisons of the performance data on the legacy system with performance on the MMWS. It reported that the operators' situation awareness improved substantially and workload was lower when using the MMWS as compared to the operational system even though the latter was manned by an eight person team and the MMWS by a four person team.

The work reported in these papers is very similar to work carried out under COMDAT on the development of MOPs (Section 4) and the evaluation of performance on the existing system (Section 5) including many of the same MOPs. Thus, it provides some validation for the approach proposed under COMDAT and its potential utility for evaluating new technology such as MSDF.

A.2.3 Modelling and simulation

An alternative to the two types of studies reported above is the use of models to predict performance and workload. Although modelling can be as expensive to implement as an experiment, it permits evaluation of a much greater range of parameter values than could ever be accomplished in experiments. The output of requirements analysis can be used to create models of complex task sequences in programmes such as the Integrated Performance Modelling Environment (IPME). The utility of such models for predicting performance times was also investigated under the MMWS project (Carolan, Scott-Nash, Corker, and Kellmeyer 2000). Several different models of four different usability tasks designed to measure the impact of different input modalities were developed and run in IPME. The performance predictions of the model were compared against the performance of people carrying out the same tasks. The estimates were quite similar. They then put the actual data into the model and compared the model's predictions with human performance data on a more complex task that utilized the original usability tasks. Again the predictions were quite good. Models of the task management functions and of the full scenario used in the evaluations discussed previously (Osga et al. 2001) were also created. Comparisons with actual data should further improve knowledge about the utility of modelling as part of the tool set available for evaluating design concepts for new systems. A similar approach is proposed in section 5 to overcome the difficulty of accessing Canadian Navy training facilities and personnel for HIL evaluations of new technology. These results suggest the approach has merit.

A.2.4 Usability analysis

Another standard approach to evaluating proposed systems is usability analysis. The use of this type of methodology during the various evaluations of the design process with the MMWS and some lessons learned are described by Kellmeyer and Osga (2000). Initially, they trace out the design process and link the process to the type of evaluation and use of SMEs. The paper includes some useful lessons learned. The process is similar to that described in section 2.1 in that it involves increasing fidelity of representation of the proposed design and a move from subjective to more objective evaluations. Some lessons learned included:

- They found that SMEs had trouble relating to a future tasking, the use of higher levels of automation, and new roles due to crew reduction. Thus, the initial evaluations tended to focus on display layout and later evaluations used scenarios that involved current taskings. A similar reaction was encountered in many of the COMDAT evaluations. SMEs could not imagine that they would not be able to handle a large increase in the number of tracks using the procedures that they do now.
- They warned against spending too much time and effort on lower fidelity levels of prototyping (storyboards, powerpoint etc). Only high fidelity prototyping can bring out the complications of dynamic usability. Their opinion was that continued refinement of low-fidelity (i.e. part-task) interfaces leads to increased display complexity. This unwanted complexity only becomes apparent when the designs are tested within the overall system. One example is the use of scrolling and timelines in the task management display discussed earlier in Section A.1.2.
- They also warned against putting extensive effort into development of the interactive prototype. They found that the interactive prototype took far too long to build and iterate

and in the end became too complicated to easily build on. They recommended focusing on key portions of the interface.

A.2.5 Summary

Many of the methods for measuring performance that have been discussed above have been proposed throughout the COMDAT project although most were not implemented because of logistical or practical limitations (see section 9.2.2). Thus, the lessons learned in this area from the manning affordability project are of particular importance in interpreting the recommendations for HIL measurement of performance in the COMDAT TDP.

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Acronyms

Acronym or Abbreviation	Definitions
2-D	2-dimensional
3-D	3-dimensional
AMP	Amplification (as in ID AMP, PRI AMP)
ARRO	Air Raid Reporting Operator
ASPO	Anti Submarine Plotting Operator
ASWC	Assistant Sensor Weapons Controller
C2	Command and Control
CCS	Command and Control System
CDS WG	Command Decision Support Working Group
CFNOS	Canadian Forces Naval Operations School
CSFAB	Combat Systems Functional Allocation Board
CO	Commanding Officer
COA	Course Of Action
COMDAT	Command Decision Aid Technology
CONOPS	Concept of Operations
CPF	Canadian Patrol Frigate
CSTC	Combat Systems Training Centre
CTA	Cognitive Task Analysis
CWA	Cognitive Work Analysis
DL	Decision Ladder
D-S	Dempster-Shafer
DRDC	Defence Research and Development Canada
ELINT	Electronic Intelligence
ESM	Electronic Support Measure
EW	Electronic Warfare
EWS	Electronic Warfare Supervisor
GCCS	Global Command and Control System
GDB	Global Database

Acronym or Abbreviation	Definitions
GUI	Graphical User Interface
HCI	Human Computer Interaction
HF	Human Factors
HGA	Hierarchical Goal Analysis
HIL	Human-In-the-Loop
HMCCS	Halifax Class Modernization Command and Control System
HSI	Human Systems Integration
HUM	Human Resources and Performance Group
ICE	Integrated Command Environment
ID	Identification
IFF	Identification Friend or Foe
IMD	Information Management Director
IP/PCT	Information Processing/Perceptual Control Theory
IPME	Integrated Performance Modelling Environment
MFTA	Multi Function Task Analysis
MMWS	Multi Modal Work Station
MOP	Measure of Performance
MS	Microsoft
MSDF	Multi-Source Data Fusion
NATO	North Atlantic Treaty Organization
NCOT	Naval Combat Operator Trainer
NTDS	Naval Tactical Data System
OMI	Operator Machine Interface
OOW	Officer Of the Watch
Ops Room	Operations Room
ORO	Operations Room Officer
ORS	Operations Room Supervisor
ORTT	Operations Room Team Trainer
OSD	Operational Sequence Diagram
OSF	Open Software Foundation
OTT2	Operations Team Training 2

Acronym or Abbreviation	Definitions
PRI	Primary
Prob	Probable
R&D	Research and Development
SA	Situation Awareness
SWC	Sensor Weapons Coordinator
T&E	Test and Evaluation
TD	Technology Demonstrator
TDP	Technology Demonstration Project
TG	Task Group
TP	Technical Panel
TS	Track Supervisor
TTCP	The Technical Cooperation Programme
U.S.	United States
VCS	Variable Coded Symbology

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The purpose of the COMmand Decision Aiding Technology (COMDAT) Technology Demonstrator Project (TDP) was to research and demonstrate multi-source data fusion (MSDF) technologies and carry out human factors (HF) studies to support upgrades to the Halifax Class Command and Control System (CCS), in the area of battle space awareness. Since the requisite HF knowledge to support this TDP did not exist, the HF component included the generation of the founding knowledge necessary for decision aid development in future projects. The major work items included

- the conduct of cognitive and functional task analyses to define the information requirements of the major Operations Room positions on Halifax Class ships;
- the development of human-in-the-loop measures of performance in order to evaluate strategies for conducting performance evaluations, define current performance in the Operations Room, and evaluate technologies including MSDF;
- recommendations for improvements to human computer interfaces in the existing CCS and the Technology Demonstrator (TD);
- the development of a concept of operations for user involvement in MSDF; and
- support for an evaluation of operator-system picture compilation performance using the final TD.

The detailed results of the HF work have been published in a series of reports over the course of the project which lasted from June 2000 to March 2007. This final report provides a summary of the reports along with related material that informed and supplemented this work, some lessons learned, and recommendations for future work. Overall, we have a better understanding of the usefulness of the methods that were investigated as well as considerably more knowledge about the information requirements and processes involved in building the tactical picture in the Halifax Class Operations Room. In addition, we have generated improved guidance for designing the interfaces needed to support operator goals and tasks as well as a better understanding of the research needed to build even more effective interfaces and decision support systems for naval command and control.

Le projet de démonstration de la technologie (PDT) d'aide aux décisions de commandement (COMDAT) avait pour objet d'étudier les technologies de fusion de données multi-sources (MSDF) et d'en faire la démonstration ainsi que de mener des études des facteurs humains (FH) à l'appui de mises à niveau du système de commandement et de contrôle (C2) des navires de la classe Halifax, dans le domaine de la connaissance de l'espace de combat. Comme la connaissance des FH nécessaire pour appuyer ce PDT n'existait pas, la composante FH comprenait la génération des connaissances de base nécessaires à l'élaboration d'aides aux décisions dans des projets futurs. Les principales tâches de recherche comprenaient :

- l'exécution d'analyses des tâches cognitives et fonctionnelles pour définir les exigences d'information des postes principaux dans la salle des opérations des navires de la classe Halifax;
- l'élaboration de mesures de rendement avec un chaînon humain dans la boucle afin d'évaluer des stratégies d'évaluation du rendement, de définir le rendement actuel dans la salle des opérations et d'évaluer les technologies, y compris la MSDF;
- des recommandations d'amélioration des interfaces humain-ordinateur dans le système C2

existant et le démonstrateur de la technologie (DT);

- l'élaboration d'un concept des opérations en vue de la contribution des utilisateurs à la MSDF;
- le soutien d'une évaluation du rendement de compilation d'un tableau de l'interface opérateur-système au moyen du DT définitif.

Les résultats détaillés des travaux en FH ont été publiés dans une série de rapports tout au long du projet, qui a duré de juin 2000 à mars 2007. Le présent rapport final résume ces rapports de même que du matériel connexe qui soutenait et complétait ces travaux, certaines leçons apprises et des recommandations de recherches futures. Somme toute, nous avons une meilleure compréhension de l'utilité des méthodes étudiées, ainsi qu'une connaissance beaucoup plus complète de l'information requise et des processus nécessaires pour constituer le tableau tactique dans la salle des opérations des navires de la classe Halifax. De plus, nous avons élaboré des directives améliorées pour concevoir les interfaces nécessaires pour appuyer les objectifs et tâches des opérateurs et acquis une meilleure compréhension des recherches nécessaires pour construire des interfaces et des systèmes d'aide aux décisions encore plus efficaces pour le commandement et le contrôle navals.

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COMDAT; Navy; command and control; Multi Source Data Fusion (MSDF); Multi Function Task Analysis (MFTA); Cogntive Task Analysis (CTA); Cognitive Work Analysis (CWA); Hierarchical Goal Aalysis (HGA); Operator Machine Interface (OMI); Concept of operations; recognition; identification; symbology; uncertainty; style guide; Measures of Performance (MOPs); test and evaluation; operations room; tactical displays