Human Factors and Intelligence, Surveillance, and Reconnaissance (ISR)

Making the case for a Human Factors Capability in the ISR Concept Development & Evaluation (CD&E) Process

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IMPORTANT INFORMATIVE STATEMENTS

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Abstract

Within the scope of the Space Based Maritime Awareness (SBMA) Project, the Intelligence, Surveillance, and Reconnaissance (ISR) Concepts & Integration (ICI) Team, part of the Space & ISR Applications (SIA) Section at DRDC – Ottawa Research Centre will support the requirement to develop and integrate ISR concepts and capabilities into the Canadian Armed Forces (CAF). Although technology is a key driver in the ISR Concept Development and Evaluation (CD&E) process, technology does not work in isolation, but rather, technology often interfaces with human operators. Certainly this is the case in the ISR process where intelligence activities are inherently human centric, as humans are the ultimate decision makers in the ISR process [1]. To the extent that this is true, it is imperative to include a Human Factors (HF) methodology in the ISR CD&E process. Unfortunately, although HF have been identified by as an integral part of the ISR CD&E process [2, 3, 4], HF has not played a prominent role in this process thereby resulting in a large evaluation gap in the ISR CD&E process [2]. The purpose of this document is to highlight the need to develop a HF capability to support and enhance the current ISR CD&E process.

Significance to Defence and Security

ISR operations are a very human-centric process. ISR operations are about collecting and providing information to human operators who in turn are required to make specific decisions regarding various courses of action in their theatre of operations. A HF evaluation methodology can and should be used to inform and advise policy and decision-makers at all levels of the ISR chain of command. By studying the impact of new ISR concepts on operator performance across of variety of operational contexts, the results of these scientifically rigorous studies will augment the current ISR CD&E process that has as its goal to provide DND with evidence based advice to inform high-level policy and decision-makers on future technologies and capabilities. A HF methodology provides additional scientific rigour that will inform the decisions of what technologies should be purchased and how they should be deployed to improve decision-making, across all ISR environments: air, maritime surface and sub-surface throughout North America within domestic, allied, and WoG partnerships.

Résumé

Dans le cadre du projet sur la connaissance de la situation maritime depuis l'espace (CSME), l'équipe Concepts et intégration (CI) du Renseignement, surveillance et reconnaissance (RSR), une partie de la Section Applications Espace et RSR (AERSR) du Centre de recherches RDDC Ottawa, soutiendra le développement et l'intégration des concepts et des capacités de RSR au sein des Forces armées canadiennes (FAC). Bien que la technologie soit un facteur clé dans le développement et l'évaluation du concept de RSR (EEC), elle ne fonctionne pas dans l'isolement, mais plutôt souvent en interface avec des opérateurs humains. C'est certainement le cas dans le processus de RSR où les activités du renseignement sont intrinsèquement centrées sur les humains, ceux-ci étant les décideurs ultimes dans le processus de RSR [1]. Dans la mesure où cela est vrai, il est impératif d'inclure une méthodologie des facteurs humains (FH) dans le processus de RSR EEC. Malheureusement, bien que le FH soit considéré comme partie intégrante du processus de RSR EEC [2, 3, 4], il ne joue pas un rôle de premier plan dans celui-ci , ce qui entraîne ainsi de graves lacunes en matière d'évaluation dans le processus [2]. Le but de ce document est de mettre en évidence la nécessité de développer une capacité de FH pour soutenir et améliorer le processus actuel de RSR EEC.

Importance pour la défense et la sécurité

Les opérations de RSR constituent un processus centré particulièrement sur l'humain. Les opérations de RSR consistent en la collecte et la fourniture d'information à des opérateurs humains qui, à leur tour, sont tenus de prendre des décisions particulières concernant diverses lignes de conduite dans leur théâtre d'opérations. Une méthodologie d'évaluation des FH peut et doit être utilisée pour informer et conseiller les responsables des politiques et les décideurs à tous les niveaux de la chaîne de commandement du RSR. En étudiant l'incidence des nouveaux concepts de RSR sur le rendement de l'opérateur dans une variété de contextes opérationnels, les résultats de ces études rigoureusement scientifiques amélioreront le processus actuel de RSR EEC qui a pour but de fournir au MDN des conseils fondés sur des données probantes pour éclairer les responsables des politiques et décideurs de haut niveau sur les technologies et capacités futures. Une méthodologie des FH fournit la rigueur scientifique supplémentaire qui permettra de communiquer les décisions sur les technologies à acquérir et la façon de les déployer pour améliorer la prise de décision dans tous les environnements de RSR (aérien, maritime de surface et sous-marin) en Amérique du Nord, dans le cadre de nos partenariats pangouvernementaux, au pays et avec nos alliés.

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1 Introduction

The North Warning System (NWS) which was developed in late 1950s to address North America's surveillance requirements for the Cold War threat is outdated. Due to changes in technology, warfare, and the rise of asymmetric threats, the current NWS ISR systems are becoming obsolete, increasingly expensive to maintain and can no longer address all current ISR requirements for the protection of North America from hostile entities. Accordingly, there is a need to replace the current NWS to meet the ISR needs of modern world technological developments and threats. To this end, the ICI team at DRDC Ottawa Research Centre has been tasked to conduct a feasibility study to determine viable options to replace the current NWS.

ISR is a term that encompasses collection operations, collection planning, collection mission management and the processing, analysis and dissemination of operational information [4]. The goal of ISR is to provide actionable intelligence to decision makers and the mechanics by which intelligence is obtained involves a complex operation of systems and processes [5]. For ISR it to remain an effective CAF capability, ISR concepts need to be continually updated and evaluated so that they can effectively shape the future ISR enterprise in a rapidly changing world [4]. In this current work, the ISR concept to be explored is ISR sensors and sensor mixes involving cross domain multi-sensor integration. The scope of the ICI Team is expected to develop, assess and evaluate ISR sensor concepts, including sensor system integration, architectures and networks of low-cost sensors; collect datasets and create demonstration products; conduct trade-off studies against performance and cost; assess orbit, sensor and ground station trade-offs. The ICI group's deliverables will enhance information and decision advantage in CAF planning, mission execution and capability development [4].

In order to accomplish this work, The ICI team is using a modelling and simulation methodology to compare and contrast the performance of different sensors and mixed domain sensor platforms. Historically, the evaluation of competing technical systems or System-of-Systems (SoS) has relied primarily on technical evaluations [2]. In evaluating technological capabilities, the physical systems as well as the service providing the transfer of information in the network are considered. Continuing in this tradition, a large component of this ICI Team's ISR CD&E process will centre on the technical merits of the sensors and sensor mixes to be examined. As such, there will be much focus on how effective and efficient the variety of ISR concepts performs in the areas of tasking (e.g., planning and directing of resources used in the mission; tasking sub-criteria could include response time, revisit time, and coverage percentage in the area of interest), detection (e.g., providing information on the target that has been discriminated from the background environment and can be broken down into sub-criteria including: number of detections, detection gaps and probability of detection), tracking (e.g., the continuous measurement of a target's position and sub-criteria for this element pertain to track life time, number of tracked targets, and inclusion of track correlation), processing (e.g., criteria involve the conversion of information in order to be usable for consumption; sub-criteria for this category may include time required, computational power and parallel processing needed), exploitation (e.g., exploitation of data consists of the number of products produced, and the time required to be integrated adequately), and dissemination (e.g., the final step of the scenario dependant elements is dissemination which is the sharing of information on the network; sub-criteria include the size of the product, synchronization of data and bandwidth from the service provider to consumer) [4].

To be sure, technology is a key driver in the ISR CD&E process for improving operator decision-making. However, technology does not work in isolation. Rather, technology often interfaces with human operators. Certainly this is the case in ISR operations where intelligence activities are inherently human centric, as humans are the ultimate decision makers in the ISR process [1]. To the extent that this is true, it only makes sense to include a Human Factors (HF) methodology in the ISR CD&E process. Accordingly, a complete evaluation of the ISR concept's ability to facilitate operator decision-making, along with higher-level policy and decision-making, an ISR evaluation cannot begin and end with the technology alone. Unfortunately, although HF has been identified by the ICI team and others [2, 3, 4] as an integral part of the ISR CD&E process, HF has not played prominently in this process thereby resulting in a large knowledge gap in the ISR CD&E process [2]. Developing and implementing a HF methodology in the ISR CD&E process allows researchers to directly observe how the development of new ISR concepts impacts operator performance [1]. This information in turn can be used to inform and advice military and civilian policy and decision-makers about the purchase and implementation of new ISR assets. As such, a complete evaluation of the ISR CD&E process must include an understanding of the HF issues required for effective and efficient decision-making in order to ensure that new ISR technologies are developed around the capacities and needs of human operators. To this end, the ICI Team is developing a HF capability to support and enhance the ISR CD&E process.

This seminal work has the goal of providing ISR researchers with a multi-disciplinary approach (technical and HF) to improve the full range of research, analysis and solution implementation activities for the ISR CD&E process. Although conceptual in nature, this work promotes a new field of HF research that examines the role that HF plays in the ISR CD&E process with the goal of ensuring that technologies and technological systems designed for human operators meet the needs of these operators. The focus of this work is to develop a deep and broad understanding of HF ISR issues in order to develop a HF framework and evaluation methodology to inform the design, development and implementation of ISR sensors and sensor platforms which will improve operator performance and inform high-level policy and decision-making about ISR purchases and applications.

2 Human Factors

The goal of HF is to improve performance and well-being through systems design [6]. A number of poignant definitions of HF should help to make clear the view espoused by Hollnagel [6]:

1. "...the objective [of human engineering, engineering psychology, and applied experimental psychology] is the same - to develop, through fundamental research and applied tests, a science that can deal adequately with the design and operation of machines for human use" [7, p. v].

2. "The main goals in human factors engineering are to - 1) Consider any man/machine combination as a total system to insure that the equipment operational requirements do not exceed human abilities 2) Consider the human performance tolerance, thereby insuring optimal speed, accuracy, and quality of performance; eliminating hazards to operating personnel; and maximizing the comfort of the operator" [8, p. 3].

3. "...human factors engineering can be defined as the application of scientific principles, methods, and data drawn from a variety of disciplines to the development of engineering systems in which people play a significant role. Successful application is measured by improved productivity, efficiency, safety, and acceptance of the resultant system design. The disciplines that may be applied to a particular problem include psychology, cognitive science, physiology, biomechanics, applied physical anthropology, and industrial and systems engineering" [9, p. 2].

4. "...[human factors/ergonomics is] the study of how people and machines interact. It is a technology for creating designs that work well in human terms" [10, p. 5].

5. "[The aim of human factors is the design of] machines that accommodate the limits of the human user..." "The goal of human factors...is to apply knowledge in designing systems that work, accommodating the limits of human performance and exploiting the advantages of the human operator in the process." [11, p. 3].

6. "...[human factors is about] the role of humans in complex systems, the design of equipment and facilities for human use, and the development of environments for comfort and safety." [12, p. xvii].

7. "The field of human factors engineering uses scientific knowledge about human behavior in specifying the design and use of a human-machine system. The aim is to improve system efficiency by minimizing human error" [13, p. 3].

Common to these definitions is the notion of making the machine, technology, or system, meet the needs of the user. Human factors research involves the study of how all aspects of the ways humans relate to the world around them, with the aim of improving operational performance [14]. This is typically accomplished by having the operators of the technology assess various merits of the technology in its ability to improve operator performance. In essence, HF ensures that technologies are not developed in isolation from the operators they are meant to help; you cannot properly evaluate systems without observing the interaction between the technology and the operator and input from the operators about the system itself. The development of the technology must be an iterative process between the operator and the technology. Unfortunately, little or no attention has been given to the role or impact of HF in the evaluation technological architectures such as ISR systems [2].

Researchers have recognized that HF has great potential to ensure that the design of many systems, products, or organisational environments, is formed around the capacities and needs of human operators. When HF does not play a role in system design, the result of the system design can be sub-optimal systems with quality deficits and reduced effectiveness and efficiency [15]. To this end, HF methodologies have been applied to a wide range of work/research domains with the goal of improving human performance. The broad and impressive extent of the application of HF research is apparent from the list of HF applications in the flagship journal, Human Factors. This list includes 30 core areas of HF application with numerous sub-topics within each of these core areas.

With regard to military research, in general, the military has relied to a large extent on HF to improve operator/soldier performance. Human factors are key component to enabling today's armed forces to implement their vision to produce battle-winning people and equipment that are fit for the challenge of today, ready for the tasks of tomorrow and capable of building for the future [16]. Modern armed forces fulfil a wider variety of roles than ever before. In addition to defending sovereign territory and prosecuting armed conflicts, military personnel are engaged in homeland defence and in undertaking peacekeeping operations and delivering humanitarian aid right across the world. This requires top class personnel, trained to the highest standards in the use of first class equipment. The military has long recognised that a strong understanding of relevant HF issues is essential if these aims are to be achieved. The defence sector is far and away the largest employer of human factors personnel across the globe and is the largest funder of basic and applied research [16].

A great deal of military research has focused on supporting operator decision-making across many different domains and occupations. The understanding of and improvement of human decision-making has become increasingly important in military contexts as there has been a continued rise in the development and use of increasingly complex technologies and distributed multinational operations. Within this context, much of the research is about discerning those cognitive variables that impact decision-making and then designing systems and processes that meet the needs of these cognitive variables. This is an important endeavour since the human cognitive system has a limited processing capacity [17]; systems, processes and technologies must be designed in such a way as to not over burden this limited capacity but rather, ensure that these systems, processes and technologies facilitate maximum information processing efficiency in order to enable fast and accurate decision-making.

As an example, one of the most extensive areas of HF research in decision-making has focused on Situation Awareness (SA): a cognitive construct that refers to our awareness, knowledge, and understanding of events in our immediate and future environment [18]. Since World War I, researchers and practitioners have come to view SA as critical for accurate decision-making and performance [19, 20, 21, 22] not only in military domains but also in such diverse areas as the nuclear power industry, aviation, road transport, energy distribution, rail, the military, and sport [23]. With the exception of disconnects that can occur between SA and decision-making [20], the prevailing assumption is that there is a positive correlation between an operator's level of SA and decision-making such that as the level of SA increases, the ability to make the best decision possible also increases.

Within military contexts, there has been a great deal of HF research applied to improve operator SA and decision-making. Of course, the development of SA does not occur on its own. Situation awareness is typically the product of a variety of cognitive processes and variables. To this end, the HF study of SA and decision-making has involved a great deal of study of other related and correlated cognitive processes and variables. In addition to studying the role of SA in operator decision-making, HF researchers have evaluated the extent to which new systems, procedural and technological concepts improve cognitive workload [14, 24, 25, 26, 27], information sharing [28], decision-making [28], and trust [25, 29]: areas that are all correlated with SA and ultimately decision-making performance.

3 Human Factors in ISR CD&E

Despite the rich and diverse history of HF research in military operations, it is interesting, if not perplexing, that HF research is virtually non-existent in the ISR CD&E process; especially when it is acknowledged and understood that the ISR process is a very human centric process and the goal of ISR is to provide actionable intelligence to decision makers. To the extent that this is true, much if not all of the cognitive HF research discussed above is extremely relevant to current ISR operations and certainly to the ISR CD&E process. Accordingly, when embarking on the development of new concepts, researchers must be mindful that ISR operations are very much human centric operations and therefore, new ISR concepts must be developed with the understanding and knowledge that they will impact operator performance (i.e., decision-making).

Recently, discussions with members of the Royal Canadian Air Force have also reinforced the idea that a HF methodology should be a necessary component of an ISR CD&E process [4]. While military personnel acknowledge the need for improved ISR technologies to facilitate their operational goals, they readily acknowledged that without certain non-technical issues in place the benefits to be gained from improved technologies will not be realized. When asked the question, “What HF issues need to be addressed in addition to the development of new sensors and sensor systems to ensure successful monitoring of the borders?”, members of the Royal Canadian Air Force (RCAF) generated four categories of concern which are akin to infrastructure requirements that need to be in place to facilitate ISR use [4].

3.1 Monitoring

The first requirement is to have 24/7 real-time monitoring of the borders. To achieve this goal, they propose a 5:1 ratio for intelligence personnel. This number is achieved to ensure one person can deploy, one can train and three are available for the primary role. Related to this is the need for redundancy of 24/7 real-time monitoring. The ability to staff multiple locations at the same time, with the same skill sets is required. Despite the cost associated with this, operators say that this is necessary.

According to the participants, intelligence personnel should have some basic skills to operate in this environment. Training or experience in areas such as electronic warfare training or future equivalent; understanding the electromagnetic spectrum; CAOC Training or equivalent; analytical training/experience; computer literacy training/experience; and specialized training/experience relating to sensor/weapons system used are considered valuable assets to have.

The future environment will likely see a blurring of lines between Tactical/Operational/Strategic/Governmental elements. As automation of processes expands, decisions that have traditionally been made at the senior levels today will likely be made from via many locations into one central point. This will not reduce the requirement to have access to an analytical team, but the ability for the decision makers to contact these experts in real-time will be critical. Experience suggests that experienced intelligence personnel will be required to act as intermediaries between the levels of command.

Information Technology (IT) support is critical to the success of any future NWS concept. Intelligence works side-by-side with the IT specialists and their numbers must be considered. IT support is a crucial aspect to ensure a Common Operating Picture (COP) for decision makers.

3.2 Data Analysis

Data analysis is conducted at all levels within the air defence process. The current construct of data analysis will not be the same in the future due to changes in the operational requirements, technical advancements and/or fiscal decisions. However, the following are tenants to consider with respect to data analysis:

1. Knowledge development. The current process to qualify an intelligence professional to work effectively within the air defence environment is 6 months to 1 year. The amount of information/intelligence to absorb is vast and the continued evolution of the battlespace requires constant study. This experience is developed after any formal training is completed.

2. Work load. The amount of data will drive the number of personnel. The more sensors, the more analysis that is required. There will be many processes that will cut down on the raw data feed, but outside of the 24/7 team, more personnel will be required to analyse data in slow time. The size of this team will be driven by the operational requirements.

3. Operator confidence in analyses. There is a certain level of trust that must be developed between the decision maker, operator and intelligence analyst. More intelligence and information can be passed and better interpreted by face-to-face discussions vice over electronic means. However, if a process can be developed to instill the same confidence/trust in the decision makers via distance technologies, this will allow operators more flexibility to execute their assign mission.

4. Tools. The tools used to analyse data will change. But an important factor that should be accounted for is interoperability between all Canadian units involved in the air defence of Canada. The tools will require training and will evolve with the mission. Analysis tools are often overlooked when selecting a sensor to meet the operational requirements. The vast amount of data will require automation tools to reduce overloading the analyst. Additionally, trust and confidence in the tools is as critical as any human interaction. This trust will help build confidence in the assessment provided to the operator. Any discussion on tools should include the IT specialists to ensure that IT support to the tool is possible. Moreover, tool requirements will also affect staffing requirements.

3.3 Information Sharing

The sharing of data and intelligence is critical to the execution of the air defence mission in Canada. The exact details as to the future devices required will change, but the following are issues to consider:

1. Sharing with International partners. Currently, Canada and the US are the two countries of concern. In the future, this requirement may expand to other countries. The requirement to

share data will be determined by future decisions, but keeping the ability to expand the sharing of data is important;

2. When is intelligence needed? Long before the decision to execute any air defence mission, the intelligence picture is developed. To provide the best assessment, intelligence personnel need to have access to all sensor data in one location (i.e., work area). Then, there must be a process to share large amounts of data quickly and to multiple analysts/operators; and

3. Classification of Data. The future information will be classified. There will be a requirement to operate and share data at all classification levels. Thus, personnel will require the appropriate clearances and this process takes time. This is an information process issue.

3.4 Operating Environment

In short, the operating environment of the future will be austere especially in the north. The north will be challenging at best and greater consideration needs to be given about how to deliver the sensor at the right place at the right time. Operating in the north takes more time, people and resources to complete any task. Therefore, any future recommendations should account for the operating environment. This suggestion also includes air, sea, and land and space solutions. Lastly, consideration must be given to use of remote and autonomous equipment in these challenging work environments. It is easy to say we will put sensors wherever we want. It is much more difficult to ensure that sensors will work in the places we want them to work; so more planning and even infrastructure, with its associated costs, must be investigated and included in a sensor upgrade architecture.

Furthermore, recent discussions at the NATO HFM ET-145 meeting [30] identified additional HF issues that, given specific operational environments will likely need to be addressed when evaluating new ISR concepts. Some of the more prominent issues identified by members of the NATO HFM ET-145 panel to be incorporated into a HF CD&E methodology included: the need for end-to-end ISR analysis because of the human centric nature of the entire ISR process which requires integrated ISR information at different levels of the ISR command; operational lessons; legal and ethical issues that impact procedural aspects of ISR applications; the role of cyber; integration of non-traditional/new ISR sensors and big data and visualization which impacts mental workload, Processing, Exploitation and Dissemination (PED), depth of information vs. more/less data, decision aids, reconfigurable workstations and data presentation; understanding and sense-making; threat cue evaluations (planning for the unusual and unexpected); bottom-up vs. top-down ISR needs; environment, social and cultural impacts can drive ISR needs; ISR lines of communication and information sharing, involving social network and architectural analyses. To be sure, an ISR CD&E methodology needs to be conducted as an end-to-end ISR analysis because of the human centric nature of the ISR process that requires integrated ISR information at different levels of the ISR command.

All of the (cognitive) HF issues mentioned up to this point reside at some stage or at various stages in the ISR end-to-end process. Whether the decision-makers reside at the operational and tactical levels or involve policy makers and high ranking military and civilian decision-makers at the highest levels of the ISR process, people are inundated with data from a multitude of sensors and sensor platforms. It is important to ensure that new ISR concepts provide data that facilitates fast, effective and accurate decision-making at all levels of the ISR process. To this end, an important part of a HF methodology would be to understand how different ISR concepts influence various HF issues at various parts of the ISR process which in turn impact concomitant decision-making.

4 The Nature of the ISR Problem Space

Before a HF methodology can be constructed, it is prudent that we look at and understand the nature of the ISR problem space. This will allow an understanding of the environment in which operators and decision-makers do their work in order to determine information requirements and information sharing within the ISR environment; important components that affect the outcome of operational tasks. When this understanding is reached, researchers will be better situated to know how to approach the problem of ensuring that the development of new ISR concepts are focused on the needs of the operators and decision-makers in order to support effective and efficient decision-making.

There are two components to the ISR CD&E process: the individual systems that contribute to enhanced ISR capabilities and the process of combining systems (e.g., System-of-Systems (SoS)) that contribute to enhancing ISR capabilities. According to Dogan et al. [3], a system can be viewed as an organized whole in which various parts are related together, generates emergent properties, has some purpose, and displays a functional division and co-ordination of labour among the parts. The different parts of the system interact with each other by exchanging energy, goods and/or information. The interactions can be linear or non-linear, causal or apparently random, which can make the system's behaviour hard to predict. Moreover, systems that interact and are affected by their environment are referred to as open systems, while systems that have no or minimal interaction with their environment are called closed. Systems also tend to be classified as simple or complex. Simple systems can be exemplified in the 'action-reaction' conventional systems found in classical physics and mechanical engineering. These tend to be closed systems and although they may contain many parts, the interactions between them are largely predictable. Complex systems, on the other hand, are usually open systems with at least one element that responds in a non-linear manner in relation to another element. This non-linear variety is difficult to predict with the consequences that these systems tend to exhibit emergent behaviours [3].

A SoS is the term used for a particular kind of complex system and refers to systems that can be described as collections of components that in themselves may be regarded as complex systems and are operationally and managerially independent [3]. Together, these systems are able to pool their capabilities to provide more functionality than the sum of the individual systems. Moreover, he SoS can possess individual systems that are geographically distributed, exhibit emergent behaviour, and develop in an evolutionary manner [3]. Simply, a SoS contains many interconnected nodes that exist across a variety of levels and sublevels and researchers are beginning to view and understand how complex behaviour can emerge from interactions between many simpler highly interconnected nodes and processes [31]. To wit, the ISR process comprises mission/concept of operations, planning and direction, collection, processing and exploitation, analysis and production, dissemination and integration, and evaluation and feedback [32]. All these nodes are highly interconnected and most assuredly include various sub-levels of interconnectivity with human operators residing at many of these nodes, working toward a common goal. To the extent that this is true, the ISR process is a very complex process that is best viewed as and studied as a SoS environment.

5 Studying HF within a SoS Environment

Traditionally, HF research has examined the interplay between operator cognition and the environment and a person's physical abilities and their environment as separate pursuits [33]. Human factors and ergonomics researchers are now beginning to view HF research within a SoS framework [33]. Like many technical and socio-technical systems that humans find themselves in, humans can be viewed as a system, defined by Hollnagel (6, p. 42) as "…consisting of many independent parts or elements that are interrelated in one way or another – acknowledging, of course, that the whole is larger than the sum of the parts". To be sure, the human is composed of many elements (both physical and cognitive) that are highly interrelated. As such, impacting one element of the human system is likely to impact another element. Given this perspective, researchers are beginning to argue that the cognitive and physical aspects of human performance should be studied in tandem. To do so otherwise would provide researchers with an incomplete picture of why people perform the way they do under certain circumstances. To this end, researchers are beginning to argue that HF should be studied within a SoS environment (e.g., ISR environments) rather than in artificial, unidimensional laboratory settings [34]. Realistically, humans live, work and operate in SoS environments and should thus be studied within SoS environments [3]. In this way, we are able to develop a more holistic understanding of which parts of the ISR SoS environment impact the different cognitive components of human performance and ultimately the quality of operator performance.

In order to study human behaviour in a SoS (e.g., ISR) environment, researchers must also identity the architecture of the environment. Researchers must identify all of the nodes and the connections between those nodes within the system's architecture. These nodes can represent different operations or departments within the ISR environment. The connections between the nodes represent the flow of information and various lines of communication between the nodes. Moreover, connections to distributed nodes (i.e., agencies external to a specific ISR operating centre) also need to be identified and their role in the ISR process explained. These external agencies can be part of a joint CAF endeavour, national agencies working in collaboration with the CAF (e.g., RCMP), as well as multinational military forces. By mapping out the ISR architecture in this manner, researchers can evaluate the extent of the new ISR concept's impact (both at the human and technical levels) throughout the entire environment.

After mapping the architecture of the ISR SoS, the HF researcher must then determine and understand what operations are performed at the various nodes within the various levels and sublevels in the ISR environment. Once this macro-level analysis is completed, then micro-level HF research can be begin: study how the operators' performance is impacted across these various levels by the new ISR concept at both cognitive and physical perspectives. From this, the researcher can determine what HF metrics are most relevant to the specific performance output in that part of the system and then how to measure them. According to a systems' perspective, changes to performance result from the relationships between components, not from the workings or 'dysfunctioning' of any component part [35]. As a result, "infinitesimal changes in one part of the system can lead to huge differences (or no differences) later on in the system…and…interactive complexity of the system can take it onto unpredictable pathways to hard decisions" [35, pp. 19–20]. Thus it is imperative that the researcher have an understanding of the environmental architecture and the relationships that exist among the multitude of operators within this environment in order to properly evaluate the impact of new ISR concepts to operator performance and decision-making.

6 A HF Framework to Guide ISR CD&E Research

6.1 HF Evaluation Methodology Framework

1. The ISR Concept:

    a. Understand the concept.

    b. Why is it needed?

        i. Statement of the military problem

        ii. What are the key issues to be addressed?

        iii. What are the current gaps that need to be addressed?

            a) Are secondary factors and limiting issues associated with the problem being addressed?

    c. Know the users.

        i. Who is the client(s)?

            a) National

            b) International

                i) Classification of information is an issue here.

        ii. What is their background, what is their understanding of the concept, what is their intent?

        iii. The issue of Commander's intent is important for operators…without it, ISR concepts can mean nothing. This helps with common thought patterns and interpretation of input.

        iv. Do any HF ISR doctrines exist?

    d. Know the operational context for concept use

        i. Do relevant operational lessons exist?

    e. Is there existing work on this concept?

    f. What are the relations to other concepts?

        i. What is/are the relations to other nodes within the concept?

a) Social Media and ISR?

g. What are the constraints for the CD&E process?

i. Technical

a) New technologies

ii. Human

iii. Legal

iv. Social/cultural/environmental

2. The Human Factors Concept

a. To understand the extent of human involvement in the ISR process, there is a need to determine the people, processes, and agencies that are involved in the ISR context:

i. Need to determine the information flow within the ISR context

a) Need to develop an operational view of ISR information flow architecture:

i) What groups are involved:

(1) HQs;

(a) North Bay, Winnipeg, Colorado Springs

(2) Collaborative elements;

(a) Army, Navy, SOF, Space;

(b) RCMP;

(c) NAV Canada;

(d) OGDs.

(3) International;

(a) Allies.

(4) Are new infrastructures required?

(5) Classification issues.

ii. Need to make explicit the composition of the groups and the ISR requirements of the operators and decision-makers within these groups;

a) Need to know what sort of ISR information the different groups of operators use;

i) Will the new ISR concepts have a qualitative and/or quantitative impact on the operators' ISR requirements?

(1) Cognitive demands;

(2) Physical demands;

(a) Human and infrastructure.

(3) Technical evaluations of concept;

(a) Non-traditional ISR technologies.

(4) Environmental demands;

(a) Cultural

(b) Social

(c) Legal

(5) Psychosocial dimensions; (level 6)

(6) Decision-making. (level 6)

b) What are/is the relationship between members of the ISR team? For example, do analysts, collectors, consumers and decision-makers interact?

i) Will the new ISR concepts impact these relationships?

(1) Information sharing.

iii. Need to determine how the new ISR concepts will impact different cognitive variables important to effective and efficient decision-making"

a) Overall operator performance

i) Communications;

ii) Decision-making;

iii) Personnel/training;

iv) Knowledge transfer/management;

v) Workload (increased loads for real-time 24/7 real time monitoring);

vi) Situation awareness (local, continental, international);

vii) Technology (e.g. interfaces);

(1) Need to discuss with SMEs

(2) AHP, Delphi, DNDAF?

b) Design issues: information fusion, technologies, infrastructure, process…

i) Need to discuss with SMEs

ii) AHP, Delphi, DNDAF, SNA?

c) It must be understood that the HF methodology within ISR CD&E might not be restricted to the technical issues of the ISR concept. New ISR concepts will likely impact:

i) Monitoring:

(1) 24/7 real-time monitoring of the borders;

(a) This will require more staff at multiple locations;

(b) Personnel should have some basic skills to operate in this new environment;

(c) The future environment will likely see a blurring of lines between Tactical/Operational/Strategic/Governmental elements;

i. This will likely require changes to decision-making process.

ii) Data analysis:

(1) The current construct of data analysis will not be the same in the future due to changes in the operational requirements, technical advancements and/or fiscal decisions;

(a) Knowledge development;

(b) Workload

i. Big data/visualization;

(c) Operator confidence in analyses;

(d) Tools.

iii) Information sharing:

(1) Sharing with International partners;

(2) When is intelligence needed;

(3) Classification issues.

iv) Operating Environment:

(1) The operating environment of the future will be austere especially in the north.

(2) Physical changes to HQs.

d) These issues may require changes to TTPs.

3. Procurement Issues

a. Need to know the key HF issues/factors that decision-makers require to address when evaluating competing sensors and concepts for improving CAF ISR capability to protect Canada; how these HF issues/factors are impacted by different sensors and sensor platforms:

i. Number of staff

ii. Training requirements

iii. Operating environment

a) Arctic

b) Command Center layout

iv. Data analysis

a) Decision aids

v. Information sharing

vi. Ease of collaborative with security partners

a) National

b) International

b. This information will help to advise decision-makers on cost-benefit trade-off information.

c. These are issues that will probably need to be kept in the back of the researchers minds when evaluating the cost/benefits of each of the sensor platform concepts.

d. This should probably be at the end of the experimentation phase.

4. Define the high level HF topics associated with the ISR concept:

   a. Literature Reviews

      i. Military Journals

      ii. Operational Journals and Reports

      iii. Technical Documents

      iv. Scientific Journals

   b. SMEs

      i. Interviews

      ii. Questionnaires

      iii. Surveys

   c. Activity Analysis

5. Data collection/evaluation techniques:

   a. Quantitative

      i. Questionnaires

         a) True/False

         b) Ratings

   b. Qualitative

      i. Cognitive Systems Engineering

      ii. Cognitive Task Analysis

      iii. Hierarchical Task Analysis

      iv. Interviews

      v. Delphi

vi. AHP

c. Modelling and Simulation

i. VIEE++

ii. CFWC

iii. NATO and allied collaborative testbed venues.

d. Military Exercises

i. Domestic and International

From this framework, and future amendments to it, it is assumed that a HF evaluation methodology can be developed to support the CAF ISR CD&E process for ISR concept development in a variety of operational contexts. This HF contribution will support scientifically rigorous informed decision-making at all levels of the ISR process. This work will also enable DRDC to leverage similar research pursuits with our allies via NATO and TTCP collaborative efforts by offering a new and supportive approach to ISR CD&E thereby further strengthening a scientifically informed decision-making process.

7 Conclusion

The HF framework outlined above does not represent a complete and final guideline to develop a HF evaluation methodology that can be used in a variety of ISR CD&E contexts. This framework is included to provide a representative sample of the extensive HF resources that can be drawn upon to develop a HF methodology for the ISR CD&E process. This framework can be expanded and edited to collect data on other related areas of cognitive HF such as the flexibility: Probing the operators' perception about the flexibility to utilize different combinations of ISR platforms at any given time assesses the ISR concept's responsiveness to unscheduled re-tasking/use of different ISR platforms; Latency of information: The operators will be asked to evaluate the latency associated with the amount of time it takes to receive information after it has been requested.

ISR operations are a very human-centric process. ISR operations are about collecting and providing information to human operators who in turn are required to make specific decisions regarding various courses of action in their theatre of operations. To this end, it is imperative that researchers involved in ISR CD&E understand the human dimension of ISR operations at all levels because ISR is about making the right decisions. Accordingly we need to know how best the facilitate operator decision-making. This means understanding information requirements, cognitive limitations, and SOPs to ensure that the ISR concepts that they are developing have their intended effect.

It is important to realize that the development and implementation of a HF ISR evaluation methodology is not for the sole purpose of examining the impact of new ISR concepts on operator performance. Rather, a HF methodology can and should be used to inform and advise policy and decision-makers at all levels of the ISR chain of command. By studying the impact of new ISR concepts on operator performance across of variety of operational contexts, the results of these scientifically rigorous studies will augment the current ISR CD&E process that has as its goal to provide DND with evidence based advice to inform high-level policy and decision-makers on future technologies and capabilities. A HF methodology provides additional scientific rigour that will inform the decisions of what technologies should be purchased and how they should be deployed to improve decision-making, across all ISR environments: air, maritime surface and sub-surface throughout North America within domestic, allied, and WoG partnerships.

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List of Symbols/Abbreviations/Acronyms/Initialisms

CAF	Canadian Armed Forces
CD&E	Concept Development & Evaluation
COP	Common Operating Picture
DND	Department of National Defence
DRDC	Defence Research and Development Canada
DSTKIM	Director Science and Technology Knowledge and Information Management
HF	Human Factors
ICI	ISR Concept Integration
ISR	Intelligence, Surveillance, and Reconnaissance
IT	Information Technology
NATO HFM ET-145	North Atlantic Treaty Organization Human Factors & Medicine Experimental Team – 145
NWS	North Warning System
RCAF	Royal Canadian Air Force
SA	Situation Awareness
SBMA	Space Based Maritime Awareness
SIA	Space & ISR Applications
SoS	Systems-of-Systems
TTCP	The Technical Cooperation Panel
WoG	Whole-of-Government

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Within the scope of the Space Based Maritime Awareness (SBMA) Project, the Intelligence, Surveillance, and Reconnaissance (ISR) Concepts & Integration (ICI) Team, part of the Space & ISR Applications (SIA) Section at DRDC – Ottawa Research Centre will support the requirement to develop and integrate ISR concepts and capabilities into the Canadian Armed Forces (CAF). Although technology is a key driver in the ISR Concept Development and Evaluation (CD&E) process, technology does not work in isolation, but rather, technology often interfaces with human operators. Certainly this is the case in the ISR process where intelligence activities are inherently human centric, as humans are the ultimate decision makers in the ISR process [1]. To the extent that this is true, it is imperative to include a Human Factors (HF) methodology in the ISR CD&E process. Unfortunately, although HF have been identified by as an integral part of the ISR CD&E process [2, 3, 4], HF has not played a prominent role in this process thereby resulting in a large evaluation gap in the ISR CD&E process [2]. The purpose of this document is to highlight the need to develop a HF capability to support and enhance the current ISR CD&E process.

Dans le cadre du projet sur la connaissance de la situation maritime depuis l'espace (CSME), l'équipe Concepts et intégration (CI) du Renseignement, surveillance et reconnaissance (RSR), une partie de la Section Applications Espace et RSR (AERSR) du Centre de recherches RDDC Ottawa, soutiendra le développement et l'intégration des concepts et des capacités de RSR au sein des Forces armées canadiennes (FAC). Bien que la technologie soit un facteur clé dans le développement et l'évaluation du concept de RSR (EEC), elle ne fonctionne pas dans l'isolement, mais plutôt souvent en interface avec des opérateurs humains. C'est certainement le cas dans le processus de RSR où les activités du renseignement sont intrinsèquement centrées sur les humains, ceux-ci étant les décideurs ultimes dans le processus de RSR [1]. Dans la mesure où cela est vrai, il est impératif d'inclure une méthodologie des facteurs humains (FH) dans le processus de RSR EEC. Malheureusement, bien que le FH soit considéré comme partie intégrante du processus de RSR EEC [2, 3, 4], il ne joue pas un rôle de premier plan dans celui-ci , ce qui entraîne ainsi de graves lacunes en matière d'évaluation dans le processus [2]. Le but de ce document est de mettre en évidence la nécessité de développer une capacité de FH pour soutenir et améliorer le processus actuel de RSR EEC.

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