Human Factors Analyses of Operator Positions in the Operations Room of the HALIFAX Class Frigate

FINAL REPORT

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EXECUTIVE SUMMARY

This project employed Hierarchical Goal Analysis (**HGA**) (Hendy, Beevis, Lichacz, and Edwards, 2002) to analyze eleven operator positions in the HALIFAX Class Frigate operations room, including: Commanding Officer (**CO**), Operations Room Officer (**ORO**), Sensor Weapons Controller (**SWC**), Assistant Sensor Weapons Controller (**ASWC**), Track Supervisor (**TS**), Electronic Warfare Supervisor (**EWS**), Air Raid Reporting Operator (**ARRO**), Anti-Submarine Plotting Officer (**ASPO**), Information Management Director (**IMD**), Operations Room Supervisor (**ORS**), and Warfare Officer. The position of Shipborne Aircraft Controller (**SAC**) was added during the analysis for completeness. HGA analyzes cognitive systems from a Perceptual Control Theory (**PCT**) perspective, where PCT suggests that humans operate as perceptually-driven, goal referenced, feedback systems (Powers, 1973). HGA identifies a hierarchy of goals and sub-goals for the analyzed system, assigns a human (or automated) operator to each goal, and identifies a controlled variable that is perceived and controlled by the operator to achieve the goal. HGA also captures other attributes associated with each goal in the form of PCT tables. Based on a military role (represented by a sea denial mission) the HGA produced 563 goals and sub-goals allocated among the 12 primary positions. Due to the matrix type organization of the operations room the majority of goals were also assigned to secondary positions.

Additional analyses emerged from the HGA approach: stability analysis and upward flow analysis. Potential instabilities arise in a system when more than one operator attempts to control the same external variable. This study found that the current doctrine and Standard Operating Procedures (**SOP**s) employed in the Halifax Class Frigate operations room act to mitigate potential instabilities identified during the analysis. The stability analysis process would be useful during the development of future capabilities and/or the addition of new equipment in order to identify potential instabilities. The upward flow analysis identifies instances where one operator controls a goal that supports a goal controlled by another operator, creating a need for upward flow of information. Link diagrams were used to capture information flow to both the primary and secondary operators and in both the auditory and visual domains. This analysis reveals the potential for cognitive overload in the current system and the opportunities for reducing overload in future systems. An overwhelming demand on the auditory channel was identified.

The HGA also led to the development of a task network in which task sequences and interactions between positions were modelled and analyzed for scheduling conflict and workload. Five critical task sequences, selected for their criticality and inclusion of all positions, were simulated in the Integrated Performance Modeling Environment (**IPME**). IPME proved to be an extremely effective tool for combining baseline task networks to simulate a multi-threat scenario, however the effort involved to accomplish this was significant.

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Finally, a criticality analysis was conducted in which each goal or sub-goal was assessed to determine activities that could pose significant risk to mission accomplishment. Activities that approached the limits of human capabilities and skills, have safety implications, or those that might jeopardize successful mission completion were designated as critical. Appropriate corrective action was subsequently determined by domain experts and Subject Matter Experts (**SME**s). In many human factors analyses, such as Mission, Function, and Task Analysis, the identification and rating of critical activities is a straightforward undertaking. The rating of goals from the HGA was a departure from this norm. The domain experts and SMEs charged with providing criticality ratings initially found it difficult, as a number of the higher-level goals appeared broad. Interpretation was subsequently augmented by using attributes captured in the PCT table as an aid to understanding the scope of the goal. The majority of proposed solutions recommended automating displays and data entry. The integration of tactical and command decision aids was also highly recommended.

The project confirmed that HGA was a suitable tool for the analyses of complex predominantly 'cognitive' systems. In full development programs such as the procurement of a new class of warship or the development of new Uninhabited Aerial Vehicle workstations, the additional time available and the inherent interest in the development of new technologies (such as multi-agent systems) makes an HGA the clear choice for conceptual phase human factors analyses. During the conduct of the work outlined above, the techniques employed and data produced were applied to the Halifax Modernized Command and Control System project with excellent results. This immediate use of the project is reported under a separate cover entitled "HALIFAX Modernized Command and Control System (**HMCCS**) Human-Machine Interface Support Contract Human Engineering System Analysis Report".

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SOMMAIRE ADMINISTRATIF

Le projet a utilisé l'analyse des objectifs hiérarchiques (AOH) (Hendy, Beevis, Lichacz et Edwards, 2002) afin d'analyser onze fonctions d'opérateurs dans le poste des opérations d'une frégate de classe Halifax, notamment le commandant (cmdt), l'officier du Centre des opérations (O C Op), le contrôleur d'armes par capteur (CAP), l'assistant du contrôleur d'armes par capteur (ACAP), le superviseur de piste (SP), le superviseur de la section de guerre électronique (SSGE), l'opérateur des renseignements de raids aériens (ORRA), l'officier du traçage anti-sous-marin (OTASM), le directeur de la gestion de l'information (DGI), le superviseur du poste des opérations (SPO) et l'officier de guerre. La fonction de contrôleur d'aéronef embarqué (CAE) a été ajoutée pendant l'analyse à des fins d'intégralité. L'AOH analyse les systèmes cognitifs du point de vue de la théorie du contrôle perceptuel (TCP), où la TCP indique que les humains dictent leurs opérations à l'aide de perceptions, d'objectifs et de systèmes de rétroaction (Powers, 1973). L'AOH établit une hiérarchie d'objectifs et de sous-objectifs pour le système analysé, attribue un opérateur humain (ou de façon automatique) à chaque objectif et détermine une variable contrôlée qui est perçue et contrôlée par l'opérateur afin d'atteindre l'objectif. L'AOH saisit aussi d'autres attributs associés à chaque objectif sous forme de tableaux de TCP. D'après un rôle militaire (représenté par une mission d'interdiction des mers), l'AOH a produit 563 objectifs et sous-objectifs attribués entre les douze fonctions principales. En raison de l'organisation du type de la matrice du poste des opérations, la majorité des objectifs ont aussi été attribués à des fonctions secondaires.

De plus, des analyses supplémentaires ont été révélées à partir de la démarche de l'AOH : une analyse de stabilité et une analyse ascendante. Des instabilités possibles surviennent dans un système lorsque plus d'un opérateur tente de contrôler la même variable externe. Cette étude a révélé que la doctrine actuelle et les instructions permanentes d'opération (IPO) utilisées dans le poste des opérations d'une frégate de classe Halifax permettent d'atténuer les instabilités possibles identifiées dans l'analyse. Le processus d'analyse de la stabilité serait utile pendant le développement des capacités futures et/ou de l'ajout de nouveaux équipements afin d'identifier des instabilités possibles. L'analyse ascendante détermine les occurrences pendant lesquelles un opérateur contrôle un objectif qui appuie un objectif contrôlé par un autre opérateur, ce qui créé un besoin de circulation ascendante de l'information. Des diagrammes d'enchaînement ont été utilisés pour saisir la circulation de l'information vers l'opérateur principal et l'opérateur secondaire dans les domaines auditifs et visuels. Cette analyse révèle la possibilité d'une surcharge cognitive dans le système actuel ainsi que les possibilités de réduire la surcharge cognitive future dans les systèmes. On a établi une demande écrasante sur le poste auditif.

L'AOH a aussi mené au développement d'un réseau de tâches dans lequel les séquences et les interactions des tâches entre les fonctions ont été conçues et analysées pour déterminer les conflits d'horaire et la charge de travail. Cinq séquences de tâches, sélectionnées

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selon leur niveau de criticité et leur inclusion de toutes les fonctions, ont été simulées dans l'environnement intégré de modélisation des performances (EIMR). L'EIMR s'est avéré être un outil extrêmement efficace pour combiner des réseaux de tâches de base permettant de simuler un scénario multimenaces; toutefois, l'effort requis pour l'accomplir a été important.

En terminant, une analyse de criticité a été effectuée au cours de laquelle chaque objectif ou sous-objectif a été évalué afin de déterminer les activités qui pourraient poser un risque important par rapport à la réussite de la mission. Les activités qui se rapprochaient le plus des limites des capacités et des compétences des humains (ayant des conséquences sur la sécurité) ou celles qui pourraient mettre en péril la réussite de la mission ont été qualifiées de critiques. Une mesure de correction appropriée a ensuite été élaborée par des experts du domaine et des experts en la matière (EM). Dans de nombreuses analyses de facteurs humains (p. ex., l'analyse de la mission, de la fonction et des tâches), l'identification et l'évaluation des activités critiques constituent une tâche simple. L'évaluation des objectifs de l'AOH était le point de départ de la norme. Les experts du domaine et les EM qui doivent fournir des évaluations critiques initialement ont trouvé la tâche difficile étant donné qu'un certain nombre d'objectifs du plus haut niveau semblaient assez vastes. Des attributs saisis dans le tableau de TCP ont par la suite été ajoutés à l'interprétation afin d'aider à comprendre la portée de l'objectif. La majorité des solutions proposées recommandaient l'affichage automatique et la saisie de données. L'intégration d'outils d'aide à la décision du commandement et tactique est aussi fortement recommandée.

Le projet a permis de confirmer que l'AOH était un outil adéquat pour les analyses de systèmes complexes principalement cognitifs. Dans le cadre de programmes de développement complets tels que l'acquisition d'une nouvelle classe de navire de guerre ou le développement de nouveaux postes de travail de véhicule aérien sans pilote, le temps additionnel disponible et l'intérêt inhérent pour la mise au point de nouvelles technologies (comme les systèmes multiagents) font de l'AOH le choix tout indiqué pour les analyses des facteurs humains à la phase conceptuelle. Pendant l'exécution du travail susmentionné, les techniques utilisées et les données produites ont été appliquées à la Modernisation du système de commandement et de contrôle des Halifax avec d'excellents résultats. L'utilisation immédiate du projet est consignée dans une autre section portant sur la Modernisation du système de commandement et de contrôle des Halifax (MSCCH) – Rapport d'analyse de l'ergonomie – Contrat de soutien de l'interface homme-machine.

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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.

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RÉSUMÉ

Les résultats sont fournis pour les analyses des onze fonctions d'opérateurs dans le poste des opérations d'une frégate de classe Halifax à l'aide de la démarche de l'analyse des objectifs hiérarchiques (AOH). À la suite des analyses de missions, une hiérarchie d'objectifs assignés à divers opérateurs a été produite. Deux analyses de suivi ont été ensuite effectuées afin d'identifier les instabilités possibles dans le système et les exigences pour la circulation ascendante de l'information entre les opérateurs. Des diagrammes de séquence opérationnelle (DSO) ont été produits pour des séquences de tâches critiques, et les réseaux de tâches correspondants ont été mis en place et testés dans l'environnement intégré de modélisation des performances (EIMR). Le produit final du projet était la production d'une liste d'activités critiques dans le poste des opérations appuyées par des solutions proposées. Le rapport conclut que l'AOH et l'EIMR sont des outils adéquats pour appuyer les analyses de systèmes complexes principalement cognitifs.

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SECTION ONE – INTRODUCTION

1.1 GENERAL

Defence Research and Development Canada (**DRDC**) approved Command Decision Aids Technology (**COMDAT)** I as a Technology Demonstration Project (**TDP**) in the year 2000 and it is scheduled for completion in the near future. The purpose of the project is to research and demonstrate Multi-Source Data Fusion (**MSDF**) technologies and carry out human factors studies to support upgrades to the HALIFAX Class Command and Control System (**CCS**) in the areas of battle space awareness, over the first decade of the new millennium.

In order to design a command and control system that incorporates effective human computer interfaces and decision support, the functions and tasks of key Operations Room personnel must be identified and analyzed. Initially, the Operations Room Officer (**ORO**), Sensor Weapons Controller (**SWC**) and Assistant Sensor Weapons Controller (**ASWC**) positions were identified as the ones that would benefit most directly from the inclusion of advanced support such as MSDF. Thus, part of the human factors input to COMDAT was a function and task analysis of the ORO, SWC, and ASWC positions [References 1 to 3]. However, over the course of the COMDAT project, it has been realized that MSDF will impact more directly on the tasks of the Track Supervisor (**TS**), Electronic Warfare Supervisor (**EWS**), Air Raid Reporting Operator (**ARRO**), and Anti-Submarine Plotting Operator (**ASPO**). In addition, it has been decided to include an analysis of the Commanding Officer (**CO**), Information Management Director (**IMD**), Operations Room Supervisor (**ORS**) and Warfare Officer positions in order to more fully understand the information requirements of the command team.

For systems such as the command and control system of a frigate, where human functions are predominantly "cognitive", the method of analysis should capture this essentially human activity. Since the analyses of the ORO, SWC, and ASWC have been carried out; DRDC has been investigating the utility of the Hierarchical Goal Analysis (**HGA**) methodology that claims to overcome the failure of traditional methods to capture important aspects of the system specification, particularly with respect to the characteristics of the human-machine interface.

HGA is a method for performing function and task analyses under the Perceptual Control Theory (**PCT**) paradigm [Reference 4]. With HGA, human activities at all levels of abstraction are directed to satisfying a hierarchical set of goals. HGA combines conventional function and task analysis into a unified process.

1.2 OBJECTIVES

The primary objective of the work described herein is to use HGA techniques to conduct an analysis of the CO, IMD, ORS, Warfare Officer, TS, EWS, ARRO, and ASPO positions that:

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a. represents the goals and sub-goals through the range of missions carried out by those positions in the HALIFAX Class Frigate;

b. identifies the critical tasks of each position; and

c. produces knowledge that can be used by both human engineers and system designers to improve the current HALIFAX Class CCS.

A secondary objective is to conduct a re-analysis of the SWC, ASWC, and ORO positions using the HGA methodology and to compare the two forms of analysis in terms of outputs, recommendations, and time and effort required to complete.

1.3 SCOPE

The analyses conducted were focused on the roles of the eleven operators in the HALIFAX Class Frigate domain listed in the Objectives section above. In addition CMC included the Shipborne Aircraft Controller (**SAC**) position in the study to facilitate the analysis of the other 11 positions.

The project employed the HGA approach to generate data and knowledge that could be used for analysis and design of the operations room system. Specifically the project generated a hierarchy of goals assigned to various operators, captured upward information flow, identified potential instabilities, produced a list of critical activities (complete with proposed solutions) and developed five critical Integrated Performance Modelling Environment (**IPME**) task sequences from a top down analysis based on the HGA.

The data produced was analyzed in order to conduct research on the efficiency and effectiveness of the methodology; follow-on analysis, such as the modelling of proposed solutions to reduce workloads in the operations room, was beyond the scope of this project. These analyses tools can be used for 'what if' modeling, however, that was not performed as part of this project. It must be noted, however, that the Halifax Modernization Command and Control System (**HMCCS**) Project is underway at the same time as this Human Factors Project and the informational output (listed in the previous paragraph) is being analyzed and used directly by the HMCCS team.

1.4 REPORT OUTLINE

This report consists of the following sections:

a. **Section One – Introduction**. Section One provides background information, the objectives and scope of the analysis, and a report outline.

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b. **Section Two – Analysis Methodology**. Section Two provides a detailed description of the methodology used to conduct the analysis.

c. **Section Three – Environmental Analyses**. Section Three describes the environment (the Canadian Maritime Forces and the HALIFAX Class Frigate) and the scenario in which the analysis has been conducted.

d. **Section Four – HGA**. Section Four provides an overview of the results and discussion of results of the Hierarchical Goal Analyses.

e. **Section Five – Information Processing (IP)/PCT Analyses**. Section Five provides an overview of the results and discussion of results of the IP/PCT analyses including the upward information flow and the potential instability.

f. **Section Six – Task Network Analysis Results**. Section Six provides an overview of the results and discussion of results of the task network analysis using IPME in the IP/PCT mode.

g. **Section Seven – Critical Activities Analysis Results**. Section Seven provides an overview of the results of the critical activities analysis.

h. **Section Eight – Concluding Material.** Section Eight presents conclusions and recommendations from the Human Factors Engineering (**HFE**) analyses of the HALIFAX Class Frigate Operations Room.

i. **Section Nine – References.** Section Nine documents references used in the report.

j. **Annexes.** This report includes the following annexes:

(1) Annex A – Glossary of Terms and Acronyms;
(2) Annex B – Scenario;
(3) Annex C – Hierarchical Goal Analysis;
(4) Annex D – IP/PCT Templates;
(5) Annex E – Operational Sequence Diagrams (**OSD**s);
(6) Annex F – Mean Time Pressures (**MTP**) Diagrams;
(7) Annex G – Information Processing Report (**IPR**) Summary File;
(8) Annex H – Upward Information Flow;
(9) Annex I – Potential Instabilities;
(10) Annex J – Critical Activities; and
(11) Annex K – Subject Matter Expert (**SME**) Session Reports.

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SECTION TWO – ANALYSIS METHODOLOGY

2.1 GENERAL

This project began with an environmental analysis that provided a baseline or anchor for all follow-on work. Naval guidance documents, doctrine, procedures and previous HFE studies were examined to define the environment in which the operations room operators would be expected to conduct the missions. Naval staff in NDHQ reviewed and confirmed the draft analysis prior to finalisation. Relevant information was extracted and provided input to the Section Three material.

This section (Section Two) provides a description of the analysis methodology that was used to produce the four main outputs/products associated with the project – an HGA, the IP/PCT data, task networks, and critical activity analyses.

The use of domain expertise was essential in this project. Access to SMEs was limited, therefore the expertise of Cdr (ret'd) Greg Aikins, LCdr (ret'd) Curtis Coates, and Lt(N) (ret'd) Julie Graveline was called upon to provide the basis of material for the goal hierarchy, the PCT data, and the task network information. Each of the domain experts were employed, during their naval careers, in the Halifax Class Frigate operations room or as the Commanding Officer of a Halifax Class Frigate, in the case of Cdr (ret'd) Greg Aikins.

2.2 HIERARCHICAL GOAL ANALYSIS

The generation of a hierarchy of goals for the Halifax Class Frigate Operations Room was an iterative process requiring domain experts and the review/approval by SMEs. It followed the ground rules for decomposing a goal structure as described in Reference 4.

Top-, first-, and second-level goals were developed for the three overarching roles of the ship – constabulary, diplomatic, and military. The upper-level goals and subsequent decomposition were so similar that only the military mission HGA was further decomposed to the lowest possible level. No bottom level was set a priori as it was found that some goals naturally decomposed further than others. The Technical Authority, prior to continued decomposition, reviewed the goal hierarchy developed inclusive of the second level.

After approval from the Technical Authority, domain experts decomposed the HGA to the lowest reasonable level. Because the HGA related to an existing system the allocation process was tentatively taking place at the same time. A goal was decomposed no further when the PCT external variables in Reference 4 did not relate to operators external to the system being studied. The completed goal hierarchy of the military role was presented to SMEs. They reviewed the results for completeness and allocation.

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The goal hierarchy was subsequently revisited and modified throughout the project, resulting in a final group of goals.

2.2.1 Goal Decomposition and Allocation

The goal decomposition process was conducted to systematically perform progressive decomposition of HALIFAX Class Frigate Operations Room crew goals. An HGA [Reference 4] models a cognitive system consisting of one or more operators by identifying goals, at various levels of abstraction, that the system needs to achieve. Goals are desired states to which current states are compared. If there is an error (i.e., current state ≠ desired state), then some action must be taken to resolve the error. This is similar to a closed system with a feedback loop where the system continues to adjust until it is in a neutral state. Unlike a task hierarchy, a goal hierarchy does not specify what actions should be taken. Instead, it specifies how the end states of actions should be assessed. Links between goals suggest possible directions where an operator may direct attention (i.e., a series of assessments that he/she may make). Based on the mission analysis the HALIFAX Class Frigate goals were progressively decomposed from top-level goals down to 'n'-level goals. The purpose of this decomposition process was to capture the hierarchical nature of both the crew and the system goals. Two additional outcomes of the analysis were the identification of upward information flow and the identification of potential instabilities. The decomposition process was assisted with the use of a purpose designed software tool - Task Architect®.

The decomposition process generated an inventory of goals in a hierarchical order such that the association between goals and operators was captured. That is, following each top-level goal, all related first-level goals were listed, and for each first-level goal, all the second-level goals associated with the first-level goals were listed, and so on through the list.

As an example of the goal hierarchy, the Table 2-1 below depicts a narrow sliver of goals from the top-level down to the fourth. The title of the goal where the ellipsis (...) is seen is replaced by the phrase "I want to perceive that".

Table 2-1 Sample Goal Hierarchy

	Goal/Objective (Level N)	Influenced ("Controlled") Variable	Assignment	Sub-goals/sub-objectives (Level N-1)	
TOP LEVEL					
	...the use of the sea is denied to enemy forces	Degree to which the enemy is denied use of the sea	CO	1	...current mission is received and acknowledged
				2	...predeployment preps are complete
LEVEL ONE					
2	...predeployment preps are complete	Status of predeployment preparations	CO	2.1	...command team planning complete

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Table 2-1 Sample Goal Hierarchy

	Goal/Objective (Level N)	Influenced ("Controlled") Variable	Assignment	Sub-goals/sub-objectives (Level N-1)	
				2.2	...effective liaison with TG 302.4 is complete
LEVEL TWO					
2.1	...command team planning complete	Status of team planning	CO	2.1.1	...OPTASK messages are held and understood
				2.1.2	...enemy forces have been identified and database held
LEVEL THREE					
2.1.1	...OPTASK messages are held and understood	Status of specific message(s)	ORO	2.1.1.1	...OPTASK EW is held and understood
				2.1.1.2	...OPTASK COMMS is held and understood
LEVEL FOUR					
2.1.1.1	...OPTASK EW is held and understood	Status of specific message	SWC	No lower levels in the analysis	

The complete goal hierarchy is included in Annex C.

In more traditional function and task analyses the lowest level is also referred to as the task level, wherein a task is defined as a specific human activity with a unique set of performance characteristics, however in goal analysis, the lowest level goal is similar to a top-level goal in that it involves a feedback loop and can be allocated to man or machine.. In this analysis the decomposition was considered complete when the goal being considered was satisfied without input from other operators in the system, and could be satisfied through simple tasks such as communication and/or manipulation of a control system.

The decomposition is graphically depicted through a Hierarchical Goal Analysis Diagram (see Figure 2-1). The goal hierarchy illustrates the logical relationships between the various mission goals. The goal hierarchy diagrams are particularly useful for reviewing the results of the mission decomposition with domain experts and subject matter experts. Its graphical nature makes it easy to understand and associate with the operational environment.

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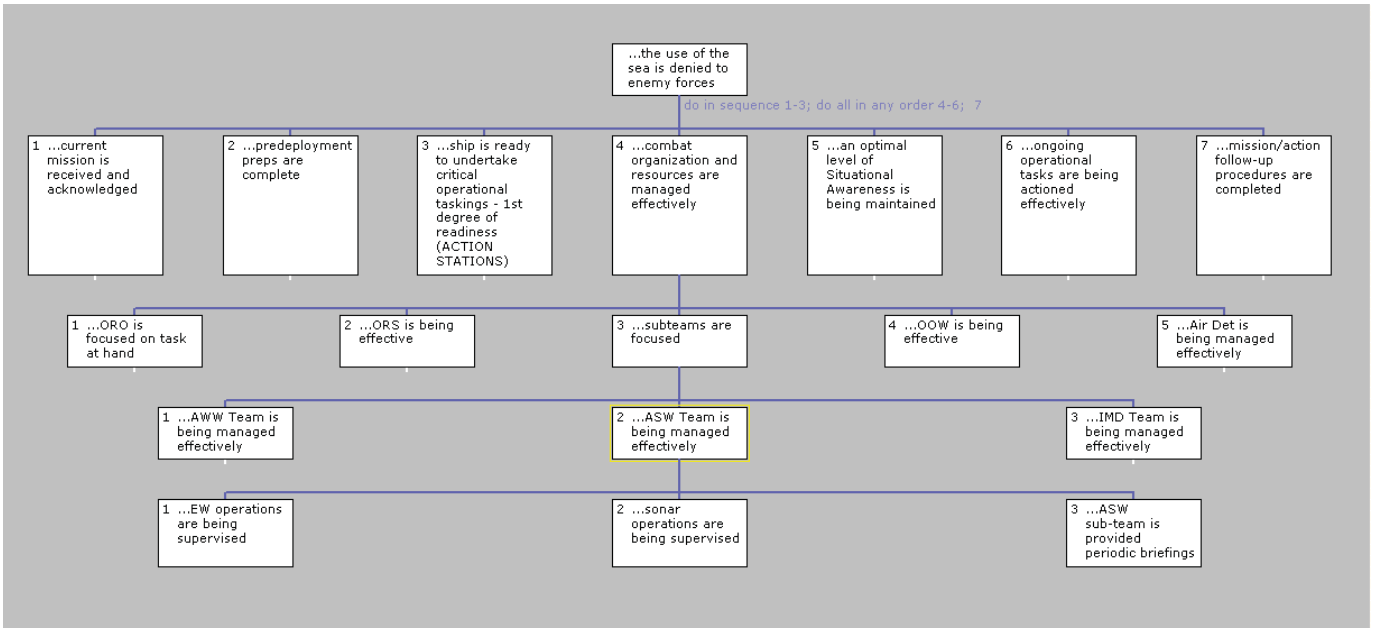

Figure 2-1 Sample Hierarchical Goal Analysis Diagram

The allocation process is simply the determination of which operator in the system is responsible for ensuring a specific goal is completed or satisfied. This study addressed an existing system with the objective of defining that system. The operators were assigned to those goals they currently hold. The only exceptions were those goals allocated to the IMD. The IMD, who was not employed in the HALIFAX Class Frigate when the project began, was allocated goals in accordance with the IMD and Information Systems Manager (**ISM**) Concept of Employment document [Reference 5].

Given the complex matrix type organization of the Operations Room the majority of goals have both primary and secondary allocations, where the secondary 'owner' of the goal is prepared to step in and assume responsibility for the goal if the primary 'owner' is occupied with another warfare area or higher priority goal. During the analysis, the secondary allocation of the goal was tracked.

Domain experts initially generated the core goal hierarchy. This was achieved in an iterative fashion as goals were modified or moved to better define the system being analyzed. The goal hierarchy development continued throughout the term of the project as each step of the project required the goal hierarchy to be revisited.

2.2.2 Goal Verification

The objective of the goal verification process was to ensure each goal was assigned to the proper primary and/or secondary operator and that the goal fell in the proper position in the

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goal hierarchy. Analysts and domain experts provided the initial hierarchical position assignment. The higher-level goal description and allocation was confirmed by SMEs during a visit to HMCS MONTREAL with the final lower-level goal allocation and descriptions being verified by SMEs during a visit to HMCS WINNIPEG. Because of the size and complexity of the goal hierarchy, the relationship of goals using only their titles was verified before the complete underlying PCT data was added. The PCT data was completed by domain experts between the two SME sessions. The verification process also ensured there were no sub-goals associated with the lowest level goals.

During the first and second SME sessions (described in Subsection 2.6), the verification process was conducted in two parts, a very structured review of the hierarchy of goals and a less structured "where is this activity" approach. In the structured approach small groups of operators systematically reviewed the goal hierarchy from top to bottom level goals in a review of completeness and flow. The less structured approach had operators describe activities they perform – associated with the military role – and challenge the domain experts to find the goal that captured the activity. The second method provided significant value as it reinforced the nature of a goal hierarchy to capture the complete requirements of a system. As an example the ARRO indicated that they made numerous voice reports to augment a linked air contact – this was found to be reflected in goal – '5.1.1.3.4 ...reports are made to support the tactical air picture'. On the rare occasion that activities were described that were not captured in the goal hierarchy, augmentation of the goal hierarchy was undertaken to better describe the goals of the system and the specific operator.

2.3 IP/PCT

In order to model the operations room system in the IP/PCT mode IPME specific information pertaining to each goal had to be collected. The 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 IP/PCT development followed Reference 4. Using the hierarchy of goals and sub-goals from the military role, along with the provisional allocation to an operator, domain experts discussed each goal and completed Table 2 from Reference 4 (see Figure 2-2 and Table 2-2 for samples of a PCT table). It was essential that each goal be considered in isolation – viewing the goals holistically caused the higher-level goals to be overwhelmingly complex – with too large a number of required inputs, outputs, knowledge states and influenced variables. The results were reviewed by the domain experts for consistency, to ensure the process remained constant, and then they were presented to SMEs in SME Session Two for review and comment. Brief descriptions of the SME sessions are presented in Subsection 2.6.

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Assigned Operator						World
		Required Knowledge States	Perceptual / Cognitive Processes	Ending Conditions	Output / Behaviour	**Output Interface**
Goal	Output	Declarative				
	Σ	Situational		**Influenced Variable(s) - Internal**		**Influenced Variable(s) - External**
				Initiating Conditions	Input / Sensation	**Input Interface**
	Input					

Figure 2-2 Example PCT Data Table

The resultant data was used to generate the upward information flow analysis and the potential instability analysis. Upward information flow looks at the operators assigned to goals and those assigned to their supporting goals and the information which is provided by the operator responsible for the supporting goal to the operator responsible for the upper-level goal. Potential instability analysis looks at variables controlled by multiple operators assigned to different goals. Both were developed in accordance with Reference 4. The results were also used during the review of critical activities as a check against the complexity of the goals being assumed by the SMEs.

The IP/PCT data was generated in three distinct steps – the development of preliminary PCT information, identification of potential instabilities, and collation of upward information flow. The detailed methodologies used for each are described below.

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Table 2-2 Sample PCT Table of a Goal Assigned to the SWC

Assigned Operator			SWC			World	
		Required Knowledge States	Perceptual/ Cognitive Processes	Ending Conditions	Output/ Behaviour	**Output Interface**	
Goal	Output	Declarative: Standard Operating Procedures Training and expertise IDCRIT Equipment Caps and Lims	INPUT - Vision - Verbal encoding INPUT - Vision - Spatial Encoding, visual pattern recognition INPUT - Audition - Passive (pre-attentive) monitoring of auditory signals INPUT - Audition - Verbal decoding, speech recognition INPUT - Memory - Verbal decoding INPUT - Memory - Spatial decoding INPUT - Memory - Recall OUTPUT - Voice - Speech production OUTPUT - Memory - Memorization	Air threat accounted for	VOICE Output MEMORY - Commit to memory (LTM and STM)	Shincom - internal	
6.3.1.1...satisfactory internal air threat level maintained	Σ			Influenced variable(s) - internal	Threat Status	Influenced variable(s) - external	ORS
		Situational: Threat Status Own Force Status Permissive ROE EOB Threat axis Equipment Status Own force dispostion/composition		Initiating Conditions	Input/Sensation	**Input Interface**	
	Input			Unaccounted for air threat	VISION - Central - Text, dial reading VISION - Central - Pattern, spatial relationship, tracking, graphic displays AUDITION- Speech input (incidental to primary task) AUDITION - Speech input (attended to, salient to the primary task) MEMORY - Recall from memory - Verbally coded MEMORY - Recall from memory - Spatially Coded MEMORY - Recall from memory - Complex operation	Audio Message - external comms SSD	

2.3.1 Detailed Methodology – PCT Data

The criteria for each goal or sub-goal was compiled in accordance with Figure 2-2.

This information was elicited from domain experts using structured cognitive walkthroughs, in which a human factors analyst "stepped-through" the entire scenario , as presented in Annex B, with each operator, and then iteratively delved into significant portions in more detail. Initial iterations focused on identifying goals, and sub-goals, and subsequent iterations focused on documenting the attributes of each goal as required by the HGA:

a. Goal: the title of the goal where the ellipsis (...) is replaced by the phrase "I want to perceive that";

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b. required knowledge states:

(1) declarative: What extra-situational knowledge (e.g., operating procedures, etc.) is required to satisfy this goal?

(2) situational: What situational knowledge (e.g., current location of assets, etc.) is required to satisfy this goal?

c. Perceptual processes: How can the information required to satisfy this goal be gathered?

d. Cognitive process: How is the information required to satisfy this goal synthesized and manipulated?

e. Initiating conditions: These are states that cause the operator to inquire as to whether the goal has been satisfied;

f. Ending conditions: The state when the goal is completed and the operator switches attention to another goal;

g. Input / Sensation: These are provided by the analyst and include any visual, auditory, kinaesthetic or cognitive input attributes associated with the goal. ;

h. Output / Behaviour: These are provided by the analyst and include any vocal, psychomotor or memory output attributes associated with the goal.;

i. Input interface: The device with which the operator gathers information or is alerted that a goal requires attention;

j. Output interface: The devices that are driven by direct actions of the operator – not to be confused with external variables;

k. Influenced variable(s) – External: The devices in the real world that require influencing to satisfy a goal; and

l. Influenced variable(s) – Internal: The specific knowledge state(s) influenced by the feedback loop in question. Knowledge gained while the goal is being actioned is tracked in this variable.

The secondary ‘owner’ of the goal, introduced in Subsection 2.2.1, is not listed in the PCT output tables, however it was captured in the goal hierarchy - Annex C. All knowledge states, perceptual and cognitive processes will be the same regardless of who is working to achieve the goal.

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The Technical Authority reviewed the PCT work, early in the process, to ensure completeness.

The data was collected using the TaskArchitect® tool, easing the workload of the domain expert and allowing for a simple method of presenting the information.

Table 2-2 above is an example of a completed PCT table of a goal assigned to the SWC. As shown the only external variable is the ORS, therefore no potential instabilities can be caused by this goal, however there could be a conduit clash (see Subsection 2.3.2 for a description of a conduit clash) if the ORS is engaged when the SWC is attempting to satisfy the goal.

2.3.2 Detailed Methodology – Potential Instability

As presented in Reference 4 "The potential for instability is obvious when two agents are simultaneously trying to drive a variable in different directions according to incompatible set-points or internal transformations..." As part of the goal analyses, influenced external variables were captured and are listed in Annex D. These were found to range from the specific equipment configurations to direction (provided to another operator). Once the goals / sub-goals were completed a database was created and filtered, based on external variables. Because the goal hierarchy represents a snapshot of all potential goals that could be elicited, without any timing, all goals associated with the same external variable must be considered for potential conflict and therefore instability.

Where the potential instabilities were conflicting information demands on a single operator by multiple other operators and not on a specific equipment configuration, the concept of a 'conduit clash' was raised. In this case, the word conduit refers to the operator who acts as a conduit of information. These 'conduit clashes' occur when other operators require the output/input from a third operator to progress their specific goal. These 'conduit clashes' were not captured in the format of the external variables, however they were investigated during the IPME Task Network analyses..

On completion of the development and classification of external variables with a potential for instability, SMEs reviewed the analyses. The SMEs provided valuable insight into the process and augmented the list of instability amelioration techniques (see Subsection 2.6).

2.3.3 Detailed Methodology – Upward Information Flow

The goal hierarchy developed for this project and PCT data collected were analyzed specifically for upward information flow used to indicate the status or completion of lower-level goals (n-1 level goals) as they relate to the eventual completion of upper-level goals (n level goals). The type (verbal or visual), importance, and frequency of the information flow were

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captured in the analysis. This analysis was performed by domain experts and then confirmed during SME Session 2 at HMCS WINNIPEG.

To determine a requirement for information flow the domain experts compared n-1 level goals with their associated n level goal. If the n-1 level goal was allocated to a different operator than the n level goal there was a requirement for information flow. Information flow communication type was captured. The domain experts also considered the secondary goal owner, for the n level goal, and captured how information would flow to this operator in the situation where the primary goal owner was occupied.

The analysis considered verbal and visual communications. Verbal communications include direct reports, copying circuits or overhearing reports (be they briefings, direct reports, or SHINCOM transmissions). Visual information flow was considered to be conveyed by an operator reading his or her own Standard Shipboard Display (**SSD**), viewing another operator's SSD, reading a stateboard, or observing another operator's actions.

2.4 TASK NETWORKS

Task networks are used to develop the IPME IP/PCT models. The IPME model requires a chronological set of events in order to run the program and identify periods of operator loading. The task network generation combined efforts from this project and previous task analysis studies. The networks represented five critical task sequences. In those studies the task sequences were represented as OSDs and were used to analyze information flow, however, no modelling was performed. They are referenced here to indicate that the operational community continues to agree that these five sequences adequately represent the most demanding periods in a Halifax Class Frigate operations room. Domain experts examined the sequences and selected the appropriate goals that would be required to be satisfied to complete the mission segments represented by the sequences. Each goal and/or sub-goal was then described in a series of tasks as OSDs. The OSDs were required as a means of allowing the domain experts to organize tasks and allow the SMEs to confirm the task networks before they were modelled in IPME. Similar to the task sequences, the tasks specifics – Time Required, Visual, Auditory, Cognitive, and Psychomotor (**VACP**) ratings were taken from the studies at References 6 and 7. The OSDs, representing goals and sub-goals, were combined in IPME each representing a sub-network within a larger network.

OSD accuracy was confirmed by SMEs prior to full implementation in IPME. Goal timings were set as a variable to allow for a probabilistic analysis of each network. Software limitations restricted the number of runs for the larger networks to 40; for this reason all networks were run 40 times in order to develop a standard and comparable set of results.

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2.4.1 Detailed Methodology

Five critical task sequences were selected and confirmed by the Department of National Defence (**DND**) representative. These sequences were also studied in the Task Analysis of the HALIFAX Class Sensor Weapons Controller and Assistant Sensor Weapons Controller Positions, Mission Function and Task Analysis Report and the Task Analysis of the HALIFAX Class Operations Room Officer Sensor Weapons Controller and Assistant Sensor Weapons Controller positions: Mission, Function and Task Analysis Report [References 6 and 7]. The final definitions of the sequences were:

a. watch turnover;

b. resolve procedure including issuance of an air warning;

c. conduct of a co-ordinated surface engagement using harpoon missiles;

d. anti-ship missile defence against an advance surface-to-surface threat; and

e. anti-submarine warfare to include torpedo counter measures and a close-in attack.

The task sequences were driven by the scenario (Annex B, which was taken from References 6 and 7) and developed by the domain experts. The sequences were then mapped against the goal hierarchy in order to determine which goals, sub-goals, and associated feedback loops, would be activated in order to achieve success or a suitable outcome from each task sequence. The difference between success and a suitable outcome is dependant on the goal being analyzed, a goal with an easily measurable result, such as "...appropriate salvo size is selected" can be successfully achieved whereas a more ambiguous goal such as "...AAW team is being managed effectively" may only have a suitable outcome and may never by 100% achievable. The PCT data from each active goal was used to confirm the tasks required for each sequence. Task information was drawn from References 6 and 7.

2.4.2 Operational Sequence Diagram Development

The goal hierarchy and the time critical task sequences described in Subsection 2.4.1 anchored the OSD development. Prior to the commitment of any tasks to a critical sequence the goals that were active or required satisfying were identified.

As described earlier (Subsection 2.3.1), each goal must be preceded with the expression "I want to perceive that", which is represented by the symbol: "…". Goals were grouped into sub-networks, and tasks sequences were developed in chronological order to complete each goal sub-network. These sub-networks were developed in TaskArchitect® then ported into the IPME development environment. Sub-networks were then built up (logically interconnected) in IPME until the full 'baseline' network was developed. As a matter of

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development procedure each sub-network was run separately in IPME in order to debug any problems. At the end of this process there were five 'baseline' networks representing the five critical task sequences and these five baseline networks were graphically depicted as the OSDs included at Annex E.

The second SME Session, at HMCS WINNIPEG, provided a review of OSDs including confirmation of specific task parameters.

2.4.3 Integrated Performance Modelling Environment

As described in Subsection 2.4.2 the baseline networks were initially developed in TaskArchitect® and then transferred to IPME.

The SAC position was included in the study due to the requirement for this position to interact with a number of the operators being studied. In modelling the operations room a surrogate position was created to represent positions which were not identified for detailed analysis. These included the Fire Control Supervisor, CANEWS Operator and Officer Of the Watch (**OOW**), who had to carry out a number of tasks; in the IPME model the operator 'none' is used whereas for the OSD models the position of 'Tactical Crew' was used to represent these operators. This was to ensure that tasks that were being performed by operators not part of the study were not shed, delayed, or interrupted thereby affecting the results.

Each network was run 40 times in order to invoke the probabilistic nature of task times. It was necessary to restrict the number to 40 as the IPME directories did not have sufficient memory to store the output from any combined network that included the Torpedo Counter Measure network. The Torpedo Counter Measure network was the largest model as it covered the longest period of time and represented all internal and external communications in a tactically complex environment.

2.4.4 Combined Networks

After the analysis of each baseline task network was completed, the complexity of concurrent goals/task networks was investigated.

Likely combinations of networks were determined, probable worst-case timing conflicts were assessed, and then the networks were triggered at the proper time to potentially overload the targeted operator. Timings were determined by selecting periods in the baseline with the greatest Mean Time Pressure for each operator and ensuring they would overlap when run in combination.

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2.5 CRITICAL ACTIVITIES

The final deliverable was the analysis associated with critical activities. For this project, activities were equated to goals. Had the study invoked a Mission Function and Task Analyses methodology, activities would have been equated to tasks and functions. Previous studies [References 6 and 7] performed critical task analyses, which were reviewed for relevance to this project. The HGA critical rating methodology and associated criteria were devised, reviewed with the SA and agreed upon. A modified Cooper-Harper Scale (Figure 2-3) was used. Rating criteria for safety, mission effectiveness, and human performance capability were set on a scale from 1 to 7. Seven levels were chosen rather than the normal 10 levels of a Cooper-Harper Scale to ease the extensive workload required to rate all goals. Additionally the granularity afforded by seven levels was deemed sufficient by the analysis team. The goals from the military goal hierarchy were then analyzed by domain experts and were assigned values in accordance with the rating scales 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. The domain expert results were then reviewed by SMEs.

2.5.1 Detailed Methodology

As introduced above, each activity (goal/sub-goal) was assessed for criticality in terms of having a significant risk of affecting mission effectiveness. Rationale for the designation and the proposed corrective action was also provided. Activities were also rated as critical if they approach the limits of human capabilities and skills, or have safety implications.

A scoring matrix was developed in order to provide ratings to each goal/sub-goal. From the outset the intent was to normalize across the three factors of mission effectiveness, human performance capability, and safety. To support the domain experts in rating the activities, the Cooper-Harper Scale [35](this information is included above) was used as a baseline and then modified.

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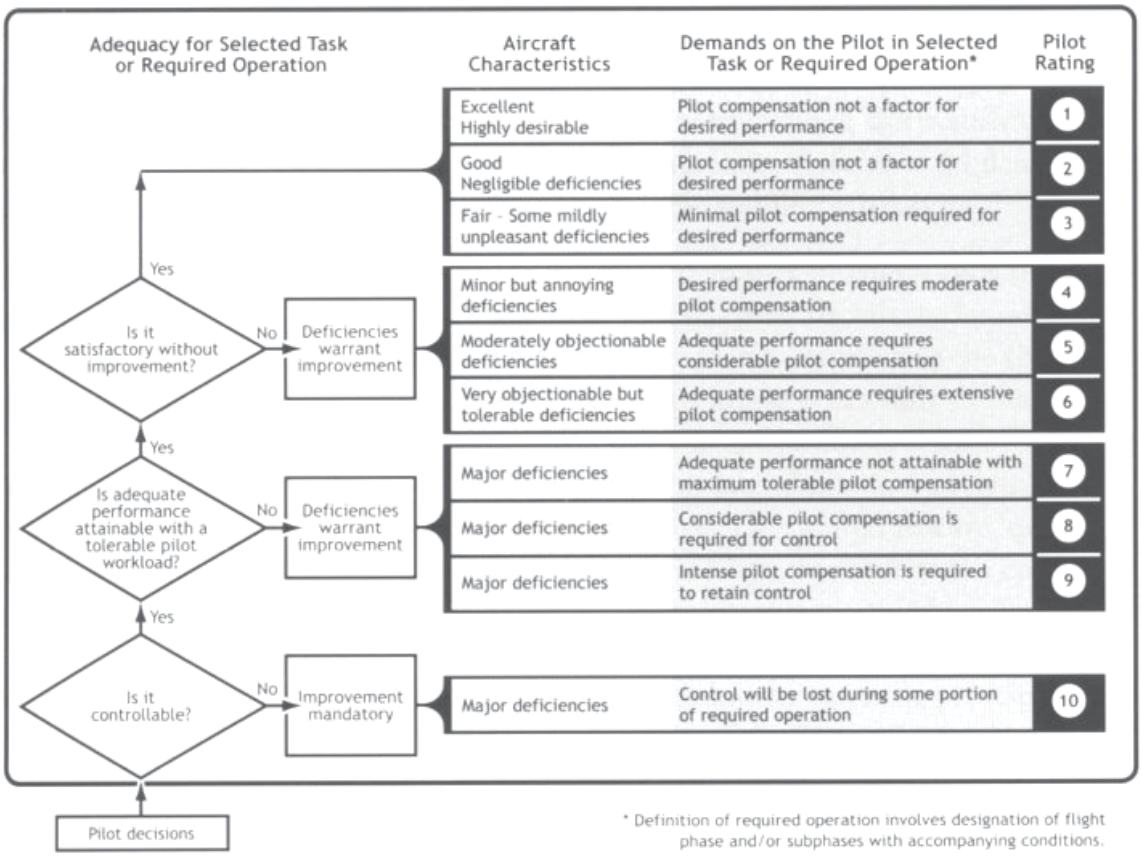

Figure 2-3 Cooper-Harper Scale

The final ratings scales (Figure 2-4 to Figure 2-6) are still based on three main questions that slot any activity into one of four main groupings. If the answer to the first question is 'YES', the response leads across to a category that is a single solution with the highest criticality rating. If the answer is 'NO', the scale leads up to more questions, the answers to which can lead to two possibilities, a lower and a higher rating within each major category. As can be seen there are a total of 7 possible ratings. As discussed previously, in order to facilitate agreement amongst the domain experts with regard to assigning ratings, and in consideration of the number of activities to be rated, the final number of categories was reduced from 10 to 7.

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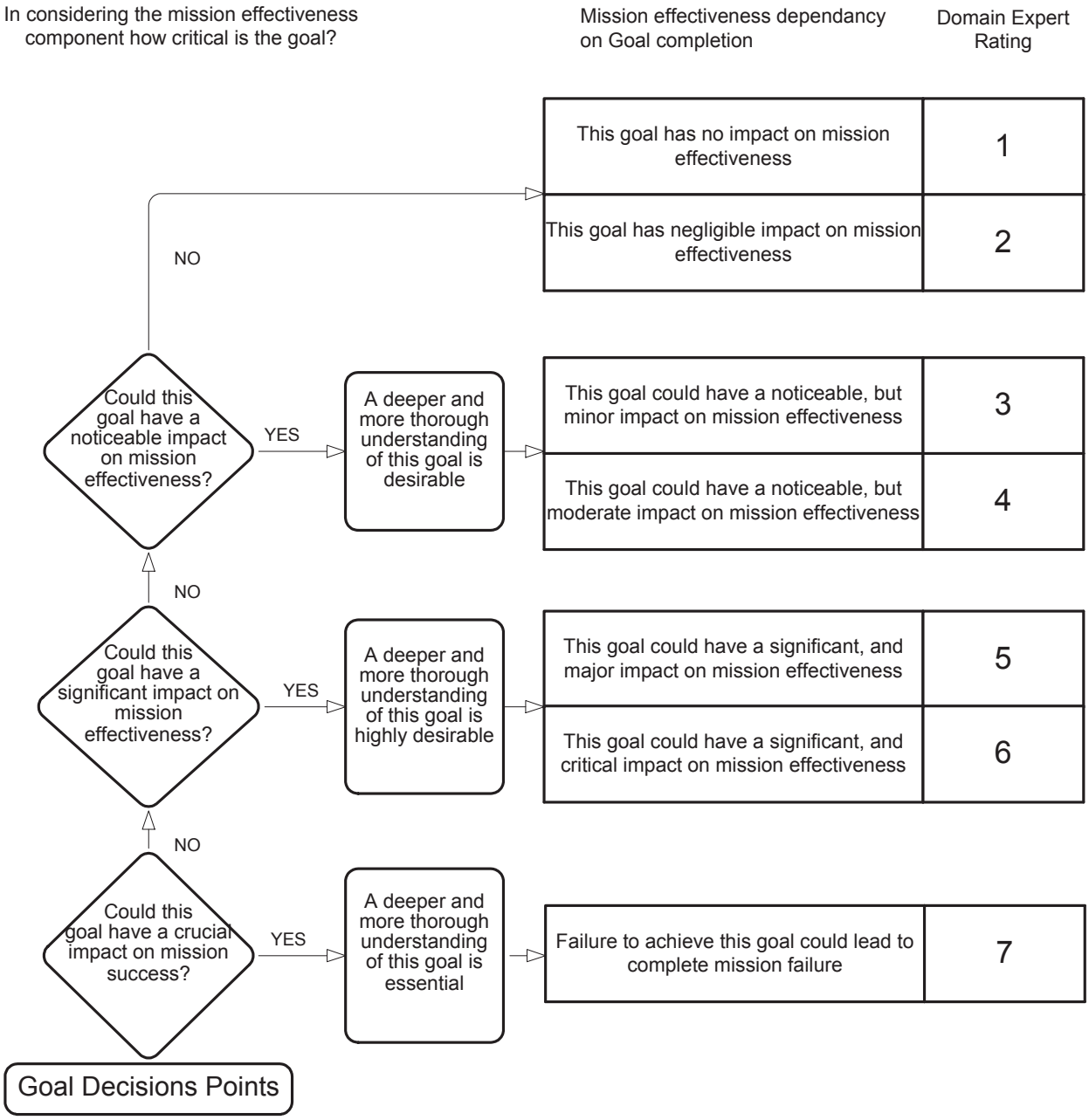

In order to determine activities that impinge on mission effectiveness, numerical value from 1 to 7 is assigned according to the degree to which the non-completion, or incorrect completion, of a given goal would jeopardize or limit the successful completion of the mission.

Figure 2-4 Mission Effectiveness Risk Rating Scale

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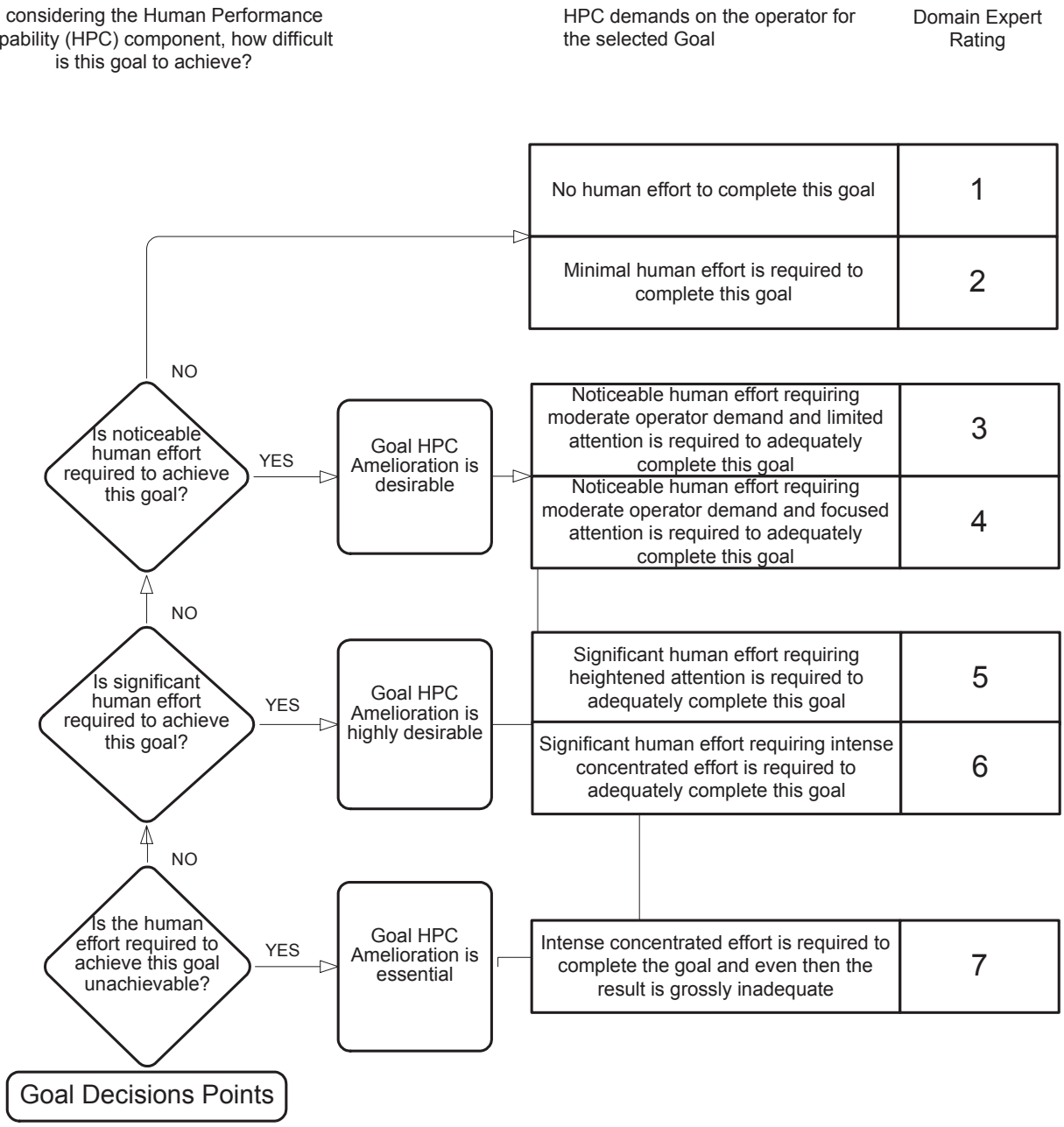

In order to determine activities that approach the limits of human capabilities, numerical values of 1 to 7 are to be assigned to each goal using the above flow chart. The question being posed is: Does achievement of the goal require the operator to undertake activities that approach or exceed Human Performance Capabilities?

Figure 2-5 Human Performance Capability Rating Scale

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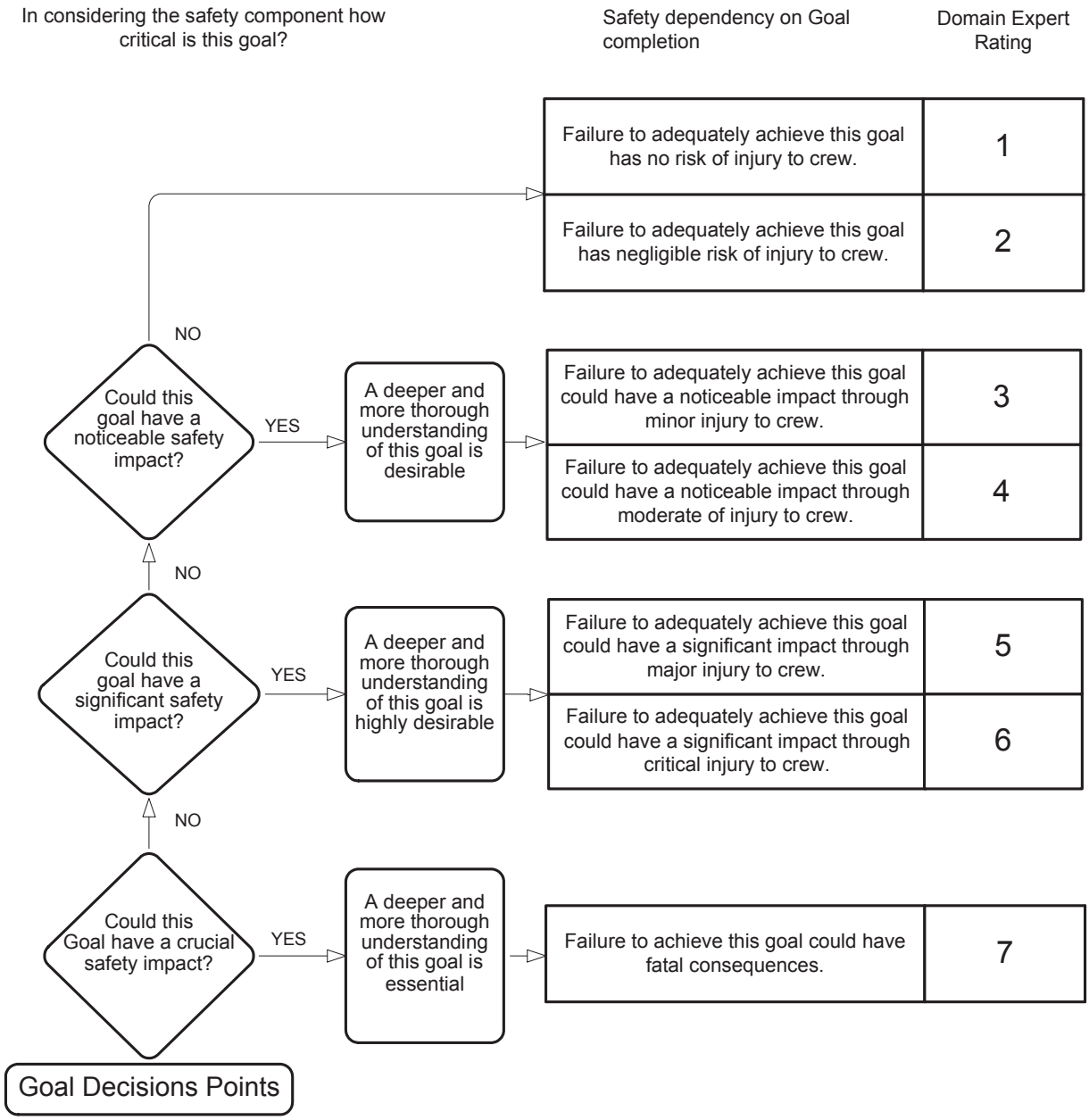

In order to determine activities that have a significant safety component, numerical values from 1 to 7 are to be assigned to each goal according to the degree to which the non-completion, or incorrect completion, of a given goal would adversely affect the safety of relevant personnel (e.g. own forces, friendly forces, non-participants within the mission environment, etc).

Figure 2-6 Safety Risk Rating Scale

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2.5.2 Domain Expert Analysis

Due to the scarcity of SMEs domain experts performed the initial analysis. The draft analysis completed by the domain experts was reviewed and commented on by SMEs. Domain experts analyzed each activity and provided a criticality rating for mission effectiveness, human performance capability and safety. Each activity was considered in an individual sense and not based on how it related to other activities in the HGA. It was decided that because the subject of the analysis was an existing system, none of the activities would have a human performance capability rating of seven (assigning a rating of seven would indicate that specific goals of the current operations room were not achievable). It was determined, knowing the current operations room, that no goal had been designed to fail, meaning at no time was the outcome "Intense concentrated effort is required to complete the goal, and even then the result is grossly inadequate" expected. In the existing system, goals had been divided or allocated to prevent this. As an example, if the goal had been to simultaneously conduct ASMD and defence against small boat attack (not a requirement of the current system), it could be expected that the Human Performance Capability (**HPC**) rating for the SWC would be a seven.

2.5.3 Proposed Solutions

Solutions were proposed for any activity that had a safety risk rating of 5 or greater, a mission effectiveness risk rating of 5 or greater and a human performance capability rating of 4 or more. The reason for reducing the cut-off for the HPC rating level to 4 was an attempt to capture the same ratio of activities for all three categories. With the HPC ratings being limited to a maximum value of 6, as described above, it was determined that a criticality cut-off of the top three rating points should be used for each factor.

A system of abbreviations was used to ease the description of the solutions:

N/A	–	Not Applicable
NOB	–	Nature Of the Business – unable to affect the rating
SRR	–	Solution the same as the safety risk rating solution
MER	–	Solution the same as the mission effectiveness risk rating solution
HPC	–	Solution the same as the human performance capability rating solution

The proposed solutions, listed in Annex J – Critical Activities, were provided in the order of safety, mission effectiveness and human performance, separated by a front slash.

The results of the critical activity analysis were compared to the initial PCT data to ensure the scope of the goal was fully understood by the domain experts and SMEs. As an example, the required knowledge listed in the PCT data was examined to ensure the requirements of the goal/activity were not inflated during this analysis process.

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On completion of the analysis of criticality, including proposed solutions, the results were presented to SMEs as part of the final SME session at HMCS MONTREAL, April 2006. The SMEs were asked to review, comment on and amend (as required) the point ratings and the proposed solutions. The results of these reviews combined with the original domain expert analysis are available in Annex J.

2.6 SUBJECT MATTER EXPERT REVIEW

There have been many references to the SME sessions employed during this project. This section will provide an overview of the three sessions – essentially the where, the who, the when, and what on each session. Prior to each session the participants were briefed on the project and the processes involved, including HGA, IP/PCT, and OSDs. The SMEs were also provided a forecast as to the uses of the analyses specifically the uses in the HMCCS project. Details of each SME session are included in Annex K.

2.6.1 First SME Session

The first session was held in Halifax NS, at the Royal Artillery Park. The session was conducted over three days, 24-26 August 2005. The combat team, including the Commanding Officer, of HMCS MONTREAL made themselves available for the session. The intent of the SME session was to review the HGA and PCT data, as generated by the domain experts, by operators currently serving in the positions being analyzed. Overall the goals of the SME session were achieved and the analysts deemed the three-day session a success.

2.6.2 Second SME Session

The second SME session was held in Esquimalt BC, in HMCS WINNIPEG. The session was conducted over three days, 29 November-1 December 2005. The combat team, including the Commanding Officer, of HMCS WINNIPEG made themselves available for the session. The intent of the SME session was to review the five critical task sequences, as generated by the domain experts, by operators currently serving in a worked-up Halifax Class Frigate. Overall the goals of the SME session were achieved and the analysts deemed the three-day session a success.

2.6.3 Third SME Session

The third and final SME session was held in Halifax NS, in HMCS MONTREAL. The session was conducted over two days, 4-5 April 2006. The combat team of HMCS MONTREAL made themselves available for the session. The intent of the SME session was to review and comment on the critical activities analyses conducted by the domain experts and to

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review and comment on the results of the IPME IP/PCT output. Overall the goals of the SME session were achieved and the analysts deemed the two-day session a success.

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SECTION THREE – ENVIRONMENTAL ANALYSIS

3.1 GENERAL

The results from the Environmental Analysis are summarized at a high level in this section of the report. This section is included to allow the reader to understand the environment in which the HALIFAX Class Frigate is required to operate in order to understand the demands on the operators. It also describes the organizational structure in which the operators work and provides an overview of their jobs and responsibilities.

The results of the Environmental Analysis process are summarized in the following subsections.

a. Evolution of the Maritime Forces Mandate and Requirements;
b. HALIFAX Class Frigate; and
c. HALIFAX Class Frigate Composite Scenario.

The analysis included the review of numerous documents, all of which are listed in Section Nine. Additionally, an exhaustive examination of Occupational Speciality Specifications was conducted to ensure the goals allocated in the HGA were indicative of the training provided and work expected of the positions analyzed.

3.2 EVOLUTION OF THE MARITIME FORCES MANDATE AND REQUIREMENTS

As stated in Leadmark: The Navy's Strategy for 2020 [Reference 1] "As the military instrument of Canada's maritime policy, the Navy is a critical element in the national imperatives of sovereignty, continental defence and engaged internationalism." The HALIFAX Class Frigate was designed and is manned to be a general-purpose ship. This role of the frigate in support of the maritime forces mandate is integral to the design and function of the Command and Control system.

Before describing the HALIFAX Class Frigate and examining the goals and tasks of the Operations Room personnel, it is important to first consider the organization of Canada's Maritime Forces their roles and their missions.

3.2.1 Maritime Forces Organization

Canada's naval forces are controlled and operated by two formation commanders as shown in Figure 3-1, MARPAC in Victoria, British Columbia and MARLANT in Halifax, Nova Scotia, while the overall Commander of the Navy, the Chief of the Maritime Staff (**CMS**) is

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situated at National Defence Headquarters (**NDHQ**) in Ottawa, Ontario. Under each of the respective formation commanders is the commander of the fleet of surface, subsurface and auxiliary units. This study will focus on the HALIFAX Class Frigates of which there are 12, five situated on the West coast and seven on the East.

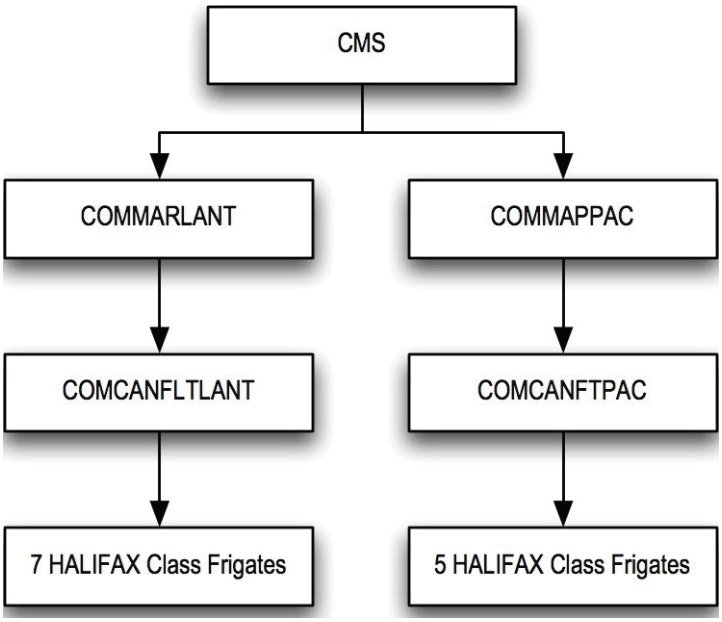

Figure 3-1 Maritime Forces Organization

3.2.2 Maritime Forces Roles and Missions

The 1994 Defence White Paper [Reference 2] identifies strategic-level roles for the Canadian Forces (**CF**). The 2001 DPG document [Reference 3] interprets these CF roles and provides direction for the use of the Canadian Maritime Forces. However it is from Leadmark: The Navy's Strategy for 2020 [Reference 1] from which the 3 basic roles, Constabulary, Diplomatic, and Military are set. The CF document, Shaping the Future of the Canadian Forces: A Strategy for 2020 [Reference 8], supports the view that these missions will indeed be applicable for the foreseeable future and categorizes the roles into: Peacetime, Operations Other Than War, Wartime Operations. The remainder of this subsection focuses on these missions and operations that are performed by the Maritime Forces in support of the roles assigned to the Canadian Forces. A correlation can be drawn between: Constabulary and Peacetime operations, Diplomatic and Operations Other Than War, and Military and Wartime Operations. The HALIFAX Class Frigate must be capable of performing and rapidly switching between all these roles.

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3.2.2.1 Constabulary Role

In peacetime, Canada's Maritime Forces provide the flexibility and immediate response necessary to react to a wide range of crisis situations. The Constabulary role, as defined in Reference 1, includes the following operations that the Maritime Forces may be tasked with but are not limited to:

a. **Sovereignty Patrols.** Maritime forces provide assistance to Other Government Departments (**OGD**s) and law enforcement agencies by identifying and providing positional data or intercepting, if required, suspected illegal aliens or contraband smugglers before or after entering Canadian waters.

b. **Aid to Civil Power.** Provinces are able to call upon the armed forces to maintain or restore law and order when it is beyond the power of civil authorities to do so. The role of the Canadian Maritime Forces, in conjunction with other elements of the Canadian Forces, is not to replace civil power, but to assist civil authorities in re-establishing law and order.

c. **Assistance to Other Government Departments.** OGDs and other levels of Government are assisted, to enforce Canadian national sovereignty and interest claims, and to conduct domestic operations, in areas such as fisheries protection, drug interdiction and environmental protection.

d. **Search and Rescue (SAR).** The Navy makes a vital contribution to the maintenance and operation of Canada's search and rescue capability. Maritime Forces must be able to respond within 8 hours to any SAR tasking. These taskings could vary from the rescue of ship and submarine crews at sea to search rescue of survivors of a downed aircraft in a remote coastal area.

e. **Oceans Management.** The broader regimen of inter-departmental and interagency measures, official and otherwise, is undertaken within both domestic and international contexts, with the aim of ensuring the regulation of activities on, under and above the sea.

f. **Disaster Relief.** Maritime Forces play a key role in responding to natural and man-made disasters. These types of disasters may range from earthquakes, floods and fires to aircraft disasters like the ill-fated Swiss-Air 111 crash off the coast of Nova Scotia in 1999.

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3.2.2.2 Diplomatic Role

Maritime Forces are tasked to maintain the capability to conduct a wide range of missions that can best be described as diplomatic. The Navy is prepared to provide the critical first response in a transition between peacetime operations and escalating regional tensions. In the event of a major conflict Canadian ships carry the power and the capability to establish and hold an initial foothold to allow time for larger joint operations to ensue. For example, in cases of loss of government control and resulting internal violence (as occurred in Rwanda in 1994) or concerns about the possible spill-over of ongoing hostilities (as occurred in the former Yugoslavia in 1996) the conduct of missions classified as Operations Other Than War are seen as a means to lessen the effects of war or prevent it altogether. Diplomatic missions, as defined in Reference 1, that the Maritime Forces may be tasked with include but are not limited to:

a. **Preventive Deployments.** deployment of forces to contribute to preventing the development of a specific crisis or conflict generally;

b. **Coercion.** the use of force, or the threat of force to persuade an opponent to adopt a certain pattern of behaviour against their wishes;

c. **Maritime Interdiction Operations (MIOs).** the surveillance, interception and, if necessary, boarding of commercial vessels to verify, re-direct or impound their cargoes in support of the enforcement of economic sanctions;

d. **Peace Support Operations (PSOs).** a generic term, describing operations designed not to defeat an aggressor, as in the case of war, but rather to assist diplomatic and humanitarian activities to achieve a long-term political settlement. The five forms of peace support operations include preventive diplomacy, peacemaking, peacekeeping, peace-enforcement and post-conflict peace building. Often described as United Nations (**UN**) Chapter VI operations;

e. **Non-combatant Evacuation Operations (NEOs).** an operation to relocate to a place of safety non-combatants threatened in a foreign country;

f. **Civil-Military Cooperation (CIMIC).** all action and measures undertaken by a military commander which concern the relationship between a military force and the government, civil agencies or civilian population in the areas where the military force is stationed or employed;

g. **Symbolic Use.** a form of naval diplomacy in which naval forces can be used purely to signal a message to a specific government, while not in themselves posing any threat to an opponent or providing significant assistance to a friend;

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h. **Presence.** the exercise of naval diplomacy in a general way involving deployments, port visits, exercising and routine operating in areas of interest to declare interest, reassure friends and allies, and to deter;

i. **Humanitarian Assistance (HA).** activities conducted by military forces, mostly in urgent circumstances, to relieve human suffering, especially when local or governmental authorities are unable, or possibly unwilling, to provide adequate aid to the population. Humanitarian aid can take the form of protection against epidemics, provision of food aid, medical aid or assistance in public health efforts such as re-establishing essential infrastructures, with or without the consent of the State, if sanctioned by a UN resolution;

j. **Confidence Building Measures (CBMs).** steps taken by past, present or potential adversaries to create a positive change in their security relationship by establishing trust and reducing the risks inherent in misunderstanding or miscalculation. Examples include agreements to prevent incidents at sea, such as the US-USSR agreement of 1972 (eventually followed by a separate Canada-USSR agreement of 1989), prior notification of major military activities, inviting observers to witness exercises and, ultimately, active cooperation; and

k. **Track Two Diplomacy.** interaction among people from adversarial groups or nations, intended to explore issues and solutions on an informal and unofficial basis. Typically, this takes the form of academic conferences in which, for example, military officers, government officials and academics participate as private individuals rather than as official representatives.

3.2.2.3 Military Role

The military role or wartime operations refer to offensive and defensive combat operations conducted inside or outside Canada, usually in concert with allies, against modern well-equipped forces. Military role missions, as defined in Reference 1, include:

a. **Sea Control.** the condition that exists when one has the freedom of action to use an area of sea for one's own purposes for a period of time in the subsurface, surface and above water environments;

b. **Sea Denial.** preventing an adversary from controlling a maritime area without being able to control that area oneself;

c. **Fleet in Being.** the use of options provided by the continued existence of one's own fleet to constrain the enemy's options in the use of theirs; and

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d. **Maritime Power Projection.** the ability to project, sustain and apply effective military force from the sea in order to influence events on land.

As described above there are many roles the HALIFAX Class Frigate must be able to perform. Flexibility of its crew, sensors, weapons and the command and control system is vital to maintaining the ships' relevance in the country's defence strategy.

3.3 HALIFAX CLASS FRIGATE

In the 1970s, the decision was made to replace Canada's ageing fleet of Anti-Submarine Warfare (**ASW**) destroyer escorts before the turn of the century. The HALIFAX Class Frigate program and the acquisition of 12 warships (Table 3-1) starting in the early 1990s resulted from this decision. These vessels represent the leading edge in naval technology today. Facts and figures within this subsection are from the Navy Website at www.navy.forces.gc.ca.

Table 3-1 HALIFAX Class Ships

Name	Hull	Commissioned	Homeport
HALIFAX	330	29/06/92	Halifax
VANCOUVER	331	23/08/93	Esquimalt
VILLE DE QUEBEC	332	14/7/94	Halifax
TORONTO	333	29/07/93	Halifax
REGINA	334	30/9/94	Esquimalt
CALGARY	335	12/5/95	Esquimalt
MONTREAL	336	21/7/94	Halifax
FREDERICTON	337	10/9/94	Halifax
WINNIPEG	338	23/6/95	Esquimalt
CHARLOTTETOWN	339	9/9/95	Halifax
ST. JOHN'S	340	24/6/96	Halifax
OTTAWA	341	28/9/96	Esquimalt

Displacement: 4770 tons full load
Dimensions: 134.1 x 16.40 x 4.9 meters (444.5 x 54 x 17 feet)
Propulsion: 1 x 8,800shp Pielstick diesel, 2 x GE LM2500 gas turbines, 47,500 shp, 2 shafts, 29+ knots
Crew: 230 – including air department
Hangar: one, for 1 CH-124

The HALIFAX Class carries a formidable array of weapons and sensor systems. For hard-kill effectiveness, this class of ship is capable of carrying: 8 Harpoon Surface-to-Surface Missiles (**SSM**s), 16 Sea Sparrow Surface-to-Air Missiles (**SAM**s), a 57mm gun, a 20mm Phalanx (Gatling Gun) Close In Weapons System (**CIWS**), 8 x 50 cal machine guns and 24 Mk-

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46 torpedoes. These ships can defend themselves using soft-kill technologies such as Infrared (**IR**) suppression, chaff and IR flares, a towed acoustic decoy (NIXIE), and a radar deception device (Reprogrammable Advanced Multi-Mode Shipborne ECM System (**RAMSES**)). In addition, the ship's torpedo-carrying helicopter significantly extends its range of operational effectiveness.

The relevant ships sensors and weapons are shown in Figure 3-2.

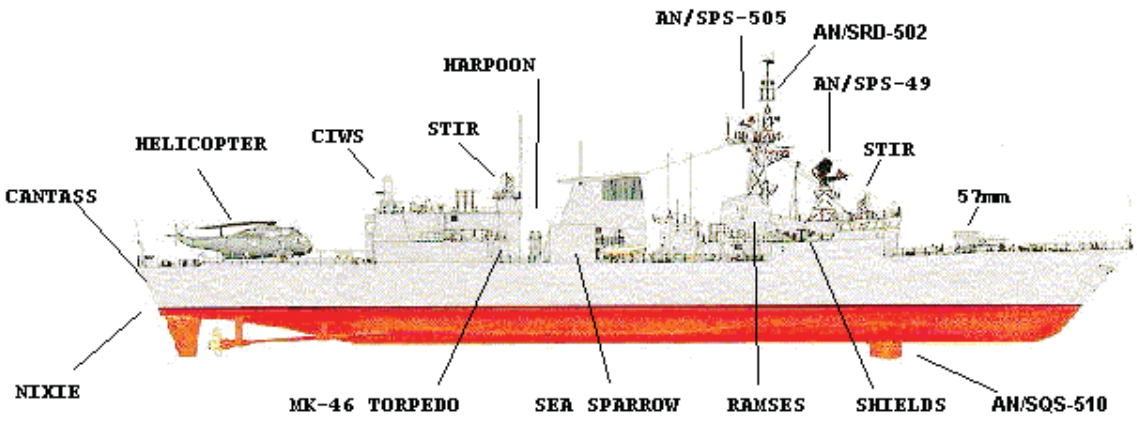

Figure 3-2 HALIFAX Class Frigate Weapons and Sensors

3.3.1 HALIFAX Crew Organizational Structure

The normal complement of 230 personnel is organized into departments as depicted in Figure 3-3 below.

3.3.1.1 The Combat Department

The Combat Department, consists of personnel from the Naval Electronic Sensor Operator (**NES OP**), Sonar Operator (**SON OP**), Naval Combat Information Operator (**NCI OP**) and Naval Communicator (**NAV COMM**) sections. The Combat Department manages and disseminates the data from all available sensors to form the Recognized Maritime Picture (**RMP**). The navigation and weather forecasting services are also functions of the Combat Department, however they are not relevant to this study.

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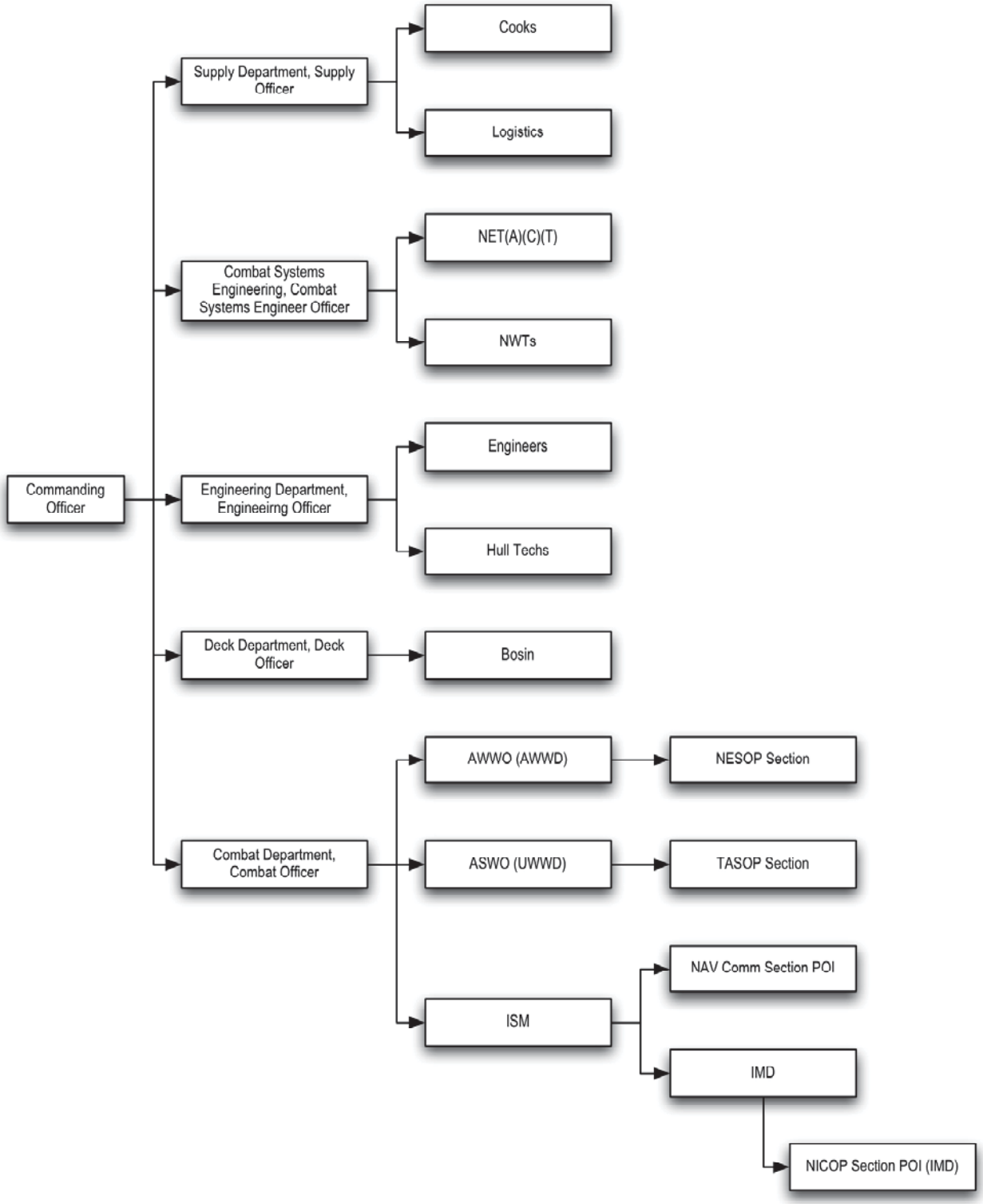

Figure 3-3 HALIFAX Departmental Organization

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The officer in charge of the Combat Department is the Combat Officer. This position is filled by either a LCdr or LT(N) qualified to assume the role of an Operations Room Officer. The ORO position is the Combat Officer's primary job at sea. To assist in the management of the department the Combat Officer has a Deputy Combat Officer, who is also qualified as an ORO, or two subordinate OROs (Weapons Officer and Operations Officer), and a Chief Petty Officer who fills an administrative role. Each section of the Combat Department is represented by a Divisional Officer (**DO**) and a Petty Officer 1st Class. The Combat Department's four sections are manned by the following occupational trades:

a. **NES OP.** Naval Electronic Sensor Operators operate the above water warfare sensors and countermeasures of the ship. These sensors include Canadian Electronic Warfare System (**CANEWS**), AN/SRD-502, SHIELD, RAMSES and the Separate Track and Illumination RADAR (**STIR**s). PO1 NES Operations man the Above Water Warfare Director (**AWWD**) position.

b. **NCI OP.** The NCI OP is responsible for the overall combat information flow. They process and manage the data collected by the ship's sensors (for example, AN/SPS-49 and AN/SPS-505) as well as other internal and external sources. This information is displayed at the various positions via the CCS. PO1 NCI OP man the IMD position.

c. **SON OP.** The SON OPs are responsible for the operation of the underwater sensors and countermeasures and the data derived from their use. The active and passive acoustic equipment they manage include the AN/SQS-510 hull mounted SONAR, CANTASS, and Sonobuoy processing gear. PO1 Sonar Operations man the Under Water Warfare Director (**UWWD**) position.

d. **NAV COMM.** Naval Communicators are responsible for the management of communications, (such as tactical voice or message traffic) incoming and exiting the ship.

3.3.1.2 Operations Room Personnel, Positions and Responsibility

The management and dissemination of information is complex. The organization required to complete these tasks successfully is shown in Figure 3-4. The personnel identified in Figure 3-4 comprise the full Command and Control (**C2**) team in the Operations Room of the HALIFAX Class.

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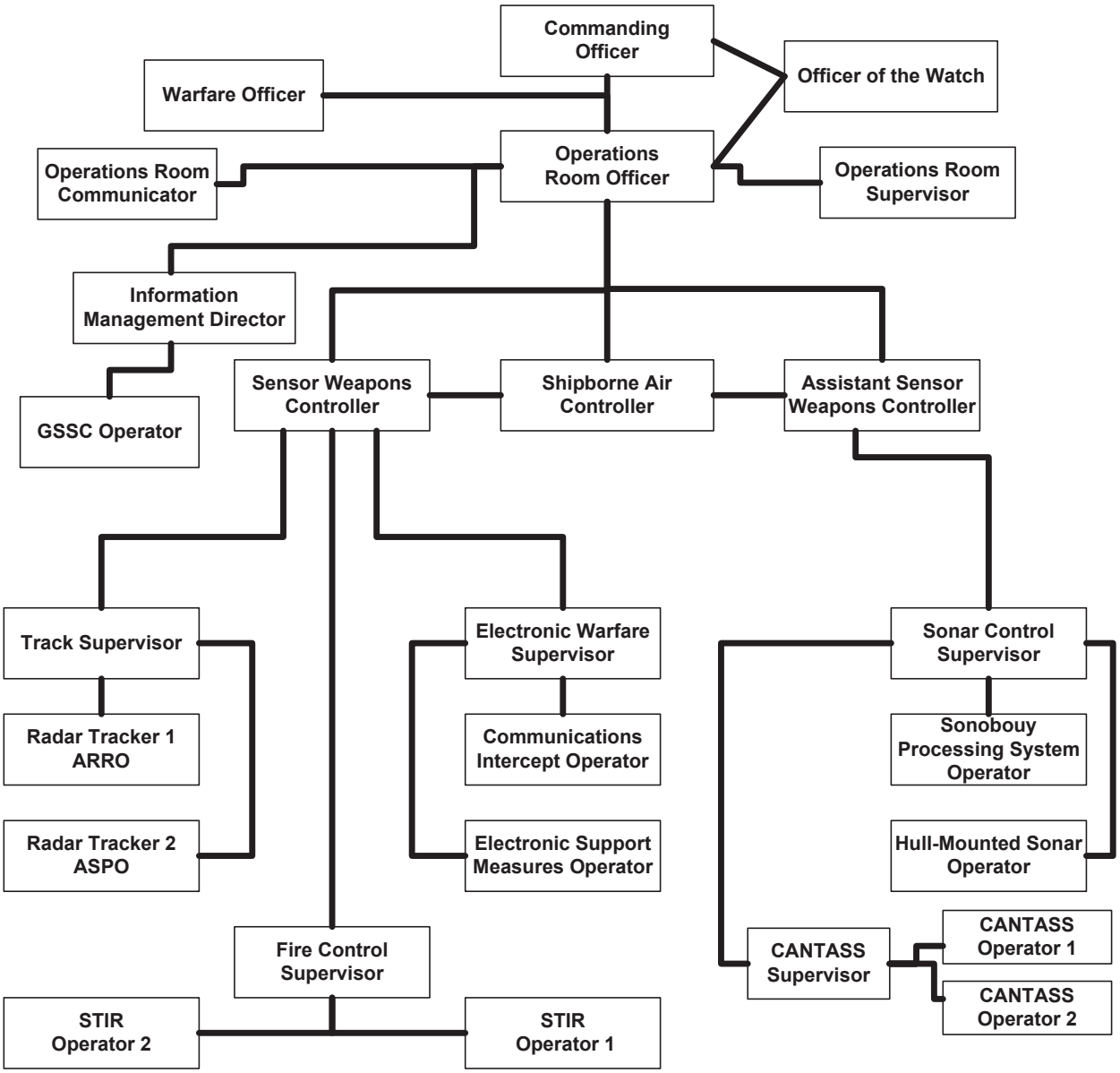

Figure 3-4 HALIFAX Class Operations Room Organization

3.3.1.3 Operations Room Watch Systems

The Watch and Station Bill for each section within a department details the manning requirements for both action stations and watch systems. The normal watch system for manning the Combat Department is the two-watch system referred to as Port and Starboard watches. The following describes the action stations and watch systems:

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a. **Action Stations - First Degree of Readiness.** The Operations Room is in its highest state of alert with all positions manned. The remainder of the ship's company is manned for weapons loading, casualty clearing and damage control. Weapons are in the "Standing-To" state to whatever policy is in effect. All positions are manned.

b. **Two-Watch System – Port and Starboard.** The ship is in its second highest state of readiness. One half of the Combat Department is on watch while the remainder is off watch. The watch hours are 7 hrs on then 5 hrs off and 5 hrs on then 7 hrs off. This watch system is also known as the Second Degree of Readiness. Depending on the weapons policy in effect ammunition may or may not be provided to the weapons. When the ship is in the Second Degree of Readiness and evolutions such as Replenishment at Sea or Rescue Stations will deplete the Combat Department of on-watch operators, minimum manning levels must be established. These levels may be required in other degrees of readiness, and may vary as dictated by operational considerations, ship's tasking, threat and other factors. The ORO must ensure that only essential personnel are retained as on-watch operators. For Watch and Station Bill planning purposes the following minimum manning levels are offered:

(1) ORO and Directors;
(2) SAC – as required;
(3) CI – 3 NCI OP;
(4) AWW – 3 NES OP;
(5) UWW – 3 SON OP; and
(6) COMM – 7 NAV COMMS (includes Snr NAV COMM);

c. **Three-Watch System – Red, White and Blue.** This watch system is seldom used by the Combat Department. In the event this watch system is in effect the Directors would not normally be manned and the ORO would be in the Operations Room or on call, able to respond at short notice to emergency situations.

d. **Four-Watch System – 1st Port, 2nd Port, 1st Starboard and 2nd Starboard.** Personnel stand one out of every four. When the ship is on independent operations with a normal tempo and overall ships manning permits the four-watch system the CO may approve its use. Although this is the most relaxed watch system, it creates a longer workday. Personnel are required to work from 0800 to 1600 hours (if not on watch), in addition to standing their watches from 1600 to 0800 hours. During the four-watch system the Operations Room is manned as required (minimum manning). The Director positions are not manned, weapons are stood down and ammunition is secured. Just as in the three-watch system the ORO would be in the

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Operations Room or on call, able to respond at short notice to emergency situations.

3.3.1.4 Weapons Readiness States

There are three weapon readiness states, Secured, Closed Up and Cleared Away, and Standing-To. These are described in greater detail in Subsections 3.3.1.4.1 to 3.3.1.4.3.

3.3.1.4.1 Secured

Secured is the normal weapon readiness state applied when there is no requirement to man weapons. Secured state is assumed when reverting to a lower degree of readiness. Once reporting that they are secured personnel remain in position and monitor communications until receipt of the order "SECURE PERSONNEL", from the Directors. Upon hearing this command all positions will release their SHINCOM terminals and stand down.

3.3.1.4.2 Closed Up and Cleared Away

Closing Up and Clearing Away duties are carried out at the order: "ASSUME THE 1st/2nd DEGREE OF ABOVE WATER WARFARE READINESS or UNDER WATER WARFARE READINESS". This readiness order is normally given once the oncoming watch has fully turned over. The on-watch personnel proceed to "Close up and Clear Away" their positions. "Closed Up and Cleared Away" is the report passed when all positions have cleared away their equipment and have sufficient personnel manning to respond to any expected threat. Once all Surface and Air Weapons Systems (**SAWS**) positions are "Closed up and Cleared Away" a report is made to the AWWD from the FC Sup that SAWS (which includes their subordinate positions) is "Closed Up and Cleared Away".

A similar report on the status of the Under Water Warfare (**UWW**) Team to the UWWD is done by the Sonar Control Supervisor (**SCS**). When all required reports have been received by the Directors, they in turn report to the ORO "Port or Starboard Watch" "Closed up and Cleared Away". At this time the required policy will be discussed with or recommended to the ORO by the AWWD and UWWD.

3.3.1.4.3 Standing-To

Standing-To is assumed on the "Policy Order" or "Action" or "Alarm" and is automatically assumed whenever the watch is relieved. Personnel and equipment are ready for immediate action with appropriate ammunition provided as required by the Policy Order, unless otherwise ordered by the Directors.

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Policy Orders are a quick and efficient means of verbally initiating Standing-To procedures to bring the AWW or UWW armament to a level required for action or exercise. The AWWD provides the Policy Order to the AWW Team as the UWWD does for the UWW Team:

a. upon receipt of all appropriate closing-up and clearing-away reports; and/or

b. whenever a policy change is required; and

c. on receipt of all "Standing-to" reports from the AWW and UWW teams the AWWD and UWWD respectively report to the ORO.

3.3.1.5 Warning Levels

Based on the threat in each area of warfare, Air, Surface and Subsurface are broken down into three warning levels, referred to as White, Yellow and Red. These levels are expressed as follows:

a. **White.** the lowest posture where no hostile or threat activity exists;

b. **Yellow.** a higher posture than white with a possibility that an attack may occur; or

c. **Red.** the highest level indicating there is a strong and imminent likelihood of an attack.

These indications are normally passed by the AWWD and UWWD when they hold the principal warfare duties of Local Anti-Air Warfare Controller (**LAAWC**), Anti-Air Warfare Controller (**AAWC**) or the ASWC. These warnings are passed externally as part of their Warfare SITuation REPort (**SITREP**) on the applicable warfare net. Warning levels are displayed on the SSD.

3.3.2 HALIFAX Class Frigate Operations Room Layout

The layout of the HALIFAX Class Frigate Operations Room is shown in Figure 3-5.

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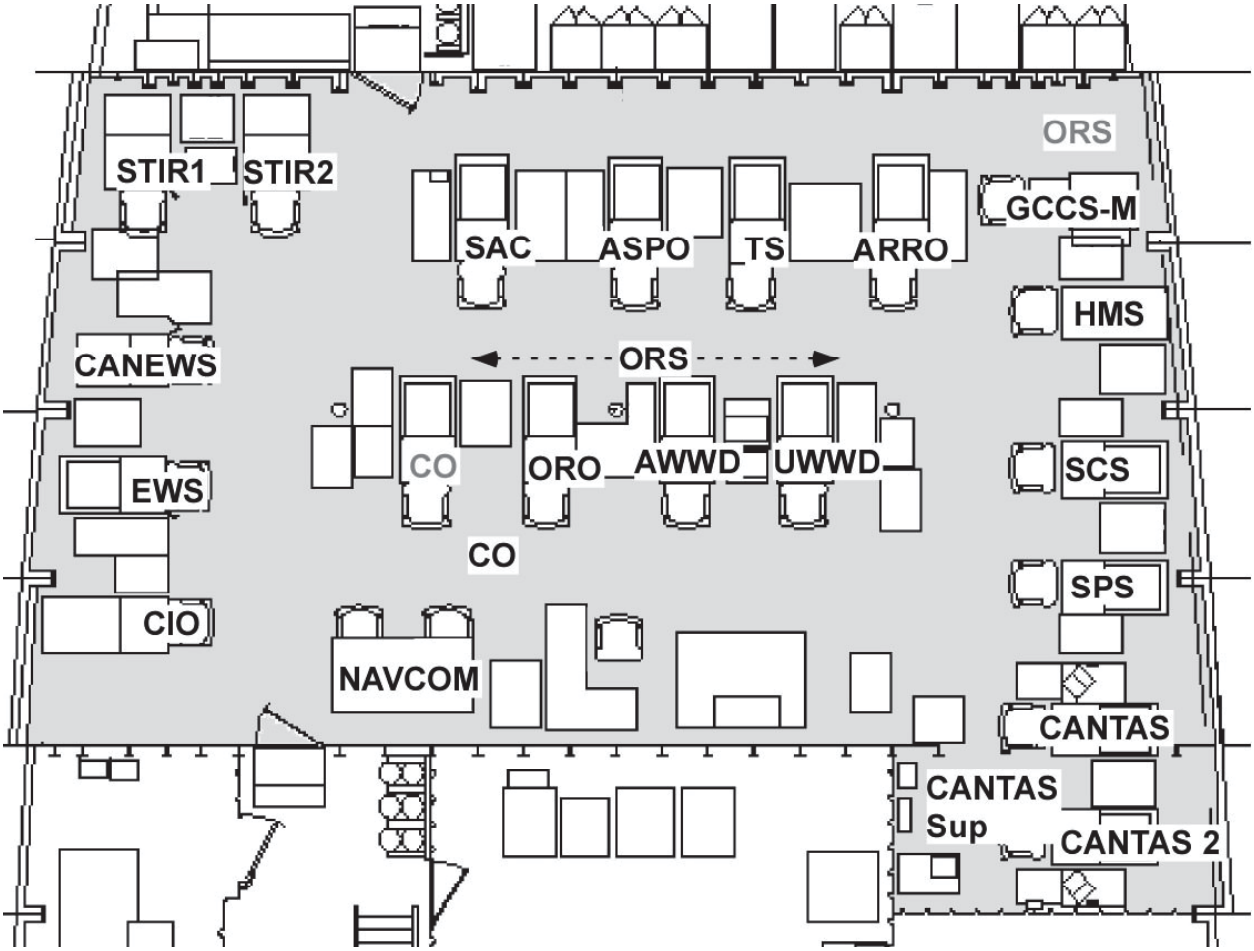

Figure 3-5 HALIFAX Class Frigate Operations Room Crew Layout

3.4 HALIFAX CLASS FRIGATE COMPOSITE SCENARIO

The composite scenario which formed the basis of this analysis is contained in Annex B. The reason for using a composite scenario was twofold: first, to focus the analysis on mission sequences that are particularly demanding from a workload perspective or are likely to be critical to requirements definition and the eventual design of the user interface; and second, to avoid wasting effort by analyzing functions that have already been analyzed, are unlikely to be critical to overall system performance, or are unlikely to provide any added value. The scenario used in this project was used in previous studies, References 6, 7 and 9. Small changes were made to the scenario to include the Warfare Officer and IMD roles, neither of which were included in previous studies.

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SECTION FOUR – HIERARCHICAL GOAL ANALYSIS

4.1 GENERAL

The objective of a Hierarchical Goal Analysis is to identify the goals (and hierarchy of goals) that must be satisfied by the system being analyzed to achieve specific mission objectives. The missions for the HALIFAX Class Frigates – broadly defined as Constabulary, Diplomatic, or Military – are described in Subsections 3.2.2.1, 3.2.2.2 and 3.2.2.3. The goals for the three mission types were decomposed to the second level; however given the overlap between all three it was decided early in the process, and agreed with by the SA, that only the mission representing the military role would be fully decomposed and analyzed as it captured the critical sequences being used to develop the baseline networks and captured the majority of all operations room goals. The additional effort to decompose the constabulary and diplomatic missions would not have generated any significant benefit. The methodology employed is described in Subsection 2.2.

4.2 GOAL ANALYSIS RESULTS

4.2.1 Goal Decomposition Products

Hierarchical Goal Decomposition Diagrams (**HGDD**s) are graphical representations of the logical relationships between the various hierarchical goals, during the performance of a mission. Typically HGDDs are developed for top-, first- and second-level goals that are identified from the mission analysis and consultations with SMEs. Lower-level goals are developed using a structured database that may or may not be able to display HGDDs. This project used Task Architect® for all goal development and was able to display all levels in HGDDs.

4.2.2 Top-Level Goals

Top-level goals represented the overall mission (constabulary, diplomatic, or military) as a series of individual elements performed either alone or in conjunction with other mission elements. As described earlier, only the military mission is decomposed in the HGA beyond the second level, the Top-level goal is: "I want to perceive that (represented as "…") the use of the sea is denied to enemy forces". This goal and its sub-goals (i.e., first-level goals) are shown in Figure 4-1.

4.2.3 First-Level Goals

The top-level goal is decomposed into first-level goals that define the sub-goals involved in satisfying the higher-level goal. First-level goals, referred to as mission objectives,

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are still general in nature and are included according to the tactical or physical requirements dictated by the mission scenario. The first-level goals of the HGA are shown in Figure 4-2, along with sub-goals associated with one of these first-level goals.

4.2.4 Second-Level Goals

First-level goals are decomposed into one or more second-level goals. Typically lower-level goals serve as an interaction with physical interface, however in this goal hierarchy the second-level goals are still very cognitive in nature. Hierarchical goal diagrams for the first level and second level of the military role are shown below from Figure 4-1 through Figure 4-8. Also included in this report (Annex C) is the entire goal hierarchy for the military mission decomposed to the lowest levels in the tabular form in accordance with Reference 4.

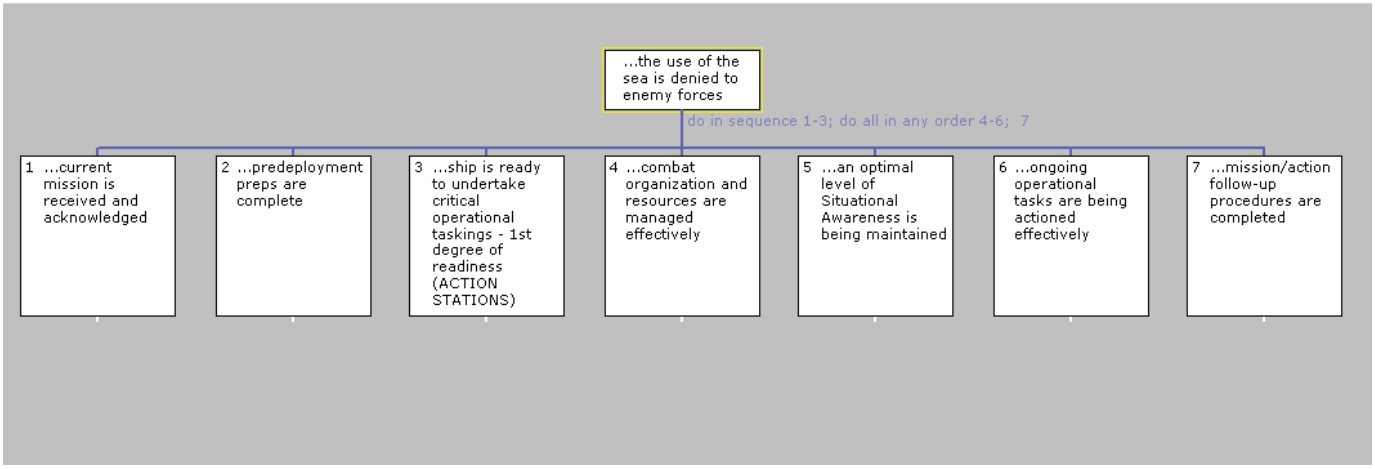

Figure 4-1 Top-Level Goal with Sub-Goals

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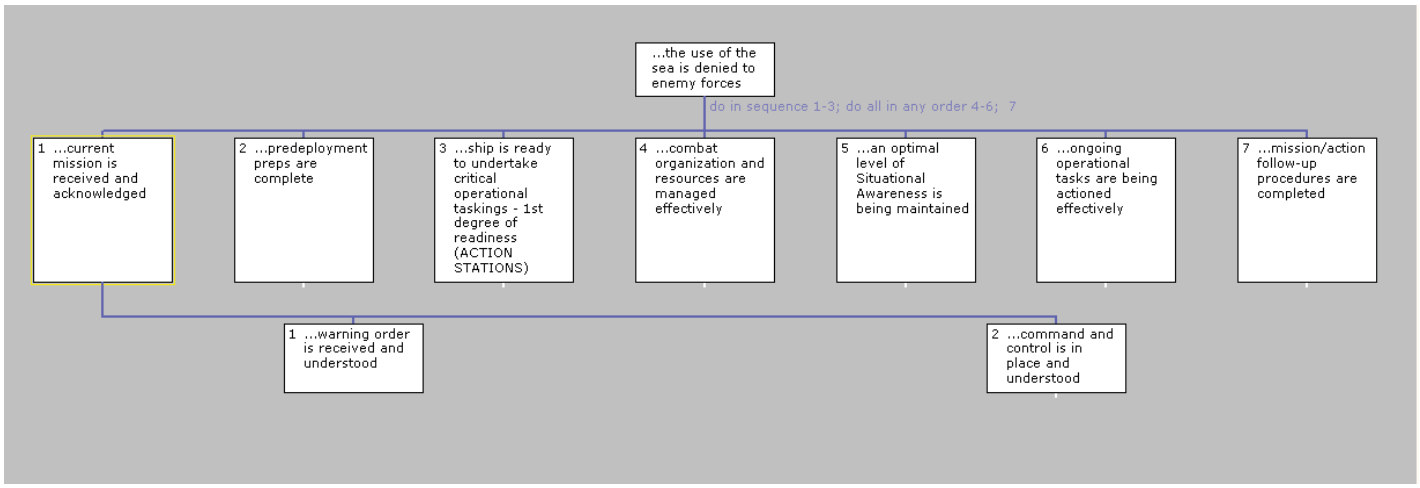

Figure 4-2 Sub-Goal 1 – "I want to perceive that the current mission is received and acknowledged"

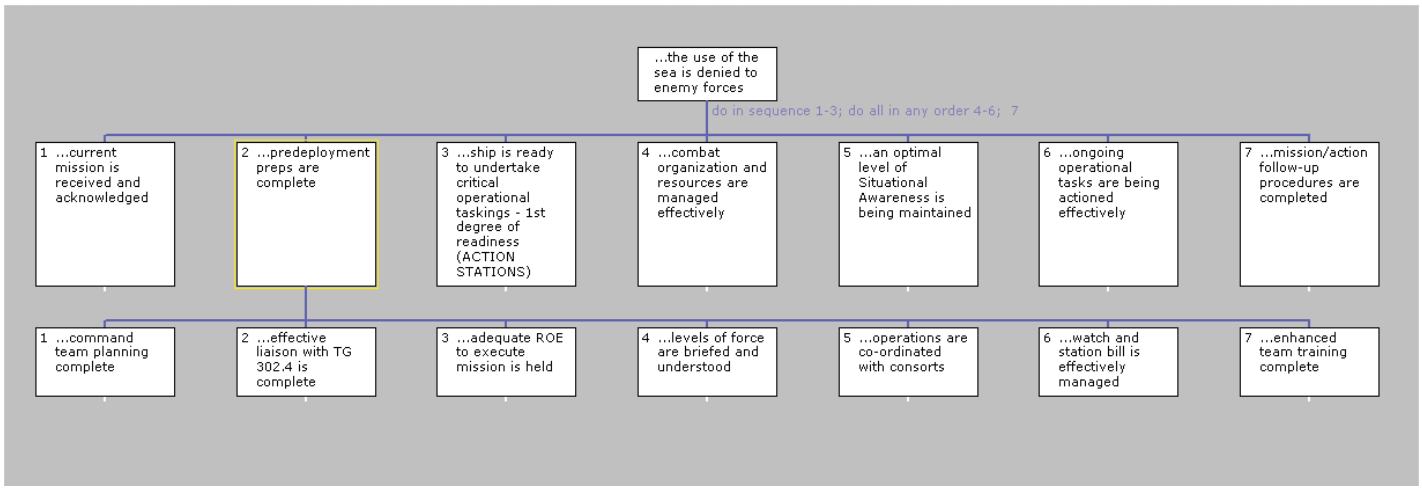

Figure 4-3 Sub-Goal 2 – "I want to perceive that predeployment preps are complete"

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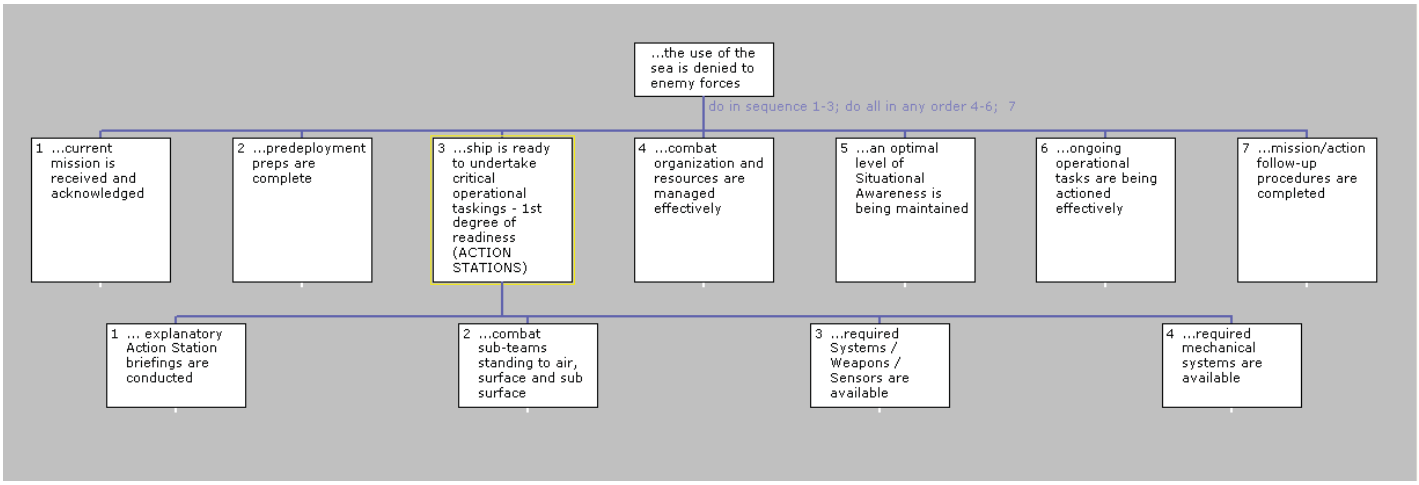

Figure 4-4 Sub-Goal 3 – "I want to perceived that the ship is ready to undertake critical operational taskings"

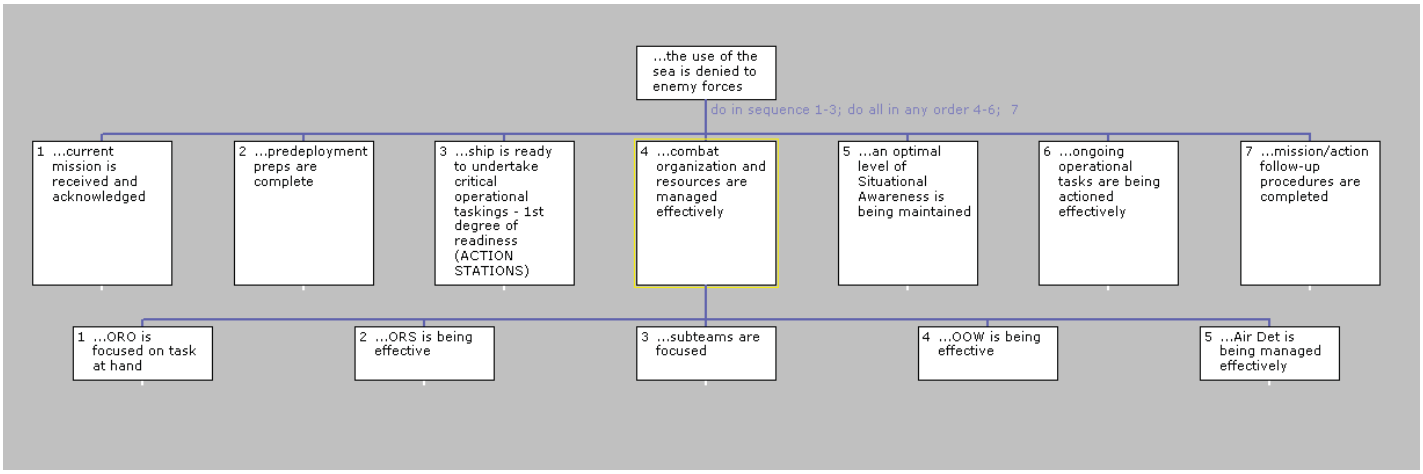

Figure 4-5 Sub-Goal 4 – "I want to perceive that the combat organization and resources are managed effectively"

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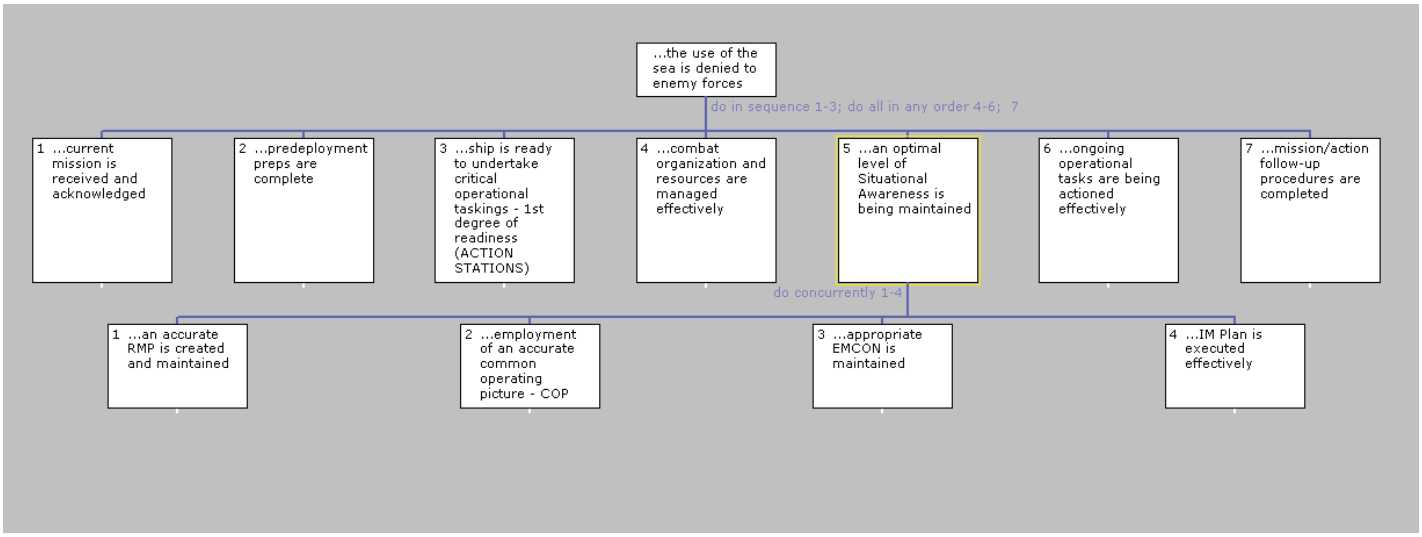

Figure 4-6 Sub-Goal 5 – "I want to perceive that an optimal level of Situational Awareness is being maintained"

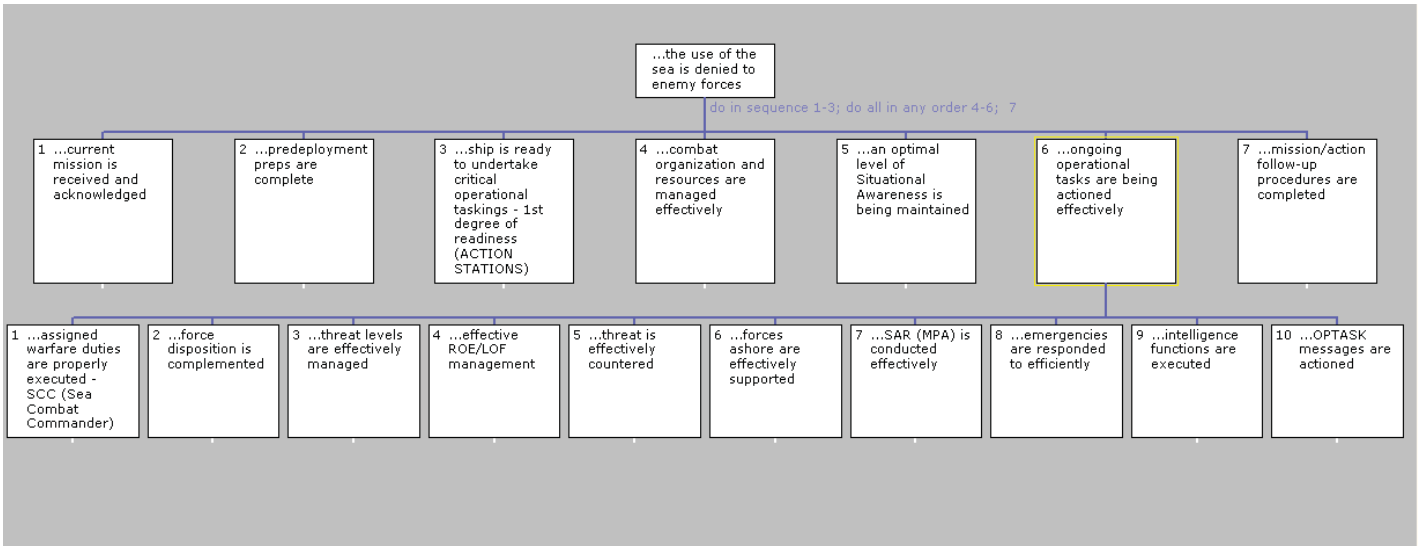

Figure 4-7 Sub-Goal 6 – "I want to perceive that ongoing operational tasks are being actioned effectively"

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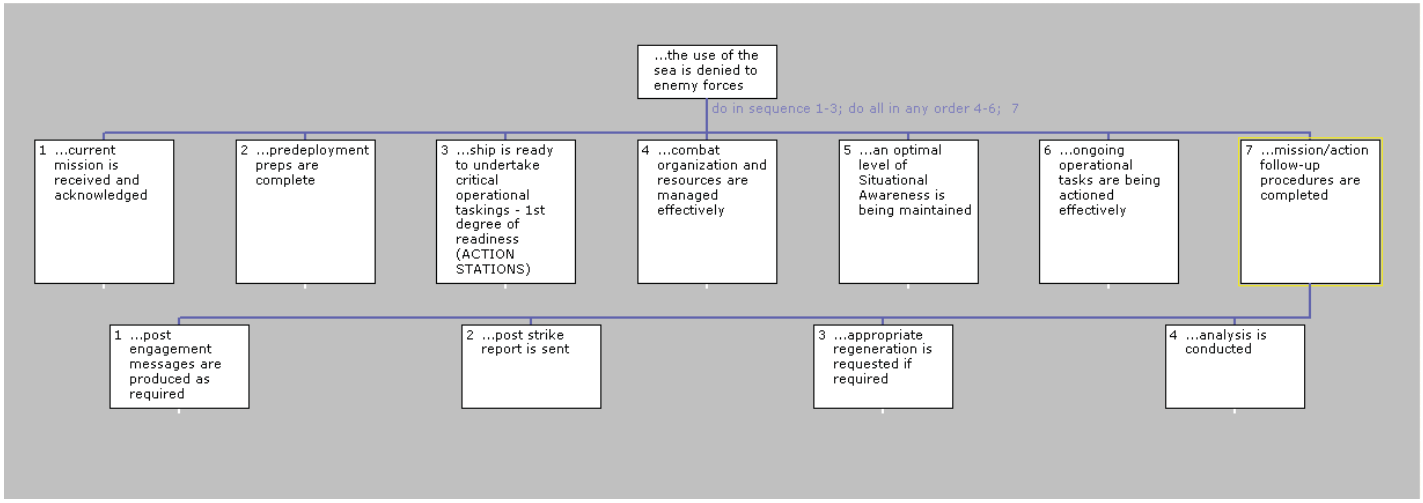

Figure 4-8 Sub-Goal 7 – "I want to perceive that mission/action follow-up procedures are completed"

4.3 DISCUSSION

4.3.1 Goal Allocation

The goal allocation (Annex C), as shown in Table 4-1, does not necessarily reflect the workload on each operator. It does indicate that goal allocation is commensurate with responsibility and experience. The exception to the rule is the Commanding Officer, who, while he has the highest level of experience, is not a constant fixture in the operations room and cannot be relied upon to drive the goals. This fact is reflected in that each first level goal, allocated to the Commanding Officer, was secondarily allocated to the ORO. The ORO is the senior operator in the operations room and is delegated certain responsibilities in the absence of the Commanding Officer.

Table 4-1 Goal Allocation

Operator/Position	Primary Allocation of Goal	Secondary Allocation of Goal
Commanding Officer	34	70
Operations Room Officer (ORO)	86	199
Sensor Weapon Controller (SWC)	111	66
Assistant Sensor Weapon Controller (ASWC)	76	53
Information Management Director (IMD)	64	14
Operations Room Supervisor (ORS)	19	196
Track Supervisor	18	40
ARRO	19	14

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Table 4-1 Goal Allocation

Operator/Position	Primary Allocation of Goal	Secondary Allocation of Goal
ASPO	5	18
Electronic Warfare Supervisor	24	22
Warfare Officer/Staff	49	5
Other	52	0
Shipborne Aircraft Controller	5	18

Given that the HGA is a "snap shot" of the complete workings of the operations room the more senior operators will naturally be allocated the majority of goals. The 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 surface and air 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.

The SCS was not identified as a position of interest in this project. Consequently the SCS was not included in the analysis, which proved to be troublesome. This operator has responsibilities similar to those of the EWS but in the ASW domain. In the HGA, goals allocated to this position were listed as owned by 'other', however, the position was included explicitly in the upward information flow analysis. The SCS position should have been analyzed.

Considering that the HGA was produced for an existing system, and that the domain experts were able to produce the goal decomposition effectively, the allocation of the goals to operations room operators was a natural outcome of the analysis. It is worthy of note that when the domain experts were taught how to complete the hierarchy of goals, the concept of goals rather than functions was not immediately apparent. Following decomposition of the first goal, the CMC team was able to revisit Reference 4 and self-critique until a good understanding of the objectives was obtained.

Given the complex matrix type organization of the Operations Room the majority of goals have a primary and secondary allocation, where the secondary 'owner' of the goal is prepared to step in and assume responsibility for the goal if the primary 'owner' is occupied with another warfare area or higher priority goal. During the subsequent analysis (specifically the upward flow of information and critical activities), the secondary allocation of the goal was tracked. Secondary allocation should be considered as a mandatory goal characteristic in all complex systems.

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One of the techniques used when employing SMEs to confirm the HGA goals and goal allocation directly assisted in developing credibility with the merits of the HGA process and capability of the analysts. SME operators were asked to describe activities performed during the application of their duties; these were then matched against goals. During this process, by the second SME session, there were no occasions when an activity or specific task identified by an SME could not be mapped against a relevant goal or sub-goal. To better support goal development a 'bottom-up' review of the goal decomposition should be conducted to validate the top-down process.

Despite the steep learning curve the HGA was eventually understood by the domain experts and accepted as a suitable and useful analytical tool. The HGA process should be considered for future human engineering analysis requirements.

4.3.2 Usage

The goal hierarchy was used as the basis for the upward information flow and the potential instabilities analysis. The PCT tables, Annex D, were also used to collect goals with the same external variables - the far right column in the table – used for potential instability analysis. These goals, along with the allocated operator, were collected and analyzed as described in Subsection 5.3.

By relating the goals and sub-goals, the need to transmit information upward, in order to satisfy parent goals, was identified. This upward information flow analysis is further described in Subsection 5.4.

The HGA provides a strong tool to be used to investigate proposed changes to the Operations Room, as the insertion of new goals/sub-goals in the hierarchy would be intuitively obvious to any analyst familiar with the operations room.

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SECTION FIVE – IP/PCT

5.1 General

This section provides results and a discussion of results for the important analyses conducted with the hierarchy of goals introduced in the previous section. The three areas of analysis are:

a. Perceptual Control Theory Analysis;
b. Potential Instabilities; and
c. Upward Information Flow.

Please refer to Subsection 2.3 for the methodology used to produce the results.

5.2 PERCEPTUAL CONTROL THEORY

5.2.1 Results - PCT

The results of the Perceptual Control Theory analysis are contained in Annex D. Each page in the Annex contains the PCT data for a goal – they are ordered by goal number. The goal hierarchy for the Halifax Class Frigate operations room, decomposed for the military role, has a total of 562 goals; therefore Annex D contains 562 PCT tables. The scope of the study (see Subsection 1.3) did not include all operations room operators; however, all upper-level goals and most lower-level goals were included in the analysis.

5.2.2 Discussion - PCT

The resultant information compiled from the PCT analysis concurs with the intuitive concept of hierarchical goals. The lowest level goals require the fewest knowledge states, and have better defined initiating conditions, ending conditions, and influenced external variables. The higher-level goals tend to require a greater number of declarative and situational knowledge parameters, have more vague ending conditions (the goals tended to be ongoing for lengthy periods of each scenario), and require influence of other operators and internal variables. The higher-level goals represent the command end of the spectrum whereas the lower-level goals require influence of individual parameters and are at the control end of the spectrum.

The collection of the PCT data was difficult due to the complexity of the type of information being sought and the terminology used to describe it. The review of PCT data by SMEs was also difficult. The volume of information that was required before meaningful review could take place made the process prohibitively time consuming. The Technical Authority, fully familiar with the PCT information requirements, was used for the review in place of the SMEs.

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The terms ‘input / sensation’ and ‘output / behaviour’ required constant review in order for the domain experts and SMEs to define the properties correctly. The expression and verbal anchors, although well understood by psychologists, are foreign to military operators and throughout the project constant redefinition of the expression was necessary. This would have been alleviated with more descriptive expressions or additional training for military individuals more familiar with operations equipment. There was also an issue of the higher-level goals simply being understood only as an aggregate of the sub-goals. The domain experts, on several occasions, had to revisit goals and assess them as stand alone entities in order to properly define their properties. In time the domain experts became comfortable with the concept and were able to accurately and concisely complete the tables. This should be considered when planning to conduct an HGA in the future as the domain experts and/or SMEs will require additional time to comprehend the concepts before proceeding with PCT data collection.

The determination of the controlled variable was difficult to achieve. In Hendy et al.’s paper [Reference 4], Table 2 does not show ‘influenced “controlled” variable’, as it is only in Table 1. The controlled variable should be included in Table 2 – separate from the internal and external variables already defined.

The specification of external variables was not a simple task. The first problem facing the analysts was the definition of the actual variable. For example, in the case of data transmission, the external variables being manipulated are the MCOIN / DWAN / COWAN interfaces, however this was reworded to reflect an operator requiring access to the system. As a second example the ‘Weapon Veto Panel’ is the physical manifestation of the interface, however the variable is the enabling of weapons through the weapon veto panel, therefore the external variable was worded to be – “Enabling of weapons through the 'Weapon Veto Panel'”. LINK 11, the current tactical datalink used in the Halifax Class Frigate, was at first considered an external variable and then dropped, as it is really a system that provides information – and that information is available to all operators simultaneously – LINK 11 is a system that enhances the SSD input interface not an external variable.

The resolution of other operators, being acted upon by the assigned operator, as external variables was eventually concluded through the definition of conduit clashes. It was decided that these clashes were not to be considered in the potential instability analysis, however it was not successfully resolved as to how to effectively model or analyze the demands on other operators in a complex multi-operator system within the current HGA structure and set of analytical tools. As an example of this issue the ORS is required to conduct a different set of tasks to support each of the ORO, SWC, ASWC, and SAC in order to facilitate a number of specific goals and if each of these operators had to have the ship’s heading be in a certain direction for each of the same goals only the ship’s heading, as an external variable, would be captured as a potential instability. However, the ‘demand’ on the operators is only captured during the task network analyses, which is an incomplete representation of the goal hierarchy and therefore does not capture all potential instabilities. In a complex matrix type organization operators that directly

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support the completion of a goal should be included in the potential instability analysis. The HGA could capture the 'demand' by including operators as a special category or external variable.

The PCT data, while time consuming to collect and difficult to review with SMEs, proved to be extremely useful in subsequent analyses. It directly supported the potential instability and upward information flow analyses through the provision of external variables, input/output interfaces and controlled variables. It also supported the critical activities analysis as the domain experts and SMEs were able to refer back to the PCT tables in order to judge the levels of knowledge required, the cognitive processes involved and the interaction with the real world expected for a specific goal.

5.3 POTENTIAL INSTABILITY

5.3.1 Results – Potential Instability

The following external variables were identified as being controlled/influenced by more than one operator and therefore potential sources of instability in the system:

a. access to message files;
b. maintenance of stateboards;
c. access to MCOIN / DWAN / COWAN;
d. tasking of CANEWS;
e. enabling of weapons through the 'Weapon Veto Panel';
f. ship's heading and speed;
g. STIR designation;
h. A/SPS 49 Radar control / configuration;
i. SG 150 Radar control / configuration;
j. application of CCS 330 overlays;
k. CANTASS employment;
l. machinery state - propulsion and power generation; and
m. communications configuration - internal and/or external.

Annex I contains tables listing the goals associated with each external variable in conflict, the allocated operator, and domain expert's suggestions for stable control.

During the analysis phase it was determined that a designation made during the collection of PCT data was insufficient. Initially the configuration of radar was considered as an external variable, however, as the analysis matured, it became obvious that the two radars are employed to support many common and several unique goals; therefore, analysing the AN/SPS 49 and SG 150 radars individually provided more detail for the instability analysis.

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5.3.2 Discussion – Potential Instability

The current command and control structure that is in place provides a number of mechanisms that prevent instabilities. Specific operators are dedicated to the configuration or assignment of weapons and sensors – any other operator wishing to influence the equipment is aware of who in the operations room is responsible for that equipment and requests any changes through them. Overall, the number of potential instabilities was found to be low for a system as large and complex as the operations room of a frigate.

When the analysts attempted to determine the potential instabilities inherent in the operations room, the earlier difficulties encountered in understanding and applying aspects of IP/PCT were re-encountered by SMEs. Despite this, the use of IP/PCT to develop a list of potential instabilities was proven to be a sound analytical tool. This tool could be applied to systems in development as a method of identifying design issues prior to implementation.

Not surprisingly and as determined through the analysis, the potential for instability seemed to increase substantially in situations where responsibilities were shared amongst multiple individuals. In future systems, the ability to create 'soft control interfaces' accessible to numerous operators could create the potential for instabilities not present in the current operations room. Future designs will need to consider this, and devise strategies that effectively manage the risk. One approach that might be effective is to limit access to equipment controls to the primary and secondary owner of the goal responsible for those specific settings. New systems must not precipitate new instabilities through poor design or excessive near concurrent control of system parameters by multiple users. As an example, a new air search radar will be configurable through a software page, however only the operators logged onto the system as ARRO or TS should have write access to the page, all others should have read only. During the design of future complex naval systems, the splitting of responsibilities for equipment or sensor settings should be restricted, if possible, to keep the responsibility with a limited number of people, preferably the owner of the goal responsible for the relevant system settings and, as a backup, the secondary goal owner.

A further area for potential instability can occur when individual operators are not aware of the reasons for which systems are currently configured. In this situation, they might be more inclined to initiate a change, unaware of other operator needs for the current configurations. A means to avoid potential confusion over the control and configuration of sensors would be to provide an explanation of current settings and sensor employment in the SSD (who input settings and why). In this way, any potential confusion over the rationale and requirement for current sensor settings could be avoided. The SSD should accommodate information providing operators with ready access to sensor configurations and the goals that they are currently supporting.

The operations room operators are constantly dealing with rapidly changing and conflicting priorities (goals). This is a source of instability that requires active management in order to avoid poor picture management and the loss of situational awareness. Current processes

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place responsibility for setting priorities with the CO and/or ORO. The ORO must be cognizant of conflicting taskings and set warfare priority via briefings and direction to Directors, while ensuring the concurrence of the CO. While this is currently executed primarily through verbal interaction, there are occasions when awareness of priorities breaks down. The use of shared situation awareness displays could help to mitigate this potential source of instability. Further, the ORS needs to know the tactical requirements (settings) and priorities but does not have a dedicated display because the ORS duties require the operator to roam to monitor subordinate operators. The implementation of shared displays could assist the ORS in maintaining awareness of the current operational picture.

The strategies for risk mitigation are numerous. Depending on the type of external variable the proposed solution for stable control varies. The discussions below captures the suggestions developed by domain experts and confirmed by SMEs.

To prevent operators from having to wait to read messages from a file, electronic messages can be electronically distributed to the appropriate recipient. The electronic message file could be developed to allow for multiple simultaneous use from the CCS work station.

The operations room should be configured to ensure visibility of stateboards to all operators who require information. All stateboards should also be accessible on SSD by a simple method of selection such as a touch screen. An electronic stateboard could have visual aids for different types of information using colour/shape/etc, which would allow more information to be displayed without losing the "information at a glance" benefit of a stateboard. Dedicated positions should be given write privileges to their specific stateboard.

To reduce the demands on the ORO to conduct electronic chat, the use of chat should be co-ordinated between the IMD and the ORO. To co-ordinate administrative and operational demands on the limited chat circuits available, the ORO should control access by Heads Of Departments and the Executive Officer to chat as required.

To preserve bandwidth availability, the IM Plan must prioritize warfare and ownship requirements. There should be an automated visual method of indicating priority and subsequent taskings of bandwidth intensive activities.

To best utilize sensors the ORO must be aware of potentially conflicting taskings and set usage priorities. Proximity between the ORO and directors would assist in this – the HMCCS layout of the operations room should take these potential instabilities into account. The ORO must remain aware of needs for weapons – an enhanced command decision aid would assist with this.

With respect to employment weapons and sensors, where they impact on ROE, the SWC and ASWC could be aware of current ROE through a more effective user interface, to prevent instabilities arising from improper use of weapons or sensors.

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The current command, control, and charge doctrine should stay intact as all demands for ship's course or speed from the operations room must go through the CO or ORO. To avoid instabilities of control the CO and ORO must remain collocated to prevent simultaneous control demands. Only one of the CO or ORO should have control of ship's course and speed, and as determined during the SME visit to HMCS WINNIPEG, in the ship the ORO is the only operator in the operations room that passes conning orders to the OOW; therefore, in this instance, HMCS WINNIPEG has eliminated the potential instability.

Potential instabilities resulting from coordination of Task Group and ownship priorities has led to the recent addition in the operations room of a Warfare Officer. The relationship between the Warfare Officer and ship's officers will have to be worked out in advance of high intensity operations, such as those modelled in the task networks. The relationship should then be rehearsed and refined.

CCS should lock out non-critical users. When the STIR is used in support of picture compilation and weapon engagement goals, priority must be given to weapons engagement. The ORO must be cognizant of conflicting taskings and set warfare priority via briefings and direction to directors. Again the proximity of directors to one another and to the ORO reduces this potential conflict.

The current limitation in defining and filtering lines, circles and arcs on CCS 330 causes a constant struggle to minimize their use. Greater granularity in the selection of overlays is required to allow for individual use. A new system should have greater capacity for overlays and the ability to preview the screen to visualize a planned overlay prior to applying an overlay.

The tactical picture compilation should take precedence over operational picture requirements – reducing potential concurrent demands for system resources.

With respect to the ship all requests for changes to engineering state must be passed through the ORO to the OOW and CO. A CCS page should exist that captures and reports the machinery states.

To avoid stepping on operators communicating by SHINCOM, a visual indicator should be added that shows that a console operator is currently on an external circuit.

To reduce the requirements for voice communications, real-time text based communications should be increased. In addition to using this for info transfer, the use of text alerts for operators to establish internal communications in other than urgent situations should be considered.

A number of the suggestions appear vague – they must be considered in the context of the external variable and goal associated with them. For complete context refer to Annex I.

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An issue that was raised and investigated was that of other operators being external variables within the system representing a cause of instability. The term coined during the project was 'conduit clashes' which was an attempt to describe the situation occurring when an operator is engaged with satisfying one goal, while another operator requires the first operator's attention for completion of a second goal. It was determined that the task network analysis would indicate when operators were overwhelmed and could not be expected to immediately support a goal.

Grouping of multiple external variables, such as the AN/SPS 49 and SG 150 as a radar, lead to the identification of potential stabilities that were not validated. External variables should be identified by their most basic component. Overall the potential instability analysis was very sound, illustrating that the Navy has adapted its doctrine and procedures in the complex environment of the operations room to prevent many potential problems.

5.4 UPWARD INFORMATION FLOW

5.4.1 Results – Information Flow

The Upward Information Flow analysis is captured in table form in Annex H. The results may be viewed in tabular format and also in link diagrams. The link diagrams are formatted to be compatible with an interactive viewer application developed during the contract. The viewer has been made available to DRDC Toronto, DRDC Atlantic and to DND. DND has found it a useful aid for developing the HMCCS HMI source documentation. Figure 5-1 illustrates the viewer's output.

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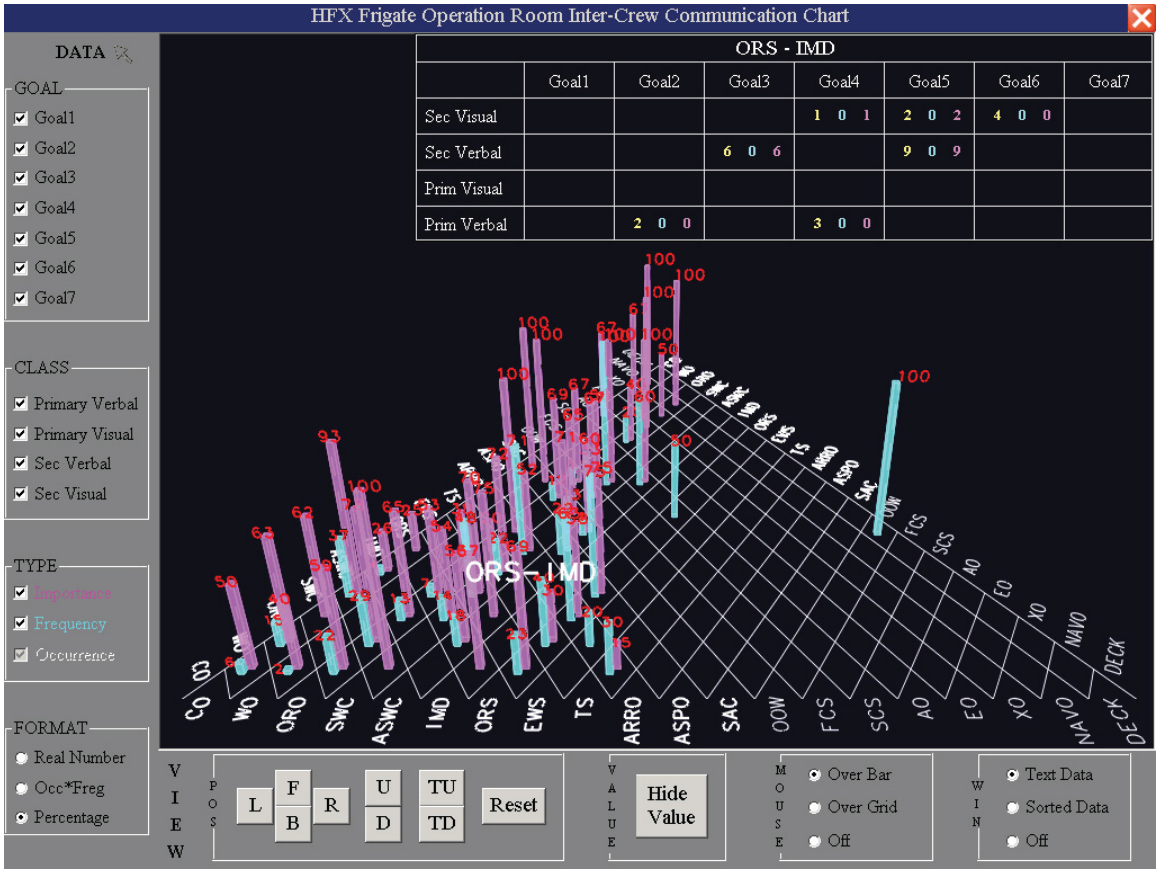

Figure 5-1 Format for Information Flow Viewer Output

The link diagrams show up to five 'views' for each top-level goal in the military HGA, these are contained in Annex H. The link diagrams capture the information flow to both the primary and secondary goal holder and information in the auditory and visual domains – for each. The fifth diagram combines both owners (primary and secondary) and both domains (auditory and visual) yielding a total information flow for that top-level goal.

The interactive view uses a series of databases that looks at total occurrences, frequency and importance (X,Y,Z) in each combination of operator and each communication type (e.g., primary verbal etc.) in absolute figures. A user guide has been included with the viewer software.

As an example of the information types that can be queried from the viewer, consider the interaction required between the SWC and ORO, considering goals where they are the primary or secondary operators in the entire military role goal hierarchy:

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a. SWC to ORO has 112 total requirements for communications of which only 59% are important (includes primary and secondary allocation);

b. SWC to ORO has 65 communication requirements that are addressed verbally, of which 58% are important (includes primary and secondary allocation);

c. SWC to ORO has 65 communication requirements that are addressed verbally of which 23% are frequent (includes primary and secondary allocation);

d. SWC to ORO has 38 important communication requirements that are addressed verbally (primary allocation only); and

e. SWC to ORO has 15 frequent communication requirements that are addressed verbally (primary allocation only).

5.4.2 Discussion – Information Flow

The information flow results were initially structured in a tabular format. This had some drawbacks, not the least of which was that the results were difficult to analyze and understand. Further, the results generated by upward information flow analysis as prescribed in Hendy et al.'s paper [Reference 4], were found to be potentially misleading in a complex matrix type system such as the Halifax Class Frigate operations room. For instance, the HGA does not capture frequency of communication. Each incident of a requirement for information to flow up the hierarchy is a single count. In an effort to overcome these issues, an information flow viewer was developed by CMC that could collate the results and clearly display the important aspects of intra-crew communications.

The viewer was presented to several SMEs and a number of observations were recorded. The more pertinent observations with respect to redesigning the operations room are:

a. The high volume of communications between the ORO and SWC represents the two areas of warfare the SWC is responsible for – air and surface;

b. Given the relatively low requirement for information flow between the SWC and ASWC, there is no requirement for them to be co-located; and

c. The information flow viewer is a useful tool for more detailed analysis, including assessing the following items:

(1) determining whether a switch in communication modality makes sense to reduce operator workload on an overloaded auditory channel;

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(2) consideration of volume and weighting of information flow (3D-buildings of different colours);

(3) studying different representations of related data to enable the information to be used for varying purposes and/or audiences; depending on the purpose a single view may not be appropriate whereas a variation may be more effective;

(4) instantaneously comparing totals of all 4 types of information flow to enable an analyst to recommend changes to communication types or goal associations; and

(5) using the viewer to identify communication patterns to enhance teaming. The current operations room layout is not ideal – by grouping operators differently (co-locating teams if appropriate) the communication efficiency could be increased.

The ability to analyze in three dimensions (communication transmitter, communication receiver, and volume) and select variables, such as communication type, primary or secondary goal allocation and first-level goal association, was well received by the numerous DND SMEs that were afforded the opportunity to view the results. The 3-D graphical representation of the upward information flow was more effective than the traditional tabular form of a link analysis.

Analysis of the data, through the use of the viewer, indicates that the volume of verbal reports to the primary operator places an overwhelming demand on the auditory channel, whereas the use of visual stimuli to support upward information flow to the primary operator is quite limited. This issue was clearly evident from the results of the information flow analysis. The verbal reports were secondary to the action being conducted by operators and constrained the available auditory communication channels for tactical discussions and the downward flow of information in the form of directions and orders. The vast majority of verbal reports could be replaced with some type of visual indication without exceeding the usual modality. The results of the upward information flow analysis provided several useful insights that were used to support the redesign of the Human Machine Interface for the Halifax Class Frigate Operations Room (HMCCS).

Another issue identified by the HGA was that the ORS provides oversight for numerous operators, a role that requires constant movement through the operations room. The ORS does, however, have a secondary responsibility for these goals. Without a dedicated console, the role of the ORS as a second for several goals is currently satisfied through visual inspection of other operators' displays and stateboards. This is not ideal, however, to anchor the ORS at a console would require a new method of oversight for subordinate operators. This item was also used in the HMCCS project.

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The usefulness of the analysis with respect to the IMD position was of limited value. Within the Navy there appears to be considerable debate and uncertainty over the role and responsibilities for the IMD and to date, there has been insufficient practical application of the position to establish consistent terms of reference. Each ship at present seems to have slightly different interpretations of the IMD role. The relationship between the IMD and the remainder of the Operations Room still needs to be refined, and hence information flow between the IMD and the Directors could not be effectively gathered or studied.

The volume of information flow between operators and the Warfare Officer is dependant on the support needed and provided by the ship's team or by staff, if embarked. As with the IMD position, this position is difficult to model accurately as each ship and squadron staffs have unique relationships. No significant conclusions were able to be drawn with respect to information flow involving the Warfare Officer.

Several key operators were not considered during this study, namely the SAC, CANEWS operator, FCS, SCS and CANTASS Supervisor. Not specifically studying these operators had an impact on the completeness of the data collected and information generated from the information flow analysis.

A traditional link analysis contains both upward and downward information flow – the analysis contained in this study only studied upward flow. The nature of this analysis – being upward information only – did not consider lateral information flow, (e.g., ARRO and the TS discussing a contact that the ARRO is analyzing in support of the SWC's higher level goal of maintaining a recognized tactical air picture). It also did not consider any downward flow; i.e. direction given to ensure a goal is completed. This was discussed with the SA, and it was postulated that the ratio of downward information flow would be proportional to the upward information flow in most cases, and therefore only one direction was needed to draw conclusions with respect to communication requirements. The HGA could be easily amended to provide the data for a complete link analysis. The downward information flow could be considered as the initiating condition in the PCT data however it would need to be explicitly defined for use in link analysis. While upward information flow was good input to the design of the operator workstation, lateral communications and downward communications should be added in order to provide a complete link analysis.

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SECTION SIX – TASK NETWORKS

6.1 RESULTS

The specific critical task sequences (watch turnover; resolve procedure including issuance of an air warning, conduct of a co-ordinated surface engagement using harpoon missiles, anti-ship missile defence against an advance surface-to-surface threat, and anti-submarine warfare to include torpedo counter measures and a close-in attack) were selected for their criticality and the requirement for participation by all operators being studied. During the SME session regarding the critical operations room sequences (see Subsection 2.6), the SMEs reinforced the selection of the task networks as representative of the most critical sequences of activities that operations room crews are required to deal with. At no time were the choice of scenarios questioned and the SMEs did not recommend other scenarios to augment the five. Given the tactical nature of the scenarios, the IMD was less involved as the position has been envisioned as an operational support and planning resource.

The results of the IPME analysis are graphical and tabular in nature. They are contained in Annexes as follows:

a. Annex E – Operational Sequence Diagrams;
b. Annex F – Mean Time Pressure plots; and
c. Annex G – .IPR summary file.

The Operational Sequence Diagrams contained in Annex E show operator activities and interactions for each critical sequence against a timeline.

The Mean Time Pressure plots contained in Annex F show the time pressure experienced by each operator for the duration of the critical sequence based on a sliding one minute window. It should be noted that in some plots, the data appears to extend off the top of the graph. In fact, these plots have a maximum at the highest point on the y-axis and the appearance of a cropped time pressure plot is only an artefact of the plotting routine.

The IPME results were combined into summary .IPR files. These files lists the tasks effected by the IPME scheduler, the operator, percent of time shed, reason shed, tasks active when shed, percent of time delayed, reason delayed, tasks active when delayed, percent of time interrupted, reason interrupted, and tasks active when interrupted. These summary files are contained in Annex G. The .IPR summary files provide a tabular listing of relevant results, averaged over the 40 runs for each network. The results are fairly self-explanatory, however it should be noted that in some cases, the value for percent shed, delayed, or interrupted can exceed 100. This occurs for ‘Receive’ tasks associated with verbal communications between the operators when the transmission task is interrupted and resumed, thereby creating the possibility of the same task being shed, delayed, or interrupted more than once per run.

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6.2 DISCUSSION

6.2.1 OSD Development

The OSDs were successfully developed and provided representations of the critical operational sequences that were easily understood, on an individual basis, by SMEs. In the multi-threat situation, the SMEs were less able to consider how the individual OSDs would impact on one another when multiple activities from different OSDs were intertwined in time. Comments received during the SME review session made it apparent that complete OSDs, showing how activities from multiple critical task sequences would occur concurrently, were required for review.

The development of OSDs was best completed on a goal-by-goal basis, that is each goal listed in the tables below had an associated OSD; however, the SMEs preferred to see the combined OSD. This was true for all the networks developed for this project. As an example, the ASMD network was developed with twenty OSDs, one for each goal listed in Table 3-1, then combined into three sub-networks: command, hardkill and softkill. All operators who reviewed these separate sub-networks indicated a desire to see the combined network to have a sense of what else was happening as a trigger for their contribution. The EWS wanted to know what the SWCs were doing with hardkill to judge their actions with respect to softkill and the ORO needed to know the status of the hard and softkill to comment on the completeness of command sub-network.

The approach to task network analysis, based on the top-down HGA, ensured complete development and representation of the critical task sequences. It ensured that all operators were included in the analysis through the development and subsequent linking of sub-networks (developed from individual goals or grouping of related goals). IPME proved to be an extremely effective tool for combining the developed sub-networks to create the baseline networks, however the effort involved to accomplish this was significant. The initial development of the networks in IPME required using the input interface in the IPME tool itself, which is cumbersome, or transferring the data from a tool with a more user-friendly interface. When it was decided to use a transfer method (from TaskArchitect® via scripting) several bugs were discovered in the IPME application that caused the work to be corrupted once it was in IPME. The corruption was subtle and not discovered until many sub-network files were loaded in IPME and run together. The discovery at this point in the operation caused a great amount of time to be wasted in the file preparation process and delayed the analysis portion of the project. This software deficiency was rectified by DRDC – Toronto.

The tables below list the goals and sub-goals that were utilized as part of each baseline network representing a critical task sequence. Goal Number and Title, from the goal hierarchy, indicate the goals active in each critical task sequence. The primary operator is also listed for reference.

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Table 6-1 Watch Turnover

Goal #	Goal Title	Allocated Operator
3	...ship is ready to undertake critical operational taskings - 1st degree of readiness (ACTION STATIONS)	CO
3.1	... explanatory Action Station briefings are conducted	ORO
3.1.1	... Ops Room is briefed in response to Action Stations	ORO
3.1.2	... AWWD team is briefed in response to Action Stations	SWC
3.1.3	... ASWD team is briefed in response to Action Stations	ASWC
3.1.4	... alert crew is briefed in response to Action Stations	SAC
3.1.5	... OOW is briefed in response to Action Stations	ORO
3.1.7	... ship's company is briefed in response to Action Stations	ORO
3.2	...combat sub-teams standing to air, surface and sub surface	ORO
3.2.1	...SAWS team are standing to	SWC
3.2.2	...UWW team is standing to	ASWC

Table 6-2 Resolve

Goal #	Goal Title	Allocated Operator
5	...an optimal level of Situational Awareness is being maintained	CO
5.1	...an accurate RMP is created and maintained	ORO
5.1.1	...an accurate tactical air picture is compiled	SWC
5.1.1.1	...co-ordination of/with other units is effective	SWC
5.1.1.1.1	...LINK management occurs to support air picture compilation	ARRO
5.1.1.1.2	...AAW communication net is effectively monitored/guarded	SWC
5.1.1.3	...effective air track management	ARRO
5.1.1.3.1	...proper identification of new air contacts	ARRO
5.1.1.3.1.2	...urgent application of IDCRIT to air contacts using RESOLVE	SWC
5.1.1.3.1.2.1	...reporting of geophysical details and air rules occurs(ARRO)	ARRO
5.1.1.3.1.2.2	...ESM is reported(EWS)	EWS
5.1.1.3.1.2.3	...SSD overlays are confirmed accurate(IMD)	IMD
5.1.1.6	...information is gathered through the use of warnings	ORO
5.1.1.6.1	...tactical procedures are known/adhered to	SAC

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Table 6-2 Resolve

Goal #	Goal Title	Allocated Operator
5.1.1.6.2	...appropriate frequencies are utilized	SAC

Table 6-3 Harpoon Engagement

Goal #	Goal Title	Allocated Operator
6	...ongoing operational tasks are being actioned effectively	CO
6.1	...assigned warfare duties are properly executed - SCC (Sea Combat Commander)	Warfare Officer
6.1.2.3	...effective execution of SAG procedures	Warfare Officer
6.1.2.3.1	...designation of target	Warfare Officer
6.1.2.3.2	...designation of firing units (**FU**s) and salvo size for each	Warfare Officer
6.1.2.3.3	...designation of the OTC/SCC/SAG Commander	Warfare Officer
6.1.2.3.4	...designation of TRU and reporting method	Warfare Officer
6.1.2.3.5	...designation of circuits to be employed	Warfare Officer
6.1.2.3.6	...designation of time-on-top	Warfare Officer
6.1.2.3.7	...issuance of PLAN GREYHOUND	Warfare Officer
6.1.2.3.8	...confirmation of receipt of order by SAG participants	Warfare Officer
6.1.2.3.9	...correct time check / grid lock is executed	Warfare Officer
6.1.2.3.10	...correct action by SAG participants	Warfare Officer
6.5	...threat is effectively countered	CO
6.5.2	...surface threat is effectively countered	ORO
6.5.2.2	...TG Surface Warfare is effectively executed	SWC
6.5.2.2.4	...the effective execution of SAG tactics (Greyhound, Grouse, Snipe)	SWC
6.5.2.2.4.1	...effective use of 3rd party targeting information	SWC
6.5.2.2.4.2	...pre-firing considerations are made	SWC
6.5.2.2.4.2.1	...flight corridor check is complete	SWC
6.5.2.2.4.2.2	...background shipping check is complete	SWC
6.5.2.2.4.2.3	...booster drop zone is clear	SWC
6.5.2.2.4.3	...appropriate salvo size is chosen	SWC
6.5.2.2.4.4	...effective TOT consideration are made	SWC
6.5.2.2.4.5	...unit reports ready for SAG action	SWC
6.5.2.2.4.6	...effective post firing reactions	SWC
6.5.2.2.4.6.1	...an effective post firing manoeuvre	SWC
6.5.2.2.4.6.2	...reckon track is generated appropriately	ARRO
6.5.2.3	...all reports supporting surface warfare are made	ORO

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Table 6-3 Harpoon Engagement

Goal #	Goal Title	Allocated Operator
5	...an optimal level of Situational Awareness is being maintained	CO
5.1	...an accurate RMP is created and maintained	ORO
5.1.2	...an accurate tactical surface picture is compiled	SWC
5.1.2.1	...coordination with/of other units is effective	TS
5.1.2.2.3	...SSD overlays are implemented	SWC
5.1.2.5	...effective use of ESM to compile a tactical surface picture	EWS

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Table 6-4 Anti-Ship Missile Defence

Goal #	Goal Title	Allocated Operator
6	...ongoing operational tasks are being actioned effectively	CO
6.5	...threat is effectively countered	CO
6.5.1	...air threat is effectively countered	ORO
6.5.1.1	...self defence is understood and executed	SWC
6.5.1.1.2	...appropriate ASMD is conducted - ZIPPO reactions	SWC
6.5.1.1.2.2	...effective hard kill is achieved	SWC
6.5.1.1.2.2.1	...VLSS/VLESSM engagement is conducted effectively	SWC
6.5.1.1.2.2.1.1	...appropriate salvo size is chosen	SWC
6.5.1.1.2.2.1.2	...appropriate salvo spacing is chosen	SWC
6.5.1.1.2.2.1.3	...appropriate range is used	SWC
6.5.1.1.2.2.2	...57mm engagement is conducted effectively	SWC
6.5.1.1.2.2.2.1	...appropriate salvo size is chosen	SWC
6.5.1.1.2.2.2.2	...appropriate range is used	SWC
6.5.1.1.2.2.3	...CIWS engagement is conducted effectively	SWC
6.5.1.1.2.3	...effective soft kill is achieved	EWS
6.5.1.1.2.3.1	...effective deployment of distraction chaff occurs	EWS
6.5.1.1.2.3.2	...effective deployment of seduction chaff / IR occurs	EWS
6.5.1.1.2.3.3	...jamming is appropriately utilized	EWS
6.5.1.1.2.3.4	...the ship is effectively manoeuvred for softkill	EWS
6.5.2.2.4.6.2	...reckon track is generated appropriately	ARRO

Table 6-5 Torpedo Countermeasure

Goal #	Goal Title	Allocated Operator
6	...ongoing operational tasks are being actioned effectively	CO
6.1.2.4	...effective execution of SAU procedures	Warfare Officer
6.1.2.4.1	...designation of target	Warfare Officer
6.1.2.4.2	...designation of SAU units & Cdr	Warfare Officer
6.1.2.4.3	...designation of circuits to be employed	Warfare Officer
6.1.2.4.4	...issuance of SAU plan	Warfare Officer
6.1.2.4.5	...SAU procedures are monitored	Warfare Officer
6.5	...threat is effectively countered	CO
6.5.3	...subsurface threat is effectively countered	ORO
6.5.3.1	...self defence is understood and executed	ASWC
6.5.3.1.1	...appropriate warnings are issued	ASWC

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Table 6-5 Torpedo Countermeasure

Goal #	Goal Title	Allocated Operator
6.5.3.1.2	...ASW preplans are effectively executed	ASWC
6.5.3.1.3	...TCMs are appropriately conducted	ASWC
6.5.3.1.3.1	...appropriate course/helm and speed are chosen	ASWC
6.5.3.1.3.2	...NIXIE is employed appropriately	ASWC
6.5.3.1.3.3	...NAEBS and/or sonobuoys are effectively utilized	ASWC
6.5.3.1.4	...Mk46 engagement is conducted effectively	ASWC
6.5.3.2	...subsurface threat is countered offensively	ASWC
6.5.3.2.1.1	...effective manoeuvring to maintain contact and prosecute	ASWC
6.5.3.2.1.2	...torpedo engagement is conducted effectively	ASWC
6.5.3.2.1.2.1	...correct settings applied	ASWC
6.5.3.2.1.2.2	...ownship torpedo is launched	ASWC
6.5.3.2.2	...SAU procedures effectively executed	ASWC
6.5.3.2.2.1	...attack plans are effectively executed	ASWC
6.5.3.2.2.1.1	...assigned sectors/station maintained	ASWC
6.5.3.2.2.1.2	...torpedo engagement is conducted effectively	ASWC
6.5.3.2.2.1.2.1	...correct settings applied	ASWC
6.5.3.2.2.1.2.2	...ownship torpedo is launched	ASWC
6.5.3.2.2.2	...search plans effectively executed	ASWC
6.5.3.2.2.2.1	...assigned sectors/station maintained	ASWC
6.5.3.2.2.2.2	...actions are coordinated with other units	ASWC
6.5.3.2.2.3	...air assets are employed effectively	ASWC
6.5.3.2.2.3.1	...helo is effectively employed to support SAU	SAC
5.1.3	...an accurate subsurface picture is compiled	ASWC
5.1.3.1	...coordination of/with other units	ASWC
5.1.3.2.3	...SSD overlays are implemented	ASWC
5.1.3.2.3.1	...furthest oncircles are accurately plotted and maintained	ASPO
6.2.2.1.1	...helo is at appropriate alert state / airborne	ORO

6.2.2 Summary Files

The workload to prepare the IPME networks and ensure they ran was extensive. Numerous scripts had to be written to increase the speed of moving data from a suitable collection medium (in the case of this project TaskArchitect® was used) into IPME. The IPME application could benefit from additional features that obviate the requirement to ‘customize’ the application to accommodate the insertion of data for complex networks.

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The IPME IP/PCT scheduling effects were unable to deal with the complexities and nuances of task interactions for every combined/multi-task run. IPME IP/PCT uses a scheduler as the logic engine to determine which tasks are active in any operator's queue at any time. The IP/PCT scheduler is invoked whenever new tasks arrive or existing tasks finish. When a new task is started the scheduler determines how the task will fit into the queues. When a task is completed the scheduler analyses the queues to determine which tasks need to be active. The scheduler uses a set of 8 specific rules, listed in the IPME user manual. The scheduler takes into account an active queue, a temporary queue and a short-term memory queue. The scheduling effects of IPME in IP/PCT mode require some modification to support a complex environment such as the operations room. For example, a typical block report only requires approximately 30% of the auditory attention of the recipient due to the structured nature of the report and the use of verbiage to separate vital pieces of like information. An example of a block report follows:

> During the ASMD task sequence the hard kill goal is supported by the sub-goal "...VLSS/VLESSM engagement is conducted effectively". This goal requires the FCO responsible for STIR 'A' will make the following report, "'A' system, target air *missile*, range *18,000 yards*, bearing *045* degrees, *closing*" as soon as the fire control system locks onto the inbound missile. For demonstration of the amount of verbiage in a block report only the information in italics is critical, the remainder is used for separation of information - enhancing intelligibility.

The addition of a task that captures the transmission and receipt of 'block reports' is required. Neither IPME version 3.0.25 nor IPME/HAWK were efficient tools for analysis on the scale conducted during this project.

6.2.3 Single Runs – Baseline Networks

With single runs, Table 6-6 to Table 6-10 indicate the number of times the IPME's IP/PCT task scheduler shed, delayed or interrupted a task – listed by operator.

Table 6-6 Watch Close-Up

Operator	# Shed	# Delayed	# Interrupted	Total
ORO	2	6	4	12
SWC	2	1	2	5
EWS	2	1	2	5
ARRO	2	0	2	4
ASPO	1	0	0	1

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Table 6-7 Resolve

Operator	# Shed	# Delayed	# Interrupted	Total
SWC	5	2	1	8
EWS	4	3	4	11
ORS	1	5	2	8
ARRO	1	3	4	8
IMD	1	2	2	5

Table 6-8 ASMD

Operator	# Shed	# Delayed	# Interrupted	Total
CO	10	3	2	15
ORO	21	19	13	53
SWC	21	25	15	61
EWS	21	18	15	54
ORS	10	8	6	24
TS	1	2	0	3
ARRO	12	16	14	42
ASPO	1	0	0	1
SAC	1	0	0	1

Table 6-9 Harpoon

Operator	# Shed	# Delayed	# Interrupted	Total
CO	0	0	1	1
Warfare Officer	0	16	1	17
ORO	0	13	4	17
SWC	0	2	0	2
ASWC	0	0	1	1
IMD	0	0	1	1
ORS	0	5	5	10
EWS	0	0	1	1
TS	0	8	5	13
ARRO	0	0	1	1
ASPO	0	0	1	1
SAC	0	0	1	1

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Table 6-10 ASW

Operator	# Shed	# Delayed	# Interrupted	Total
CO	53	63	56	172
Warfare Officer	9	14	11	34
ORO	18	44	38	100
ASWC	63	70	49	182
ORS	12	5	8	25
ASPO	37	15	16	68
SAC	15	5	5	25

6.2.4 Multi-Threat

Table 6-11 describes the combinations of task networks employed to investigate multi-threat scenarios, showing the operator targeted, and the lag required between the triggering of the task networks to maximize the operator's workload.

Table 6-11 Combined Networks

Combination	Targeted Operator	Timing Interval
Watch Close-up & Resolve	ORO	550 second delay to Resolve
	SWC	500 second delay to Resolve
	EWS	620 second delay to Resolve
	ORS	220 second delay to Resolve
	ARRO	550 second delay to Resolve
ASMD & Resolve	ORO	No delay – start simultaneously
	SWC	No delay – start simultaneously
	EWS	100 second delay to Resolve
	ORS	No delay – start simultaneously
	ARRO	80 second delay to Resolve
Harpoon & Resolve	CO	100 second delay to Resolve
	Warfare Officer	100 second delay to Resolve
	ORO	100 second delay to Resolve
	SWC	100 second delay to Resolve
	ORS	100 second delay to Resolve
	TS	100 second delay to Resolve
ASW & Resolve	CO	550 second delay to Resolve

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Table 6-11 Combined Networks

Combination	Targeted Operator	Timing Interval
	ORO	550 second delay to Resolve
	ORS	550 second delay to Resolve
Harpoon & ASMD	CO	325 second delay to ASMD
	ORO	325 second delay to ASMD
	SWC	325 second delay to ASMD
	ORS	325 second delay to ASMD
ASW & ASMD	CO	525 second delay to ASMD
	ORO	525 second delay to ASMD
	ORS	525 second delay to ASMD
ASW & Harpoon	CO	No delay – start simultaneously
	Warfare Officer	No delay – start simultaneously
	ORO	No delay – start simultaneously
	ORS	No delay – start simultaneously
ASW, Harpoon, & ASMD	All operators	Start ASW & Harpoon together – 325 second delay to ASMD

The longer network is listed first with the timing interval referring to the triggered start time of the second or third network.

The combined networks were developed in order to stress specific operator positions. The results are portrayed textually in the summary files and graphically in MTP plots.

It is apparent that a number of things happen when an operator is overloaded. The number of tasks shed, delayed or interrupted increases, the instantaneous time pressure increases and the length of delays is increased. Table 6-12 shows the marked changes in these three parameters when the baseline networks representing the fine critical task sequences listed in Subsection 2.4.1 are combined.

Table 6-12 Full Multi-Threat Simulation Results

Operator	# Shed	# Delayed	# Interrupted	Total
CO	86	84	56	226
Warfare Officer	36	62	26	124
ORO	106	114	63	283
SWC	48	35	22	105

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Table 6-12 Full Multi-Threat Simulation Results

Operator	# Shed	# Delayed	# Interrupted	Total
ASWC	51	65	44	160
IMD	0	0	0	0
ORS	30	28	30	88
EWS	16	13	8	37
TS	8	28	27	63
ARRO	14	15	12	41
ASPO	35	23	15	73
SAC	17	6	7	30

The torpedo counter measure network was the longest and most complicated, therefore the tasks and operators affected in the full multi-threat environment are skewed to the Anti-Submarine Warfare regime.

6.2.5 IPME Output

The baseline networks, once developed, debugged and approved, were easily combined in IPME to create a simulation of a true multi-threat environment. The varying of timings when combining networks also provided useful information. The combining of sub-networks , to create each of the five baseline networks, was managed by IPME in an extremely efficient and effective manner.

Notwithstanding the above, the combined IPME networks could not be visually generated as an output in the form of an OSD, thereby reducing the SMEs' effectiveness in reviewing the results. This was particularly apparent when reviewing combined networks such as ASMD with an 80 or 100 second delay to a resolve being initiated. The SMEs voiced a desire to see which tasks were in conflict in the form of an OSD not just from the .IPR summary output files. It is highly desirable that IPME be capable of producing OSDs representative of the entire network being analyzed to assist operators in the workload analysis and validation process.

The IPME output was somewhat limited, it took several scripts to combine the output from the 40 runs into a useful format. Given the extensive effort to generate and run the networks, it would be difficult to make a case that the output from IPME as it currently exists provides an efficient means of workload analysis.

The theory of 'Time Pressure' was difficult for the SMEs to understand. Using the information provided by IPME and Reference 4 the SMEs were still confused with workload or cognitive effort. There was a requirement to remind the SMEs that the majority of the time pressures were caused by tasks conflicting in the auditory channel and that typically an operator

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receiving a transmission would either say ‘wait I’m external’ or the operator making the report would know that recipient would be available in short order and wait.

This situation was exacerbated by the presentation of the Mean Time Pressure data generated by IPME, which was somewhat deceptive. The calculations used in IPME did not provide a normalizing function to present the data on an easily understood scale, i.e. as a percentage of available time. Due to the nature of the calculation of MTP there were occasions when a single Instantaneous Time Pressure (**ITP**) skewed the output, causing the SMEs who were reviewing the plots to focus on a single large number, and not the occasions when the MTP was greater than one for an extended period of time. The Mean Time Pressure plots need to be modified to prevent spiking caused by a single occurrence of an extremely large Instantaneous Time Pressure.

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SECTION SEVEN – CRITICAL ACTIVITIES

7.1 RESULTS

The results for the critical activities analysis are contained in Annex J. No single operator or group of operators had a monopoly on critical activities; the percentage of an individual's goals that were considered critical was distributed evenly across all operators. The CO did have the highest percentage – 91% of all CO goals were considered critical, however the next two operators by percentage were the ASPO and EWS respectively. There was also an even distribution by goal level – the first through lowest levels had a relatively equal ratio of goals considered critical or non-critical. Given this the review of goals for criticality cannot be streamlined by considering only a specific group of operators or level of goals. Each goal must be given the same amount of consideration and analysis.

Table 7-1 indicates the number of activities determined as critical.

Table 7-1 Number of Critical Activities

Rating Criteria	Value	Number	Cumulative Number
Safety	7	71	71
	6	0	71
	5	3	74
	4	1	75*
	3	1	76
	2	0	76
	1	486	562
Mission Effectiveness	7	40	40
	6	87	127
	5	148	275*
	4	118	393
	3	117	510
	2	42	552
	1	10	562
Human Performance Capability	7	0	0
	6	50	50
	5	78	128
	4	133	261*
	3	212	473
	2	89	562
	1	0	562

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* The targeted number of activities for provision of solutions.

Using this selection criterion, 355 or 63% of the activities were considered for proposed solutions.

The majority of proposed solutions put forth by the SMEs recommended automating displays and data entry. The integration of tactical and command decision aids was also highly recommended.

7.2 DISCUSSION

In any Human Factors analysis the rating of activities is a common task. Traditionally tasks are rated considering such factors are vision, auditory, psychomotor, cognitive loads while their criticality is rated using safety, mission effectiveness, efficiency, system reliability and cost [References 6 and 7]. The tasks themselves stand-alone, are entities onto themselves and therefore are relatively simple to rate. The rating of goals from the HGA was a departure from this process. Because of the goal hierarchy all but the lowest level goals require completion of subordinate goals, in order to complete the closed feedback loop discussed earlier, the criticality of a goal required knowledge and understanding of the sub-goals. The domain experts and SMEs charged with providing ratings initially found it difficult, as a number of the higher-level goals are very broad in scope, such as managing resource effectively, which created much debate in identifying a criticality rating. The abilities and performance of the entire team had to be taken into account before providing a score.

The hierarchical nature and requirement for subordinate goals to be successfully completed for the completion of the goal being analyzed caused the domain experts to consider if the operator was responsible for the review of sub-goals. If so this increased the human performance capabilities as the operator would be drawn into a supervisor role as well as operator to complete the goal.

Due to the nature of their business, the operations room operators do not have a large number of goals that directly affect the safety of their shipmates, other friendly units or neutrals, relative to the total number of goals. However, the initial assigned ratings indicated differently because some SMEs were considering poor response to enemy action as a safety hazard to the crew. It was determined that an instance of ineffective goal accomplishment that places the entire ship in hazard due to enemy action should be considered a mission effectiveness issue, not a safety issue. Once this criteria was evenly applied, the domain experts and SMEs were consistent with their application of safety ratings.

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SECTION EIGHT – CONCLUSIONS AND RECOMMENDATIONS

8.1 GENERAL

The conclusions are grouped by area of analysis. Each conclusion is associated with a discussion point and the relevant subsection is noted.

8.2 ENVIRONMENTAL ANALYSIS

The environmental analysis that resulted in the three top-level goals and each of those goal's first-level sub-goals are timeless. Besides slight terminology differences, these goals have been consistent across navies and time, providing strong assurance that the HGA at the top and first levels is fully reflective of the true environment (Subsection 3.2). The lower-level goals are more closely related to the type of ship the operations room is supporting or the specific role the ship is designed to support. As an example a ship such as the USN Ticonderoga Class Cruiser is designed for anti-air warfare is not generally tasked with the ASW missions expected of the Halifax Class Frigate, therefore the goals, in the Ticonderoga Class, related to AAW will be expanded whereas the ASW goals would be reduced.

8.3 HGA ANALYSIS

The goal hierarchy for the three roles (top-level goals) down to the second-level goals were similar enough that the decomposition of the most complex top-level goal was sufficient to define the system. Decomposing the other two roles would not have generated any more insights than already gained from the military role decomposition. The structure of the HGA allowed for a side-by-side review and the confidence that this decision was not going to reduce the quality of data generated from the project (Subsection 4.1).

Goal allocation was found to be generally commensurate with responsibility and experience (Subsection 4.3.1).

The Sonar Control Supervisor position should have been analyzed (Subsection 4.3.1).

A 'bottom-up' review of the goal decomposition should be conducted to validate the top-down process (Subsection 4.3.1).

The HGA process should be considered for future human engineering analysis requirements (Section 4.3.2).

The HGA provides a strong tool to be used to investigate proposed changes to the Operations Room (Subsection 4.3.2).

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8.4 PCT ANALYSIS

The conclusions in this section cover the PCT data, information flow and potential instabilities analyses. Overall the PCT output was applicable because the activities being analyzed were linked by a completely decomposed HGA. The learning curve was substantial for the Human Factors Analysts to grasp the full utility of the combined HGA and PCT analysis methodology. Having understood the paradigm, any follow-on analysis could be easily accomplished using the methods employed in this project.

8.4.1 PCT Data

The resolution of internal, external, and controlled variables was difficult to achieve (Subsection 5.2.2).

The PCT data, while time consuming to collect and difficult to review with SMEs, proved to be extremely useful in subsequent analyses processes (Subsection 5.2.2).

When planning to conduct an HGA in the future, the domain experts and/or SMEs will require additional time to comprehend the concepts before proceeding with collecting PCT data (Subsection 5.2.2).

The ‘demand’ on the operators is only captured during the task network analyses, which is an incomplete representation of the goal hierarchy and therefore does not capture all potential instabilities. In a complex matrix type organization operators that directly support the completion of a goal should be included in the potential instability analysis (Subsection 5.2.2).

8.4.2 Potential Instabilities

Overall, the number of potential instabilities was found to be low for a system as large and complex as the operations room of a frigate (Subsection 5.3.2).

The use of IP/PCT to develop a list of potential instabilities was proven to be a sound analytical tool (Subsection 5.3.2).

During the design of future complex naval systems, the allocation of access to or authority for equipment or sensor controls should be restricted to the owner of the goal responsible for the relevant system settings (Subsection 5.3.2).

The SSD should accommodate information providing operators with ready access to sensor configurations and the goals that the sensors are currently supporting (Subsection 5.3.2).

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The use of shared situation awareness displays could help to mitigate instabilities caused by lack of team awareness of rapidly changing and conflicting priorities or goals (Section 5.3.2).

External variables should be identified by their most basic components to prevent the identification of invalid potential instabilities (see Subsection 5.3.2).

Overall the potential instability analysis was very sound, illustrating that the Navy has adapted its doctrine and procedures in the complex environment of the operations room to prevent many potential problems (Subsection 5.3.2).

8.4.3 Information Flow

The three-dimensional, graphical representation of the upward information flow was more effective than the traditional tabular form of a link analysis (Subsection 5.4.2).

The absence of several of the operators from the HGA / PCT analysis reduced the overall effectiveness of the upward information flow analysis (Subsection 5.4.2).

The vast majority of verbal reports could be replaced with some type of visual indication (Subsection 5.4.22).

The role of the ORS as a back-up (secondary allocation) for several goals is currently satisfied through visual inspection – to anchor the ORS at a console would require a new method of oversight (Subsection 5.4.2).

The relationship between the IMD and the remainder of the Operations Room still needs to be fleshed out. Interaction with the Directors was not considered (Subsection 5.4.2).

The volume of information flow between operators and the Warfare Officer is dependant on the support needed and provided by the ship's team or by staff, if embarked. This is difficult to model accurately as each ship and squadron staffs have unique relationships (Subsection 5.4.2).

While upward information flow was good input to the design of the operator workstation, lateral communications and downward communications should be added in order to provide a complete link analysis (Subsection 5.4.2).

8.5 TASK NETWORKS

The HGA supported top-down approach to task network analysis and ensured complete development of the critical task sequences. It ensured that all operators were included

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in the analysis through the development and subsequent linking of sub-networks to create the five baseline networks (Subsection 6.2.1).

IPME proved to be an extremely effective tool for combining the baseline networks, once they were developed in order to facilitate the analyses of the operations room in a multi-threat environment (Subsection 6.2.1).

The IPME application could benefit from additional features that obviate the requirement to 'customize' the application to accommodate the insertion of data for complex networks (Subsection 6.2.2).

Neither IPME version 3.0.25 nor IPME/HAWK were efficient tools for insertion of the data that was required for analyses on the scale conducted during this project (Subsection 6.2.2). HAWK was very labour-intensive as an input interface and IPME was limited in acceptable output file size.

The combining of sub-networks, representing sub-goals in support of a single critical task sequence, was managed by IPME in an extremely efficient and effective manner. (Subsection 6.2.5).

It is highly desirable that IPME be capable of producing OSDs representative of the entire network being analyzed to assist operators in the workload analysis and validation process (Subsection 6.2.5).

The number of the communication tasks being shed, delayed, or interrupted during each run evidenced the presence of conduit clashes (Subsection 2.3.2).

The Mean Time Pressure diagrams need to be modified to prevent spiking caused by a single occurrence of an extremely large Instantaneous Time Pressure (Subsection 6.2.5).

8.6 CRITICAL ACTIVITIES

The hierarchical goal structure requires subordinate goals to be considered when assigning the criticality ratings. Criticality is affected by how well the operator can work around the incompletion of subordinate goals (Subsection 7.2).

The majority of proposed solutions recommended automating displays and data entry. The integration of tactical and command decision aids was also highly recommended (Subsection 7.2).

The results of the initial PCT analysis need to be compared to the critical activity analysis to ensure goal complexities are not inflated creating an excess of critical activities (Subsection 7.2). The PCT data considered were the input and output interfaces and the required knowledge states.

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Goal criticality is not related to operator or goal level; each goal must be given the same amount of analysis when considering criticality (Subsection 7.1).

8.7 OVERALL

The analysis methodologies were found to be applicable to the complexities of the Halifax Class Frigate's operations room and would therefore be applicable to similar system being designed or reviewed. Given the specialized knowledge required by the analysts and the high level of effort required to complete the analysis to gain a realistic level of return HGA would best to applied to systems with multiple operators and broad capabilities. The goal hierarchy as the starting point is extremely scalable. The analysis could be extended to cover new positions or new goals by a relatively simple modification to the existing analysis.

The data that was created has future applicability. The format in which the data is presented and the tools used to collect the information lend themselves to reuse for future projects. Future analysis of additional goals, operators, or systems could be easily added to the existing results, and the impact with respect to upward information flow, potential instabilities, and / or critical activities could be easily determined. This could allow an easy transition, for example, to analysis of the operations room functions for a new ship design.

The database created was useful for the HMCCS Project. The results of the upward information flow, potential instability, critical activities and task networking were directly applied to the redesign of the operation workstations, operator interface and operations room layout. The application of potential instabilities analysis results – the requirement to restrict access to system configuration functionality – is directly applicable to HMCCS design. The ability to add goals to the system without adding operators or to add operators without adding goals allows the analysts to examine the change in information flow between operators and the potential of overwhelming or reducing the workload on individuals.

The change in scope of goals, if additional sub-goals are added, may result in the HPC rating reaching seven, making the goal untenable. A good example of this analysis would be the addition of a land attack mission to the current scenario. This would likely overwhelm the SWC, as they would be unable to maintain a recognized air picture, defend the ship against a missile attack and conduct offensive operations. The analysis methodology would, however, enable an effective options analysis to be conducted to determine means to re-allocate functions to an effective configuration to achieve the system goals.

8.8 HGA / PCT TO MISSION FUNCTION TASK ANALYSIS COMPARISON

A comparison between the HGA / PCT methodology and the traditional Mission Function Task Analysis methodology was conducted. This was reported on in detail in the paper titled Applied Comparison between Hierarchical Goal Analysis and Mission, Function and Task

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Analysis. This paper will be presented at the Human Factors and Ergonomics Society 50th Annual Meeting, October 16-20, 2006.

8.9 RECOMMENDATIONS

There are a number of recommendations that have come out of this project. The majority are related to HGA and IPME as they applied directly to this project, however there are a couple of recommendations that relate to future work, these are presented at the end of this section.

The controlled variable should be included in Table 2 of Reference 4, separate from the internal and external variables that are already defined.

To identify a complete set of information requirements in a complex environment such as an operations room, future analyses should include lateral and downward information flow to augment the upward information flow that is conceived during the HGA process.

IPME, as a complete HFE software solution, should be improved to enable OSDs to be produced as an output. OSDs are invaluable when reviewing analysis with SMEs and should be readily available from IPME.

IPME requires a better presentation of Mean Time Pressure to remove spikes caused by a single occurrence of an extremely large Instantaneous Time Pressure. The current requirement of transferring the output files to graphing software is time consuming and can be error prone.

IPME requires the addition of a task type that captures the transmission and receipt of 'block reports'. In an environment such as an operations room a typical operator can hear more than one report simultaneously. The IP/PCT scheduler be adjusted and the resultant output analyzed to determine the effect on tasks shed, delayed and interrupted given the true abilities of the operators.

The IPME IP/PCT mode user manual requires a more effective method of describing Instantaneous Time Pressure in order for operators to better assess the output. The literature that

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accompanies the software requires more examples to allow a HFE not familiar with IPME to be able to conduct analysis and apply the results to the real world.

PCT data must be reviewed prior to finalising the critical activity analysis to ensure the requirements of the goal/activity were not inflated during this analysis process. Both the domain experts and SMEs found it invaluable to be able to refer to the PCT data while compiling and analysing the goals with respect to criticality.

The HGA as a Human Factors Engineering tool provides a very complete structure for capturing the requirements of complex systems. Given that it should be considered as a technique used in the project definition phases of large projects.

Given that the potential instability analysis was a very sound tool, prior to the addition of any new equipment or control panel into the operations room, a potential instability analysis should be conducted.

DUE TO THE EQUIPMENT-INDEPENDENT NATURE OF THE HGA, ESPECIALLY AT THE HIGHER GOAL LEVELS, IT WOULD BE A SUITABLE TOOL FOR ANALYSES OF FUTURE MULTI-PURPOSE SHIPS. IF THE OPERATIONS ROOM'S GOALS ARE HELD THEN IT CAN BE USED TO LOOK AT ISSUES SURROUNDING REDUCED MANNING AND AUTOMATION OF PROCESSES.

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ANNEX A – GLOSSARY OF TERMS AND ACRONYMS

AAWC. Anti-Air Warfare Controller
ARRO. Air Raid Reporting Operator. Air Raid Reporting Operator
ASPO. Anti-Submarine Plotting Operator. Anti-Submarine Plotting Officer
ASW. Anti-Submarine Warfare
ASWC. Assistant Sensor Weapons Controller. Assistant Sensor Weapons Controller
AWWD. Above Water Warfare Director
C2. Command and Control
CANEWS. Canadian Electronic Warfare System
CBM. Confidence Building Measure
CCS. Command and Control System
CF. Canadian Forces
CIMIC. Civil-Military Cooperation
CIWS. Close In Weapons System
CMS. Chief of the Maritime Staff
CO. Commanding Officer. Commanding Officer
CTA. Cognitive Task Analysis
DND. Department of National Defence
DO. Divisional Officer
DPG. Defence Planning Guidance
DRDC. Defence Research and Development Canada
EWS. Electronic Warfare Supervisor. Electronic Warfare Supervisor
. firing unit.
HA. Humanitarian Assistance
HFE. Human Factors Engineering
HGA. Hierarchical Goal Analysis. Hierarchical Goal Analysis. Hierarchical Goal Analysis
HGDD. Hierarchical Goal Decomposition Diagram
HMCCS. Halifax Modernization Command and Control System. HALIFAX Modernized Command and Control System
HPC. Human Performance Capability
IMD. Information Management Director. Information Management Director
IP. Information Processing
IPME. Integrated Performance Modelling Environment. Integrated Performance Modeling Environment. Integrated Performance Modeling Environment
IPR. Information Processing Report
IR. Infrared
ISM. Information Systems Manager
ITP. Instantaneous Time Pressure
LAAWC. Local Anti-Air Warfare Controller

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MIO. Maritime Interdiction Operation
MSDF. Multi-Source Data Fusion
MTP. Mean Time Pressures
NAV COMM. Naval Communicator
NCI OP. Naval Combat Information Operator
NCPM. Naval Combat Procedural Manual
NDHQ. National Defence Headquarters
NEO. Non-combatant Evacuation Operation
NES OP. Naval Electronic Sensor Operator
OGD. Other Government Department
OOW. Officer Of the Watch
ORO. Operations Room Officer. Operations Room Officer
ORS. Operations Room Supervisor. Operations Room Supervisor
OSD. Operational Sequence Diagram. Operational Sequence Diagram
PCT. Perceptual Control Theory. Perceptual Control Theory
PSO. Peace Support Operation
RAMSES. Reprogrammable Advanced Multi-Mode Shipborne ECM System
RMP. Recognized Maritime Picture
SAC. Shipborne Aircraft Controller. Shipborne Aircraft Controller
SAM. Surface-to-Air Missile
SAR. Search and Rescue
SAWS. Surface and Air Weapons System
SCS. SONAR Control Supervisor
SITREP. SITuation REPort
SME. Subject Matter Expert. Subject Matter Expert
SON OP. Sonar Operator
SOP. Standard Operating Procedure
SSD. Standard Shipboard Display
SSM. Surface-to-Surface Missile
STIR. Separate Track and Illumination RADAR
SWC. Sensor Weapons Controller. Sensor Weapons Controller
TD. Technology Demonstrator
TS. Track Supervisor. Track Supervisor
UN. United Nations
UWW. Under Water Warfare
UWWD. Under Water Warfare Director
VACP. Visual, Auditory, Cognitive, and Psychomotor

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ANNEX B – HFX FRIGATE MISSION DESCRIPTION

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ANNEX C – HIERARCHICAL GOAL ANALYSIS

Annex C contains the completed HGA in accordance with Table 1 (illustrated below) from Reference [4]. The goals are grouped by Level 1 Goals.

TABLE 1: A hierarchical goal analysis 4 levels deep.

	Goal/Objective (Level N)	Influenced ("Controlled") Variable	Assignment (role/ID)		Sub-goal/sub-objectives (Level N-1)
Level 1					
1	...the conduct of the mission	Mission occurring	Mission Commander	1.1	...aircraft being pre-flighted
				1.2	...aircraft taking-off and departing
				1 3	.aircraft ingressing to the mission area
				1.4	.. aircraft conducting mission segment
				1 5	*...abnormal handled*
				1.6	*...retasking completed*
				1.7	etc.
Level 2					
1.2	...aircraft taking off and departing	Flight status	Pilot Flying	1 2 1	...aircraft is prepared for TO
				1.2.2	...the aircraft rolling on the runway
				1.2.3	the aircraft intersecting the outbound track and climbing to cleared altitude
Level 3					
1 2.1	...aircraft is prepared for take off	Preparedness for take off	Aircraft Commander	1.2.1.1	...the TO clearance has been received and understood
				1.2.1.2	...the pre-TO checklist has been completed
				1.2.1.3	. the departure has been planned
				1.2.1.4	...the TO brief has been prepared
				1.2 1.5	the TO brief has been delivered and confirmed
				1.2.1.6	...the aircraft is positioned for TO
				1.2 1.7	...etc.
Level 4					
1.2 1.1	. the TO clearance has been received and understood	Clearance status	Aircraft Commander		No lower levels in the analysis
1.2.1.2	...the pre-TO checklist has been completed	Checklist status	Aircraft Commander		No lower levels in the analysis

Table 1 from Hendy, K.C., et al., Analyzing the cognitive system from a perceptual control theory point of view, in Cognitive Systems Engineering in Military Aviation Environments: Avoiding Cogminutia Fragmentosa!, M.D. McNeese and M.A. Vidulich, Editors. 2002, Wright-Patterson AFB: Dayton, OH. p. 201-250.

Annex C Table of Contents

Level 1 Goal	Page #
...current mission is received and acknowledged	C.2
...predeployment preps are complete	C.3
...ship is ready to undertake critical operational taskings - 1st degree of readiness (ACTION STATIONS)	C.5
...combat organization and resources are managed effectively	C.8
...an optimal level of Situational Awareness is being maintained	C.10

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...ongoing operational tasks are being actioned effectively	C.14
...mission follow-up action is completed	C.20

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ANNEX D – IP/PCT TEMPLATES

Annex D contains the completed IP/PCT Templates in accordance with Table 5 (illustrated below) from Reference [4]. The templates are a suitable way of displaying the cognitive and perceptual components of individual goals. The Annex is ordered by goal corresponding to those listed in Annex C. There are occasions when the complexity of the goal required two pages to completely capture the attributes describing the goal.

TABLE 5: An illustration of a completed template for an activity involving both internal and external variables.

CO PILOT						WORLD
		Required knowledge states	**Perceptual / Cognitive processes (pick list)**	**Ending conditions**	**Output / behaviour**	**Output interface**
	Output	Declarative: • radio op procedure • comm procedure	1 Automatised 3 Verbal encoding and decoding 5 Memory recall and memorisation	• clearance obtained and understood (e = 0)	**Voice Output** • establish radio link (voice, keyboard etc) • transmit clearance request **Memory** • add contents of clearance to memory	• Radio head • PTT • display controller • audio pickup and/or • keyboard
Goal 1.2.1.1 ...the TO clearance has been received and understood	Σ	Situational: • radio ON/OFF • position in checklist • aircraft status • flight plan / intentions • clearance status		**Influenced Variable(s) (Internal)**	IV1: Clearance belief (1) IV2: Clearance status (1)	**Influenced Variable(s) (External)** EV1: ATC clearance (1) EV2: Clearance request (1) EV3: VHF1 Freq.
				Initiating conditions	**Input / sensation (pick list)**	**Input interface**
	Input			• clearance not obtained and understood (e ≠ 0) • if e ≠ 0 obtain clearance else do nothing	**Memory** (1.2 recall verbally encoded) **Vision** (1.1 Central, text) **Audition** (4 Attended speech) **Kinaesthetic** (1.1 Simple tactile input)	• audio transducer and/or visual display • published charts / frequencies

Table 5 from Hendy, K.C., et al., Analyzing the cognitive system from a perceptual control theory point of view, in Cognitive Systems Engineering in Military Aviation Environments: Avoiding Cogminutia Fragmentosa!, M.D. McNeese and M.A. Vidulich, Editors. 2002, Wright-Patterson AFB: Dayton, OH. p. 201-250.

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ANNEX E – OPERATIONAL SEQUENCE DIAGRAMS

Operational Sequence Diagrams (**OSD**s) were prepared in accordance with the guidelines in Subsection 7.1.2.10 of the Human Engineering (**HE**) Procedures Guide [Reference 35]. They are particularly useful for the analysis of highly complex systems, which require much time-critical information, decision-making and action functions by multiple users. By using symbology to indicate actions, inspections, data manipulation (transmission, reception, and storage), time delays and decisions, OSDs show the flow of information and operator functions throughout the system in relation to the mission timeline. Special symbols have been incorporated into the OSDs to provide the additional information necessary for translation to a probabilistic model. Symbols used are presented in Figure F-1.

The layout and graphic symbology used in OSDs generally follow the conventions laid out in the HE Procedures Guide. A number of additional graphic elements have been added to improve readability and convey the additional information available from the network database. The following subparagraphs provide a brief summary of the OSD formats with an explanation of deviations from the HE Procedures Guide:

a. **Continuous Task Symbols.** Continuous task symbols are used to indicate an ongoing task, which starts either at the beginning of the segment or upon completion of another task. Continuous tasks are indicated by a vertical arrow pointing down from the centre of the symbol. Operations and inspection tasks may be performed on a continuous basis. An example of a continuous task would be the monitoring of the SHipboard INtegrated COMmunications (**SHINCOM**) System by the ORO, SWC or ASWC.

b. **Flow Loopback Symbols.** Tasks to be performed repeatedly (such as Hook Track) are represented by means of an arrow from the last task in the sequence back to the task, which starts the sequence. In order to enhance the readability of the complex task relationships, the return symbol has been truncated to a short loopback arrow supplemented with a text label indicating the destination task of the loopback.

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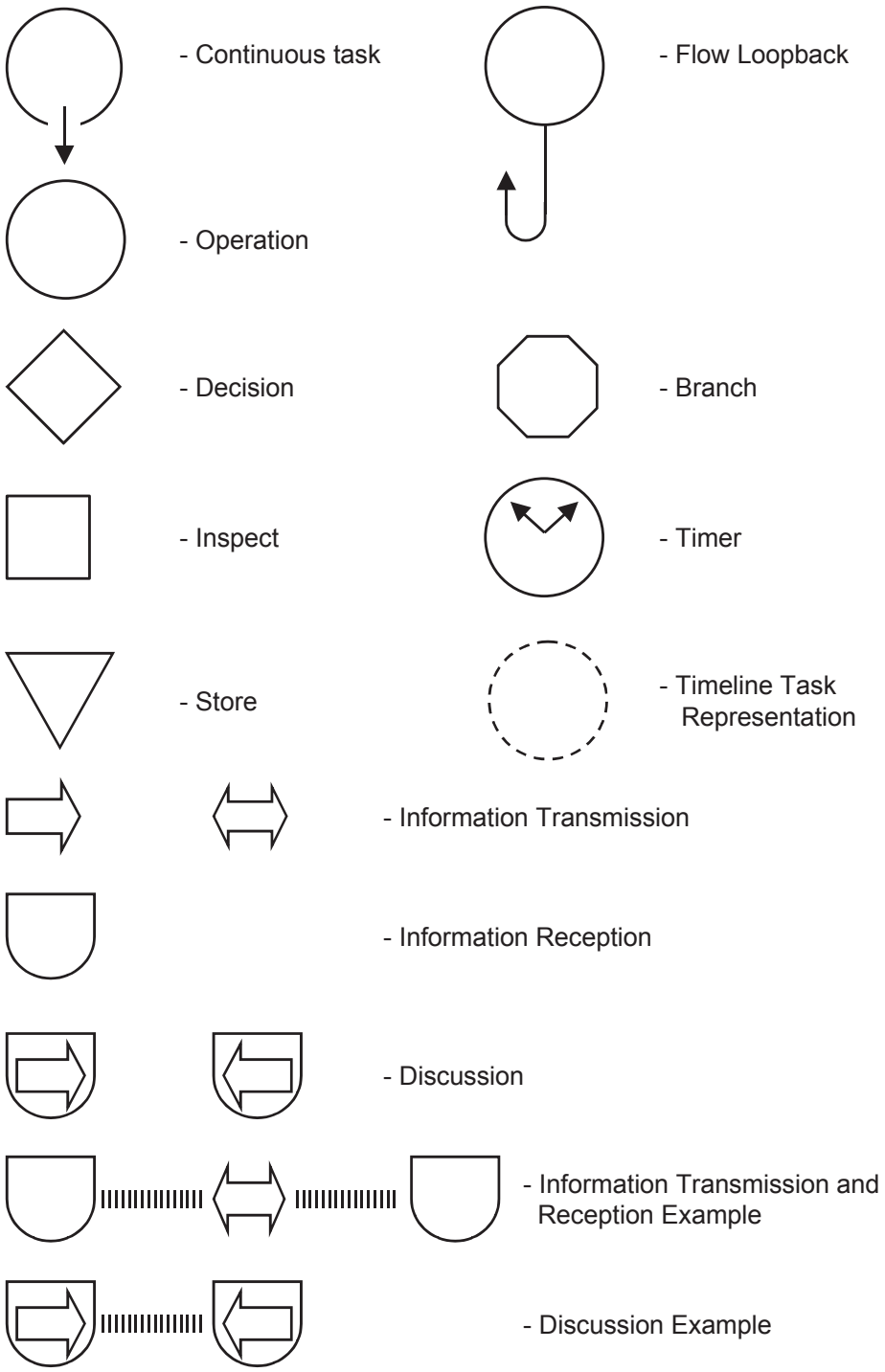

Figure F-1 Operational Sequence Diagram Symbology

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c. **Elapsed Time and Temporal Displacement.** OSD symbology is presented against a time scale, which runs vertically from top to bottom. Time elapsed during the performance of a task is represented by the vertical spacing between successive tasks (that is, equivalent to the task completion time). The time scale on OSDs is not necessarily continuous (partially to conserve paper when few activities are occurring), but task interrelationships are accurate. For example, tasks performed simultaneously are drawn beside each other, space permitting. If a task starts chronologically after another has been completed, regardless of whether they are related or not, it is drawn on a lower line (row) than the first task. In this way, the logical and time-oriented flow of tasks and information is maintained. The times (in minutes and seconds) recorded in the left-hand column are based on estimated most likely task completion times and are used cumulatively to determine total elapsed time.

d. **Timer Symbols.** In order to represent time gaps between successive tasks, a timer is used (represented by a small analogue clock face). Where one task logically follows another task after a fixed or variable time delay, the timer symbol is drawn between the respective task symbols. Timers may also have a variable time associated with them to reflect the randomness of the real world.

Order of OSDs

Watch Close-up	E.5 – E.24
Resolve	E.25 – E40
ASMD	E.41 – E.68
Harpoon	E.69 – E.104
ASW	E.105 – E.164

Presentation

In this annex each OSD is presented in a format of four sheet of paper per row. The diagram below demonstrates the format.

Page 1	Page 2	Page 3	Page 4
Page 5	Page 6	Page 7	Page 8
...	...	...	...

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Page 41	Page 42	Page 43	Page 44

Where the time scale runs continuously down pages 1,5...41 and the operators are listed across the tops of each page in sequence 1-to-4, 5-to-8...41-to-44.

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ANNEX F – MEAN TIME PRESSURE DIAGRAMS

The Mean Time Pressure Diagrams are graphical depictions of the mean time pressure, as calculated by IPME IP/PCT for individual operators during specific runs.

The y-axis (vertical) of each diagram is the mean time pressure. For consistency in presentation this has been capped at a value of two. In accordance with the time pressure theory and value above one is an indication that tasks are in conflict and the IPME IP/PCT scheduler has had to delay a task. Because of this the value of two was selected as a maximum value as any number greater is not an indication of increased time pressure, just that the scheduler waited longer in the cycle to invoke a delay.

The x-axis is the time in seconds. Each diagram also has a label listing the operator, as a 2-letter designation (IPME restriction), and the specific run. This labelling scheme is also used in Annex G.

2-letter designation

CO- Commanding Officer	RS – Operations Room Supervisor (ORS)
WO – Warfare Officer	EW – Electronic Warfare Supervisor (EWS)
OR – Operations Room Officer (ORO)	TS – Track Supervisor
SW – Sensor Weapon Controller (SWC)	AR – Air Raid Reporting Operator (ARRO)
AS – Assistant Sensor Weapon Controller (ASWC)	SP – Anti-submarine Plotting Operator (ASPO)
IM – Information Management Director (IMD)	

Order of Diagrams

Watch Close-up Baseline F.2
Resolve Baseline F.5
ASMD Baseline F.7
Harpoon Baseline F.9
ASW Baseline F.11
Watch Close-up & Resolve – 220 second delay F.13
Watch Close-up & Resolve – 500 second delay F.15
Watch Close-up & Resolve – 550 second delay F.17
Watch Close-up & Resolve – 620 second delay F.19
ASMD & Resolve – no delay F.21
ASMD & Resolve – 100 second delay F.23
ASMD & Resolve – 80 second delay F.25
Harpoon & Resolve – 100 second delay F.27
ASW & Resolve – 550 second delay F.29

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Harpoon & ASMD – 325 second delay F.30
ASW & ASMD – 525 second delay F.31
ASW & Harpoon – no delay F.32
ASW & Resolve & ASMD F.33

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ANNEX G – IPR SUMMARY FILE

The IPR summary files contained in this Annex are generated from the output from the IPME tool. They are a combination of the output from the 40 runs of each critical task sequence or combination of sequences. Each file contains a list of the task that are shed, delayed or interrupted, the operator assigned to each task, the reason for the disruption and the percentage of time (out of the 40 runs) that the task was disrupted. A number of the smaller files also list the other tasks that were active when the task in question was shed, delayed or interrupted.

Operator ID 2-letter designation

CO- Commanding Officer	RS – Operations Room Supervisor (ORS)
WO – Warfare Officer	EW – Electronic Warfare Supervisor (EWS)
OR – Operations Room Officer (ORO)	TS – Track Supervisor
SW – Sensor Weapon Controller (SWC)	AR – Air Raid Reporting Operator (ARRO)
AS – Assistant Sensor Weapon Controller (ASWC)	SP – Anti-submarine Plotting Operator (ASPO)
IM – Information Management Director (IMD)	

Order of IPR files

Watch Close-up Baseline	G-2
Resolve Baseline	G-3
Harpoon Baseline	G-4
ASMD Baseline	G-7
ASW Baseline	G-17
Watch Close-up & Resolve - 550 second delay to Resolve	G-25
Watch Close-up & Resolve - 500 second delay to Resolve	G-27
Watch Close-up & Resolve - 620 second delay to Resolve	G-29
Watch Close-up & Resolve - 220 second delay to Resolve	G-31
ASMD & Resolve – No delay – start simultaneously	G-35
ASMD & Resolve – 100 second delay to Resolve	G-42
ASMD & Resolve – 80 second delay to Resolve	G-48
Harpoon & Resolve - 100 second delay to Resolve	G-55
ASW & Resolve - 550 second delay to Resolve	G-58
Harpoon & ASMD - 325 second delay to ASMD	G-65
ASW & ASMD - 525 second delay to ASMD	G-69
ASW & Harpoon - No delay – start simultaneously	G-75

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ANNEX H – UPWARD INFORMATION FLOW

The upward information is presented in two formats. The first is are link diagrams that summarize the information flow between operators by type of information. The second format is the raw data generated from the goal hierarchy developed earlier in the project in accordance with Table 8 from Hendy et al. reference 4.

ANNEX H – TABLE OF CONTENTS

Link Diagrams H-2
Upward information from goal hierarchy H-30

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ANNEX I – POTENTIAL INSTABILITIES

Annex I contains the completed stabilities analysis templates in accordance with Table 7 (illustrated below) from Reference [4]. The underlying information was collected from the IP/PCT data from Annex D.

TABLE 7: A stability analysis.

Influenced Variable (external)	Operator or System Assignment	Goal / Objective / Reference	Potential for Simultaneous Control (pick list)	For stable control
Pitch Angle				
	• Operator 1	• ...the aircraft rotated for TO	• Operator 1 and FMS	• push/pull disconnects AP with voice and visual warnings
	• Operator 1	• ...the glideslope intersected		
	• Operator 2	• ...the altitude maintained	• Operator 1 and Operator 2	• hand over procedures, voice and visual warning if multiple inputs are detected
	• FMS	• the altitude at x feet		
			• Operator 1 and 2 and FMS	• as above
Variable 2				

Table 7 from Hendy, K.C., et al., Analyzing the cognitive system from a perceptual control theory point of view, in Cognitive Systems Engineering in Military Aviation Environments: Avoiding Cogminutia Fragmentosa!, M.D. McNeese and M.A. Vidulich, Editors. 2002, Wright-Patterson AFB: Dayton, OH. p. 201-250.

Annex I Table of Contents

Influenced Variable (external)	Page #
Access to Message Files	I.2
Maintenance of Stateboards	I.3
Access to MCOIN / DWAN / COWAN	I.4
Tasking of CANEWS	I.5
Enabling of weapons through the 'Weapon Veto Panel'	I.6
Ship’s heading and speed	I.7
STIR designation	I.8
SPS 49 Radar control / configuration	I.9
SG 150 Radar control / configuration	I.10
Application of CCS 330 overlays	I.11
CANTASS employment	I.12
Machinery state - propulsion and power generation	I.13
Communications configuration - internal and/or external	I.14

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ANNEX J – CRITICAL ACTIVITIES ANALYSIS

Annex J lists the activities (goals) in order of criticality in order of Safety Risk Rating (SRR), Mission Effectiveness Risk (MER) and Human Performance Capabilities (HPC). The acronym NOB is Nature of the Business, which indicates that in the domain and subject matter expert's opinions the risk associated with the specific goal could not be mitigated, as it is part of conducting the business associated with the operations room in a Halifax Class Frigate.

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ANNEX K – SME SESSION REPORTS

1000-1368 annexes final\1000-1368 Annex K SME session reports\1000-1368 Annex K SME sessions.doc

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Human Factors Analyses of Operator Positions in the Operations Room of the HALIFAX Class Frigate: FINAL REPORT (U)
Analyses des facteurs humains des fonctions d'opérateurs dans le poste des opérations d'une frégate de classe Halifax : RAPPORT FINAL (U)

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(U) 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 (OSDs) 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.

(U) Les résultats sont fournis pour les analyses des onze fonctions d’opérateurs dans le poste des opérations d’une frégate de classe Halifax à l’aide de la démarche de l’analyse des objectifs hiérarchiques (AOH). À la suite des analyses de missions, une hiérarchie d’objectifs assignés à divers opérateurs a été produite. Deux analyses de suivi ont été ensuite effectuées afin d’identifier les instabilités possibles dans le système et les exigences pour la circulation ascendante de l’information entre les opérateurs. Des diagrammes de séquence opérationnelle (DSO) ont été produits pour des séquences de tâches critiques, et les réseaux de tâches correspondants ont été mis en place et testés dans l’environnement intégré de modélisation des performances (EIMR). Le produit final du projet était la production d’une liste d’activités critiques dans le poste des opérations appuyées par des solutions proposées. Le rapport conclut que l’AOH et l’EIMR sont des outils adéquats pour appuyer les analyses de systèmes complexes principalement cognitifs.

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