Chapter 4 – SYSTEM OF SYSTEMS

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4.1 INTRODUCTION

Once dismissed as novel technology that would never be useful within a dynamic environment, uninhabited military vehicles (UMVs) are being developed in greater numbers and growing sophistication as the modern military strives for greater persistence over the battlefield, more real-time intelligence, and the ability to strike heavily defended targets. New system architectures designed for interoperability are being developed to integrate multiple platforms into a common mission control element giving the war-fighter access to a large volume of real-time information. Couple that with a geographically dispersed command and control structure and the UMV operator is faced with unique challenges as traditional inner-loop control tasks are replaced with battle management and command coordination consistent with an effects based, network centric environment. The end result is an entire set of new Human Factors related challenges facing developers to ensure successful human systems integration. Resolving issues associated with connectivity, knowledge and action consistency, and transfer of control have taken center stage along with traditional Human Factors issues related to information management, information processing, decision aiding, levels of autonomy, command and control, manpower and skills, and training. To be successful, these issues must be addressed during the early stages of systems engineering to ensure proper human-centered development of UMV systems within a system-of-systems architecture.

It begins with understanding the concept-of-operation in which UMVs will operate and then identify mission system requirements. As Bruce Clough [27, Chapter 7] correctly states, "The hardest part of making a decision isn't deciding, it's knowing what to decide with." What is the situation and how best can decision aiding be applied? Clough continues with another lesson learned, "Best autonomy method used is related to task to accomplish, there is no optimal method for any task." All too often Human Factors engineers and designers try to make the leap from theory and principles directly to developing user interface concepts without a clear understanding of the operator tasks and requirements. The end result tends to be concepts that are not supported by the system architecture, or are not conducive to the real world. Following a disciplined Systems Engineering approach that combines top-down requirements development with a bottoms-up rapid prototyping capability should result in a human-centered design that is both optimal and credible. Using rapid prototyping tools that provide standard widgets, display templates, and auto-code generation allows the user interface designer to produce concepts that can be evaluated early and often by the operator as well as integrated directly with the final mission control system.

The following sections within this chapter address Human Factors issues and future research associated with human information processing and information management within the context of command and control and network centric operations. In addition, issues associated with migration of operator control and the impact on teams, interoperability, and situation awareness are discussed. The chapter concludes with a section on manpower and skills which addresses operator selection and training.

4.2 COMMAND AND CONTROL: HUMAN INFORMATION PROCESSING AND TRUST IN TIME DELAYED SYSTEMS

4.2.1 Human Information Processing (HIP) Capabilities, Limitations, and Detractors

4.2.1.1 Human Information Processing Models

Network centric capabilities interweaving sensors, humans, and decision aids will yield increases in sources and quantity of information. These advances will place heightened cognitive demands on UMV operators performing C2 tasks. The increased cognitive demands associated with a dependence on large complex data sets has been hypothesized to result in information saturation and higher levels of perceived mental workload by the National Science Foundation (NSF) and the National Research Council (NRC) [1]. The challenge is no longer the lack of information, but instead finding the required information at the right time. With the increase in available information, UMV operators performing C2 tasks will be stretched to accommodate the computational demands of complex network centric technology. To better understand the potential for overtaxing the UMV operator's cognitive capabilities a review of Human Information Processing (HIP) theory and associated supervisory control issues are presented below.

Human information processing models have been used as a framework to describe cognitive processes and characterize interactions with the environment. These models provide insight into cognitive process that occur when an individual perceives information from the environment, acts on that information, and responds to the environment [2]. The HIP models depict a sequence of serial processing stages where information from previous stages is manipulated, transformed, and/or combined with other information before passing to the next stage.

The HIP flow begins in the sensory stage when a sense organ encounters a stimulus that is within its capabilities and of sufficient intensity to initiate processing. At this stage, if attention is diverted from the stimulus, it is stored in a short-term memory store (STSS). Sensory storage is available, but is temporary and limited in terms of capacity and decay [3]. When a stimulus is attended to, it enters the perception stage where meaning is attached to its attributes to aid in detection, identification, and recognition of the stimulus (e.g., sound is detected, identified as warning, and recognized as critical). Perceptual processing occurs quickly and automatically with minimal attentional resources driven by sensory based bottom-up processing and top-down processing via long-term memory (LTM) [3]. Depending on the stimulus' attributes, either bottom-up or top-down processing may dominate. For example, when a stimulus' characteristics are ambiguous, learned rules and skills supplement the information required to identify and recognize information (e.g., radar image identified as a critical target). After perception, processed information then enters the decision making and execution stage [4]. Depending on the decision maker, task and environment, individuals may rely on different decision making processes [5]. An individual may utilize one or more means for decision making including 1) automatic, perceptual, pattern matching processes, 2) controlled, analytic decision making processes, or 3) heuristics and biases. Each of these requires the use of memory processing to gather information from LTM and actively rehearse it in working memory (WM). Once a decision has been reached, an action is selected and a motor response is executed. From the motor response, new stimuli emerge and the process begins over again creating a continuous closed feedback loop [4].

Human information processing stages are dependent on attention, and the processing that occurs following the sensory stage draws from a limited supply of attentional resources. Therefore, an individual's ability to attend to stimuli is limited and influences how information is perceived, processed, and acted upon. Information that does not receive required attentional resources will not enter consciousness. The momentary direction of one's

attention may be described in terms of selective attention. The limits of selective attention are realized when unnecessary elements of the environment are selected for processing. Although selective attention is critical in complex systems, most task environments require operators to attend to several sources of information simultaneously. A considerable amount of time sharing is needed, during which the abilities to divide attention and parallel process are essential. A prominent theory of divided attention in human task performance is the multiple resource model proposed by Kantowitz and Knight [6] and extended by Wickens [4,7,8]. The theory suggests a dimensional system of resources consisting of distinct stages of processing (encoding, central processing, and responding), sensory modalities (visual, auditory), WM processing codes (spatial, verbal), and response modalities (manual, vocal). Each dimension is thought to contain limited resources that can be distributed between and within tasks.

With respect to HIP and multiple resource models, UMV operators' cognitive workload can be described as the relationship between resource supply (HIP processing capacity) and task demand. When task demands exceed resource supply, an operator's performance decreases and mental workload is perceived. Of particular importance for UMV operator interface design is that the negative effects of workload are triggered when tasks are similar in the sensory modality, processing operations, and/or responses given by an individual [4,9,10,11]. However, when parallel processing is supported through the utilization of multiple modalities [4,12] a rich data environment can be realized, leading to a system design approach that successfully optimizes information processing, reduces workload, and maintains enhanced situational awareness in dynamic complex systems. This concept is expanded upon below with respect to leveraging user-centered design concepts in developing UMV operator interfaces to maximize information management and individual performance in C2 environments.

4.2.1.2 Environmental Stressors that Degrade Cognitive Performance

4.2.1.2.1 Impact of Provocative Environments

One of the benefits of operating in a network centric environment is that information requisite for effective C2 decision making can be supplied to UMV operators in the field. However, the environment UMV operators may be embedded in could adversely affect cognitive performance, subsequently degrading C2 decision making. In particular, environments such as surface and ground operations that induce whole body vibration, whole body motion, motion induced fatigue, and motion sickness and associated negative after effects are of concern. The critical issue is that UMV operators may be exposed to physiological stressors, such as motion sickness, that could degrade cognitive and/or fine motor skill performance with a potentially damaging affect on the attainment of a desired military effect.

With respect to whole body vibration and motion, and motion induced fatigue, the literature is inconsistent regarding their impact on cognitive C2 task performance. It is established that whole body vibration in the range from 2 – 12 Hz can effect human performance including decreased fine motor skills, fatigue, accident-proneness and health hazards [13,14,15]. However, the impact of whole body vibration is not completely clear because it is a multi-variate problem that is further compounded by individual differences [16].

Research on the impact of whole body motion on human performance has not revealed a direct relationship between provocative motion and cognitive performance, but it has established a positive relationship with motion sickness and degradation of fine motor skills [13]. Dobie [13] posits that dropout rates in whole body motion studies may indicate that individuals are capable of sustaining a high level of cognitive and general efficiency until they remove themselves from the provocative sensory environment. Research on the ability of individuals to complete C2 tasks while underway in ground vehicles shows that vehicle motion in a variety of

terrain types did not degrade cognitive performance in C2 tasks unless motion sickness resulted, in which case cognitive performance differences were found between moving and stationary conditions [17].

Motion induced fatigue is another plausible human performance detractor for UMV operators performing C2 tasks underway in ground and surface environments. The concern is that motion induced fatigue has shown a positive correlation with degraded sense of well being and lack of motivation [13]. This variant of motion induced fatigue called Sopite Syndrome, is related to motion sickness and results in individuals becoming unmotivated, drowsy, and experiencing loss of concentration resulting in task inefficiency and accident proneness that is not readily recognized by the sufferer or their supervisor(s) [13].

The important aspect to extract on whole body vibration and motion, and motion induced fatigue is that they are indirect contributors to degraded cognitive performance via motion sickness and sopite syndrome symptoms. They are also direct contributors to degraded physical abilities (e.g., fine motor skills) that may be required to manipulate an autonomous UMV C2 user interface. In addition, it has been shown that from a temporal perspective the impact of the aforementioned environmental factors on cognitive performance is linked to a step function instead of a linear function [13]. This may explain why their direct impact on cognitive performance has not been explicitly demonstrated in the empirical literature as a result of short exposure durations utilized in experimental designs. The impact of motion sickness on cognitive performance is discussed below.

Motion sickness is another example of a response to provocative environments that causes diminished cognitive and motor performance. It is plausible that UMV operators performing C2 tasks could be embedded on surface and ground platforms where seasickness and vehicle motion sickness are highly probable. With respect to seasickness rates among naval warfighters, Pethybridge [18] found in the UK Navy that 10% to 30% of naval crews suffered from seasickness during commonly experienced sea conditions and incidence rates of 50% to 90% in high sea states. The U.S. Navy's, Naval Medical Information Management Center reported that from 1980 to 1992, 489,266 new cases of motion sickness were diagnosed and 106,932 reoccurrences were recorded [13]. These figures represent a staggering loss of manpower and funds that heighten the importance of understanding the impact of seasickness on cognitive performance.

In regards to the human performance decrements associated with motion sickness, the findings are controversial depending on the type of motion sickness (chronic or acute) and the performance metrics used [19,20,21]. However, findings on chronic motion sickness in military personnel induced by sustained vestibular stimulation (e.g., motion) across multiple days revealed drowsiness, lethargy, and apathy as primary symptoms [22]. The impact of these symptoms included participants being incapacitated, refusing to perform assigned tasks, and spending a majority of their time sleeping or lying down.

Unfortunately, the use of pharmacological interventions to mitigate motion sickness introduces many problems. The efficacy and human performance decrements associated with anti-motion sickness drugs is subject to individual differences. However, the documented side effects of these drugs have been deemed unacceptable for individuals making complex operational C2 decisions, or in control of sophisticated or potentially hazardous equipment [13]. In particular, Cowings et al. [17] has shown that Promethazine (an anti-motion sickness drug), significantly degrades performance on cognitive and psychomotor tasks and decreases alertness.

While a majority of the literature on the impact of motion sickness on cognitive and fine motor skill performance has been centered on surface applications to drive ship hull design, some efforts [17] have looked at C2 operations in the ground environment using the United Defense C2V M4 vehicle (a four workstation C2

combat vehicle). Cowings et al. [17] used the C2V M4 vehicle and C2 tasks to measure performance on cognitive and motor skill tests, and motion sickness in an array of provocative, but realistic, terrains using physiological sensors and subjective reports. Seven of their eight participants reported motion sickness symptoms and composite cognitive and motor skill performance scores progressively declined during field exercises in a variety of terrains. Four of the participants indicated moderate to severe motion sickness symptoms that were not mitigated by short halts in vehicle movement. With respect to cognitive and fine motor skill performance, decrements in ability were greatest during vehicle motion and comparable to blood alcohol content (BAC) equivalencies at or above 0.08% in three participants during movement and two participants during vehicle halts.

4.2.1.2.2 Impact of Sleep Loss and Duty Cycle

Degradation of UMV operator's cognitive performance and information management capabilities in the operational environment is not limited to provocative motion, but may also arise from sleep loss and duty cycle (e.g., shift schedules). Sleep loss resulting from prolonged operations, duty cycle, and/or poor quality sleep due to motion sickness is a valid area of concern that may impact cognitive performance of UMV operators performing critical C2 tasks. Humans appear to have a limited ability to mitigate the impacts of sleep loss, but only when intrinsic motivation is sufficient, resulting in performance at pre-sleep deprived levels if wakefulness does not exceed 24 hours or the amount of sleep is greater than 50% of the individual's normal regimen [23]. The sleep loss research suggests that the relationship between sleep loss, performance and motivation is not a simple one, with motivation masking the effects of sleep loss on performance, but both motivation and performance gradually being diminished by increasing sleep deprivation. Signal [24] and Harrison and Horne [25] support the notion of sleep loss ultimately overcoming intrinsic motivation masking effects, stating that a host of cognitive skills required for decision making are reliant on the prefrontal region of the cerebral cortex, which is affected by as little as one night of sleep loss [26,27,18,29]. The skills that are affected include: attending to complex information while filtering out distractions, following a situation and recognizing the need to apply new strategies, lateral thinking and innovation, risk assessment, maintaining interest, controlling mood and behavior, the ability to self monitor performance, and the ability to communicate effectively [25]. All of the aforementioned skills are key components of effective C2 decision making in time critical situations, normal situations, and situations where normal conditions are slowly degrading.

In a network centric environment, the ability to communicate and monitor performance is critical for adding value to the network's information superiority. Autonomous UMV operators will inevitably be part of a time sensitive kill chain requiring concise communication with manned elements, and the ability to self-monitor performance is a concern from an automation bias and performance perspective (automation bias occurs when operators rely upon automated recommendations and downplay contradictory information) [30]. With respect to communication, the naturalness of speech, decoding of word meanings, and clarity of articulation have been shown to degrade with sleep loss [25]. Harrison and Horne [25] also noticed that sleep deprivation lead to increased confidence on ambiguous tasks indicating a degraded ability to self-monitor performance, which may foster automation bias when interacting with automated decision aids.

Another variable in the cognitive impact of sleep loss is the influence of the circadian system [24]. The combined effect of sleep loss and circadian rhythm produces the poorest performance at the circadian nadir [31]. The implication being that UMV operators working night shifts and experiencing sleep loss are more likely to experience performance decrements than their counterparts working a day shift [32].

4.2.1.3 The Need to Support Supervisory Control to Enhance Information Management

The sections above discuss the innate cognitive capabilities and limitations of UMV operators and how they could be decremented by the operational environment (e.g., provocative motion, sleep loss, and duty cycles), all of which is critical for designing user interface concepts that support information management in the complex C2 domain. An additional information management concern from a cognitive perspective is the need for appropriate levels of automation to support effective supervisory control and deter automation bias. Supervisory control involves an operator planning activities that are mediated by the system, implementing the plan via instructional commands to the system, monitoring the system to ensure the plan is executed, intervening when the system errs or needs assistance, and learning from the experience to understand what, why, how, and when the system took the actions it did to fulfil operator intent [32]. In information rich NCO environments, effective information management will be multi-variate in nature accounting for cognitive capabilities and limitations, environmental stressors, and appropriate levels of automation that facilitate cognition and supervisory control while avoiding automation bias pitfalls. All of these aspects are essential for supporting the use of knowledge based behaviors to complete C2 tasks involving planning, higher-level operation, and time pressured contingency interventions (e.g., time sensitive targets and system health failures). Discussed below are user-centered design operator interface concepts that show benefit for information management tasks.

4.2.1.4 References

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4.2.2 User-Centric Information Management Concepts for Autonomous UMV Command and Control

Given the vast expanse of data that is available to UMV operators in a network centric environment, the capabilities and limitations of HIP, autonomous UMV supervisory control issues, and the impact of environmental stressors on cognitive performance, it is essential that a user-centered design of information management user interface concepts is undertaken. With respect to information management in a NCO environment the challenge is not only an abundance of data, but that information is poorly organized, represented, and displayed to the UMV operator who has to allocate attentional resources to an array of complex activities. For these reasons, systems, displays, and technologies need to be developed to aid in task execution while accommodating cognitive processing of an operator.

With respect to current UMV operators, they are often hindered by issues such as high workload and reduced situational awareness (SA) due to the complexity of the system and visual saturation [1]. To mitigate these issues, UMV operator interfaces need to be designed with an understanding of where the HIP bottlenecks occur in a task flow and present information in forms that are easily perceived, interpreted, and responded to. Several means for presenting C2 information to autonomous UMV operators is discussed below, including multi-modal interfaces, why to avoid 3D visual displays, data fusion, and decision aids.

4.2.2.1 Multi-Modal Interfaces

Traditional design strategy has focused on visual interaction and this strategy is employed in current UMV operator user interface designs [1]. In depicting information using spatial or graphical representations, visualization techniques use the human visual system to facilitate comparison, pattern recognition, change detection, and utilize various cognitive skills by the human perceptual system. These techniques have used a relatively standard set of interaction paradigms, leveraging common visual constructs such as windows, icons, menus, and direct manipulation via pointing devices (WIMPs). The pervasiveness of these paradigms provides some measure of their success, yet they are limited when a user is visually overloaded. To overcome visual saturation, designers must consider new design approaches that allow individuals to process an optimal amount of essential data. An approach discussed below leverages the auditory system in concert with the visual system because second only to the visual system, the auditory system is one of the most important and highly utilized communication channels. The ultimate goal of this visual-auditory multi-modal interface concept is to realize a holistic design that incorporates theoretically sound, principally driven multi-modal interface components that achieve a genuine symbiosis between user and system.

Instead of constraining UMV operator information management to visual interaction conventions, augmenting information via other modalities may greatly enhance HIP. One approach with great potential is to leverage the auditory paradigm of Speech, Earcons, and Auditory Spatial Signals (SEAS). The main goal of this multi-modal interaction paradigm is augmenting traditional visual interaction with auditory cues to substantially enhance cognitive information management capacity. Multiple sensory system processing can substantially improve individual information management capacity by enhancing perception, augmenting sensory processing, and speeding reaction time. Within the SEAS paradigm, the design goal is to present information in a modality that is readily perceived and in a form that is readily interpretable. A new class of multi-modal interactive systems would ensue, which would leverage available user senses, adapt to specific user's perceptual and cognitive needs, and respond to such needs by facilitating intuitive interaction with users. System characteristics can then be guided by the capabilities of human performance in terms of sensory processing (e.g., is an auditory signal loud enough to be heard), perception (can both visual and auditory stimuli be identified by user), decision making (e.g., can a user's working memory be efficiently used or is there cognitive overload), and response execution (e.g., can a user respond both manually and vocally). Based on the HIP models discussed above, a multi-modal interface can be designed that reduces mental workload, overcomes HIP bottlenecks, and optimizes human performance.

Effectively applying auditory design guidelines to autonomous UMV operator interfaces may lead to improved C2 task performance by optimally distributing information processing across human sensory systems (i.e., visual and auditory). For example, Samman et al., [2] found that participants processed nearly 3x more information when it was distributed across various sensory systems (e.g., verbal, tonal, and spatial) as compared to stimulating a single sense. In general, the empirical literature on multi-modal interfaces suggests that speech, earcons, and auditory spatial cues can be processed simultaneously with minimum interference because such information activates distinct brain regions, thereby utilizing different HIP resources.

Realizing the full potential of multi-modality means not limiting the dimensions of HIP processing to the verbal-spatial dichotomies typically associated with sensory and working memory processing codes, and extending beyond vocal-manual response modalities. The findings of Samman et al. [2,3] suggest that leveraging multi-modal sensory systems, working memory, and response modalities promotes maximum information management capacity. Within this concept, the independence of multi-modal resources can be leveraged in multi-modal interaction design to strategically utilize alternate resources at different points in operator-system interaction to streamline an operator's cognitive load. Thus, effectively designed multi-modal

displays will facilitate perception such that an operator searching a complex system can accurately detect when, what, and where in the environment relevant information is located.

To validate the utility of multi-modal interfaces for autonomous UMV C2 Samman, Jones, Stanney, and Graeber [4] implemented the interface design tenets bulleted below and adhered to speech, earcons, and spatial audio design guidelines garnered from open literature.

- Speech, earcons, and auditory spatial (SEAS) cues can be processed simultaneously with minimum interference because such information activates distinct brain regions utilized by different HIP resources.
- SEAS should exploit human's capacity to attend to a wide variety of different sound dimensions, including location, pitch, intensity, and semantic content to direct attention and enhance human information processing.
- SEAS should design parallel task processing with non-overlapping HIP resource demands.
- SEAS suggest that an individual can recall more in two tasks designed with different types of materials combined than in a single task, especially if the modalities or types of representation are very different.
- SEAS auditory displays are most appropriate for simple and short information sources.
- SEAS uses earcons, auditory icons, and data auralization to semantically map information to particular sound parameters (e.g., spectral type, rhythmic regularity, pitch, timbre, register, dynamics) or environmental sound cues to convey intended messages.

The multi-modal autonomous UMV operator interface Samman et al. [4] designed was empirically evaluated against a purely visual interface concept for C2 of UMVs. Participants were asked to complete a set of primary tasks associated with a tactical situation display where they captured radar images of targets and paired UMVs with the targets based on the required weapons for effective prosecution. Participants also completed secondary tasks associated with detection and resolution of UMV health issues. All participants completed conditions requiring control of one, two, or three groups of four UMVs where each individual UMV required supervisory control.

The general pattern of results for all of the performance metrics recorded support the concept of integrating SEAS design tenets into C2 displays. The objective of the SEAS auditory cues in this study was a reduction in operator attentional and visual perception bottlenecks, while also assessing how many autonomous UMVs a single operator could effective control. It was hypothesized that the integration of SEAS cues would reduce perceptual bottlenecks created by a purely visual interface, thereby allowing operators to perform perceptual tasks faster and more consistently.

Overall, the results suggest that the benefits of multi-modal interfaces are realized as workload increases, particularly for secondary selective attention tasks [4]. This may be attributed to improved operator alertness levels and the opportunity to process secondary tasks and formulate an answer in parallel with primary tasks when using a multi-modal SEAS interface. In addition to gains in primary and secondary task performance, the data also revealed that subjective assessment of workload was perceived as lower with the use of the multi-modal SEAS interface than the baseline purely visual interface [4].

4.2.2.2 Three Dimensional Visualization

Three dimensional display technologies come in a variety of form factors to suit an array of applications. The assortment of 3D displays includes spatially immersive displays (SID) (e.g., domed simulators, virtual environment CAVEs), stereoscopic head-mounted displays, spatially augmented reality (SAR) displays, shutter goggles, autostereoscopic displays, and multi-layer depth displays. Intuition suggests 3D displays should afford a symbiosis between an operator and the local or remote physical environment they are working within, thereby enhancing SA and decision making. However, many studies have shown cognitive performance decrements for certain tasks when using 3D displays as compared to traditional 2D displays (e.g., God's-eye or bird's-eye views) [5,6,7,8]. These studies have shown that tasks requiring precise discrimination of relative depth or distance in the z-axis (orthogonal to the display), local surface orientation, relative curvature, relative size, distance bisection, and co-planarity are no better with 3D than with well designed 2D displays and in some cases significantly worse (relative distance, local surface orientation, relative curvature, and global orientation).

Three dimensional displays have also been shown to be sub par for information organization, a critical component of autonomous UMV operator information management. Cockburn and McKenzie [9] examined the efficacy 2D, 2 1/2 D (receding incline plane), and physical and virtual 3D models for information organization and retrieval. The results indicated performance decrements with the use of physical and virtual 3D information storage systems, suggesting there is limited use of the third dimension in information organization and retrieval tasks.

4.2.2.3 Data Fusion

Data fusion is a method for information reduction that classifies, correlates and filters sensor data to provide UMV operators a more concise picture of the battlespace [10]. Sensor data inputs are gathered from onboard (e.g., RADAR, FLIR, IFF, etc.) and offboard sources (e.g., JTIDS), then analyzed for information quality and proportionally combined to reduce ambiguity and inaccuracy. Data fusion provides UMV operators a comprehensive tactical picture that is requisite for effective battle management by fusing the data sources in a manner that operators can have high confidence in the identification and position of tracks. The power of data fusion is seen in Figure 4-1 where a tactical picture is created using un-fused and fused tracks respectively. This figure highlights the benefits of sensor data reduction whereby a visual display is created that is easier to interpret and it enhances decision making.

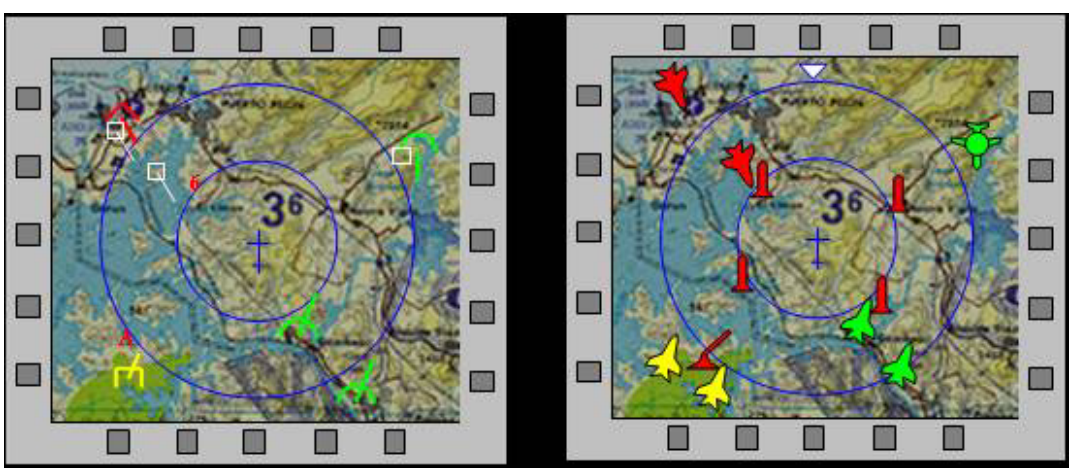

Figure 4-1: Comparison of Tactical Situation Displays with Unfused and Fused Data.

4.2.2.4 Decision Aiding

As systems grow more complex, the use of automation to help operators complete time critical human supervisory control tasks will be needed. However, Cummings [11] notes it is equally important to recognize the essential role operators play in supervisory control tasks and allocate decision making functions between humans and computers accordingly. In the C2 domain, uncertainty and time pressure are elements in the decision making process and therefore, decision aids must provide autonomous UMV operators the ability to comprehend the battlespace and how various decisions may affect the future. Cummings and Guerlain [12] suggest that decision aids for C2 applications must support knowledge-based behaviors (KBB) that require complex cognitive processing beyond application of rule based behaviors for known situations. Command and control tasks utilize KBB because the C2 environment is unscripted, open-ended and requires information integration and evaluation from a multitude of sources to form a decision in response to events in the battle space.

A key to a successful C2 decision aid for a network centric environment is the inclusion of human-computer interactive sensitivity analysis tools to determine how warfighter adjustments of decision variables could impact an overall cost function [13]. Allowing warfighters to interact with decision aids provides safety benefits, fosters SA, and permits operators minor adjustments of computer-generated solutions creating a robust system capable of flexibly responding to uncertain and unexpected events. Cummings [13] notes that a critical design element of the sensitivity analysis capability is a data presentation user interface that indicates the severity of cost function change and qualitative information regarding the impact of resource allocation shifts on the intended effect.

Another reason it is critical that operators are kept in the autonomous UMV and decision aid supervisory control loops is that UMVs are envisioned to operate in areas of uncertainty, making them subject to automation “brittleness” [13]. Automation brittleness is the concept that automated decision-support algorithms are typically fixed in code in initial design phases, and therefore unable to resolve unforeseen circumstances [14,15,16]. Higher levels of automation are ideal for rigid tasks that do not require flexibility in decision making and have a low probability of system failure [17] Conversely, higher levels of automation are not recommended for dynamic decision making environments like C2 and thus decision aids incorporating interactive sensitivity analysis are requisite because of the risks and the complexity of both the C2 domain system and the inability of decision aids to be perfectly reliable [18].

An example of a current decision aid is the Associate concept where the decision aid is able to assess the external and internal situation, make decisions based on a common view of the mission goals and plans and operator intent, and execute tasks in accordance with these goals [19,20]. As the state of the battlespace changes and data becomes available, data fusion provides a synthesized tactical picture to the autonomous UMV operator through the Information Manager (IM). The IM is responsible for deciding if and how the synthesized data will be presented to the operator. The data is also available to a Situation Assessment function along with measures of operator performance and intent gained by monitoring actions and comparing those to pre-determined plans and goals. Once a picture has been developed of the situation the Associate can make decisions based on a shared view of the mission goals [21]. Through task networks determined by comprehensive cognitive task analysis of the operator tasks in the battlefield, the Associate can determine a course of action bounded by the operator’s intent and mission goals.

The Associate concept utilizes the following four levels of authority [21]:

- Manual: The associate system may never propose a plan on its own. The operator has full control over the plan’s proposal and execution. The operator sends plans to the associate, and the associate responds like an assistant when the plan has been executed.

- Permission: The associate system may propose a plan, but may not activate it without explicit permission from the operator. The associate sends the proposed plan to the operator. The operator can accept or reject the plan or submit his/her own. The associate only executes plans that are commanded by the operator. After a pre-programmed time with no operator response, proposals are implicitly rejected.
- Veto: The associate system may propose a plan and may activate it if the plan is not explicitly rejected by the operator within a given timeframe. The associate sends the proposed plan to the operator. The operator can accept or reject the plan or submit his/her own. However, if the plan is not explicitly rejected or implicitly rejected (because the operator submitted his own plan) by the operator within the pre-programmed timeframe, the associate can execute the plan.
- Autonomous: The associate system may propose and activate a plan. The associate system has full control over the plan's proposal and execution. Communication is limited to the associate informing the operator after execution is complete.

Each of these authority levels can be assigned independently to the plans generated, giving the operator flexibility to choose which portions of the mission planning and tasking s/he wants the associate to undertake. Categories for assigning authority to the associate might include information management (i.e., display configuration, data transfer), mission contingency planning (i.e., attack planning), vehicle contingency planning (i.e., aircraft and systems failure), and mission plan execution (i.e., attack scripting).

The concept of an Associate is beneficial from the perspective of lowering cognitive demands utilized in decision making, however, the level of authority provided to the Associate has its trade offs with regard to supervisory control, automation bias, and automation brittleness. These are all facets of decision aids that need future research, particularly within a swarming autonomous UMV network concept.

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4.2.3 Trust in Time Delayed Systems

4.2.3.1 UMV and Time Delays

4.2.3.1.1 Notions of Time Delays

The operative context of UMV is characterized by their complex dynamic environment. In such situations, control is not total. Indeed, the operator's actions are combined with the process dynamic and he is not alone in this process [1]. Therefore, the environment in which he is acting leads him to update, according to the context, his mental representation of the system. The operator's lack of action is equal to a change in the problem to solve. This kind of environment makes more critical the management of UMVs because this system presents important time delays; cognitive needs introduced by the evolving aspects of the environment are thus associated with latency.

The concept of time delay gathers a certain number of subdivisions (Figure 4-2). We can define a response delay, an information delay and a feedback delay. Each of them has a specific influence on the conduct of robotic systems.

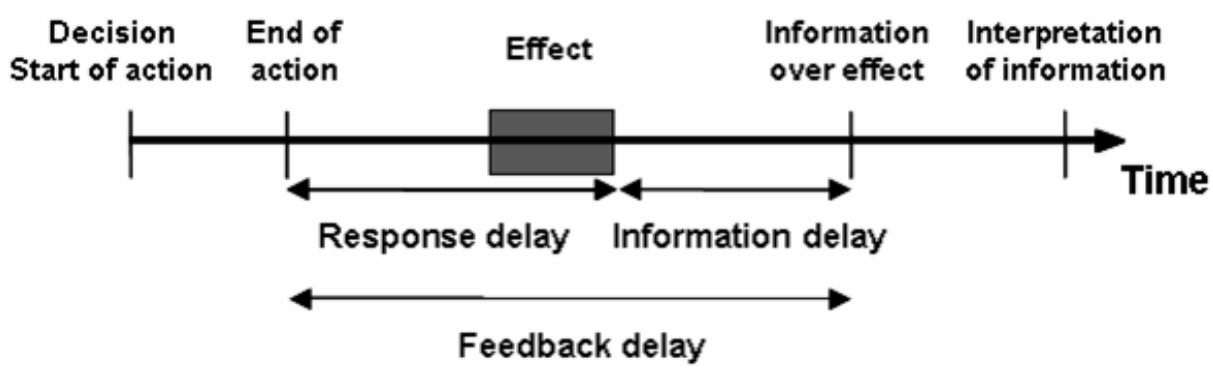

Figure 4-2: Time Delays.

A response delay is the lag between the action and its effect on the controlled variable [1]. It is under the influence not only of automation, but also of actions (nature, time and sequence of execution). Indeed, from the operator's point of view, an information delay (time delayed information over the effect) can be added by itself to the response delay. A too long information delay will lead to decrease for the operator in observing his own actions effect. Also, it makes the mental evaluation of the plan making toward a specific goal more difficult [2]. The difficulty of observing the cycle "information gathering-diagnosis-action-evaluation of actions" all in one makes the building of mental representation of the process evolution more

complicated [3]. In this case, the operator must hypothesize the current state of the system in order to make decisions and corrects it according to his results. However, a slick anticipation may be obviously not very relevant, in situations where uncontrolled factors can interfere with the actions effects. With these difficulties, one found an extra error production. Indeed, Ferrel [4] shows in a tele-operation task, that the presence of information delay increases the production of errors (59% of errors made versus 6% in non time delayed conditions).

Information over the process given to the operator is not always synchronised with events, but can be produced with some time delay. The feedback delay, or latency, is thus the sum of the response delay and the information delay. We notice an obvious deterioration of performance when time delay happens, because of the lack of synchronization between the operator's time and the process time. In practical, we note, in a technological context, that it is not possible to reduce latency to zero: Moreover, one will be careful for this latency to be either constant, or equal for all sensorial feedbacks, and inferior to a critical threshold [5].

The nervous system itself, have some time delays in the visual-motor loop. Nature has developed some processes allowing us to forecast the consequences of our actions and thus to anticipate the sensorial feedback up to a certain level. With regard to visual information, Keele and Posner [6] have estimated this threshold at 200 ms. In best cases, these predictive mechanisms allow us to compensate latency until a threshold of 250 ms: any time delay higher than this value damage the performance. Nevertheless, over this crucial threshold, operators show a certain form of adaptation to time delays by using specific strategies allowing them to reach a certain performance in their activity, while accepting a lowering system dynamics.

4.2.3.2 Move and Wait, a Strategy Facing Time Delays

With time delays, operators develop some strategies allowing them to fulfil their aim. So, they seem to adopt on their own initiative, and spontaneously, a "Move and Wait" strategy (MaW), i.e., they act, wait for the feedback (in general a visual one) before beginning a new move. This strategy allows operators to limit the incoming of unstable and unwanted movements [7], but without excluding them. In return, the task is considered, by the operator, as divided into various intermediary goals [4]; the fluidity of the movement is then particularly affected. The activity is no longer considered as a whole, but like a succession of given actions. Consequently, we notice a linear relation between the completion time and the intensity of time delay, and this, even for complex and time consuming tasks [8]; the main effect being due to the wait for feedbacks.

Beneath 0.2 s of time delay, operators do not seem to be obliged to use the MaW to obtain good results. Beyond this value, not applying this strategy compels the operator to provoke an oscillation of the system. Indeed, the late perception of system responses leads the operator to modify his instruction (most of the time by amplifying it). The operator, noticing that this action is over dimensioned will configure an opposite instruction which will be in itself amplified. And thus, this process will oscillate and diverge.

While most of the beginners have jerky non-coordinate and over amplified movements, training leads to "smooth" movement. In fact, the training modifies the quality of concerned representations, in order to make them more flexible in the action at a given moment. So, we notice a smoothing of the imperfections, with the coming of a strategy of delayed feedbacks: the operator makes a certain number of actions without waiting for feedbacks (MoveS and Wait). This use of delayed feedbacks shows some characteristics:

- It shows up after a great number of trials.
- It is rather the exception than the rule.

- It's only use during in mastered activity (trust in the system).
- The operator doesn't try to predict the position or the velocity of its actions, but only the success or the failure of the action.

4.2.3.3 Visual Perception and Time Delays

The visual perception, through artificial sensors, is one of the main means to extract from the environment the necessary elements to a decision-making. It allows evolving UMV order. Yet, the operator must use remote artificial vision systems and therefore through a dissociation between visual space and action space. This involves a reduction of environmental clues resulting from the contraction of the visual field, and then tends to make the perception of the action space complicated [9]. The presence of the screen provokes by itself a change in the control space [10]. This perceptive activity can be described by the completion of two distinct tasks: the exploration of the environment and the search for targets within a visual scene delimited by a sensor field. As far as this first task is concerned with those feedback delays, we note a similar behaviour in tele-operation tasks. So we find again negative effect of time delay in exploration; performance decreases through a linear function with time delay. Consequently, going down to 2.5s of time delay, we notice that performance reduces by 50% [11].

Added to these problems, we found certain alterations of the perceptive mechanisms implicated in visual research. Indeed, according to the Features Integration Theory [12,13] various strategies can be brought into action with this type of activity. However, with time delays, only a serial features conjunction mode is chosen (sequentially attention based process of exploration which is very expensive in cognition and not very fast) [14]. This choice will lead to a compromise produced by a central mechanism of management [15] between cost, performance and trust associated with a given strategy.

Being in a downgraded situation will tend to select a strong and statistically sure mode in order to carry out this task of targets research. This choice is made in spite of being costly. Indeed, a non detection becomes critical in cases of strong time delays; the cost of new research initialization becomes too important compared with a serial exploration. Two mechanisms can be at the origin of this behaviour. First, fear of an incorrect and ineffective realization of the task, creates certain anticipation based on previous experiments. Thus, the waste of time from a non detection is foreseen by the operator. He selects, consciously, this mode of research in order to prevent this kind of incidents. Second, a cognitive control/regulation mechanism would carry out during the activity a cost evaluation of the tasks realization. This last would involve the creation of a feeling of difficulty, with the consciousness of loosing control of the situation, i.e., a "failing risk of the cognitive capacities because of the saturation of the cognitive resources" [16]. This consciousness leads the operator to select a strong serial features conjunction mode in order to reduce this feeling of difficulty.

From a certain control, it becomes possible to release some resources from the time delays management to prevent a "cognitive overload", and thus to restore a certain confidence in the system. From this confidence is restored, the acquisition of new research mode would be possible. A redistribution of additional resources towards other tasks is then possible. This implies that the use of research mode strongly depends on the existence of a free resources span. The reduction of this last (starting with one second of time delay) involves the impossibility of more powerful research modes "choice".

Time delays in a multi-tasks system involve quickly a cognitive capacities overload, and thus induce a change of strategies used in the realization of the activity. We note the use of MaW, with regard to the exploration of the environment, or the inhibition of powerful perceptive mechanisms of visual research. These facts bring the operator to wonder about his self-confidence and the trust in the system. This questioning is the result of

uncertainties due to system time delays, involving difficulties of representation and thus of understanding the situation.

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4.2.4 Uninhabited Military Vehicles and Trust

4.2.4.1 Time Delays and Representations

The UMV system with all the inherent time delays creates spatial and temporal uncertainties for the operators. This means that real time reaction is not possible [1]. Keren and Roelofsma [2] suggest that uncertainty and time delays affect the decisions through only one common dimension. Time delays eliminate the effect of certainty such as uncertainty would do, because time delays carries part of risk, which leads to uncertainty. The problem arises from dissociation between the operator's universe and the UMV universe. The more important this variation is, the more it is difficult to synchronize process time and operator's time. This involves great difficulties in answers adjustment, which must be relevant with the time sequences of the environment. The operator encounter two linked difficulties in this process, to adapt the production of commands in due time, and to build and maintain a representation of the system in a temporal and implicitly spatial scale because of the environment dynamics. The cognitive requirements related to the UMV management are fulfilled by the creation of an internal representation of the system, its evolution, and the action plans. This represents more or less the reality and depends on the nature of the external representations [3], which can be considered as the primary support of the activity. Their informational levels are directly associated with the quality of the operator's internal representation. Thus, the simpler the operator's system model is, the closer the feedbacks must be to reach an acceptable level of performance. The more distant feedbacks are, the less the operations on these mental representations are able to work, and the more the model needs other regulations such as anticipations. Paradoxically, anticipations require relatively powerful system of internal and external representation.

Time delays in a system leads to some difficulties of building and maintain relevant mental representations with respect to a given objective.

4.2.4.2 Representation and Understanding

The representation of the world allows its understanding. However, the knowledge by itself of the system in its environment cannot fully satisfy understanding. Indeed, understanding is not a property of environments; there is no understanding without an intention which directs the analysis and building of relations on a limited part of the environment components [4]. Thus, intention and understanding are closely linked: understanding a situation consists in building a coherent representation of the world for the goal to achieve and, to update it to satisfy the evolving requirements of this universe. The difficulty of understanding the situation comes from the weak quality of the system representation. Creating consistency between past, current, and future events and the operator's intentions is complex. The lack of predictability leads to a restriction of anticipations, a short-term control, a permanent high workload [4,5,6], and an increased need for confidence [7]. Problems related to the building of an operative system representation in an environment, leads to a progressive loss for the operator's understanding over his controlled/supervised system.

4.2.4.3 Understanding and Trust

In the case of UMV, the symbolic intermediaries create, for the operator, a certain representation of the world [8]. This synthetic view of the reality raises the question of trust in the system. Indeed, information for the

operator presents some specific deformations of the vehicle environment (be it wanted or not). Then, the understanding of the situation depends of the consistency, towards a given intention, of the external representation of the world provided by the system, and the world itself. The ease and stability of this relation are directly related to the quality and the speed of trust acquisition. Well, the temporal gap between action and his effect tends to increase the uncertainty and then the need for trust [9,10].

Trust can be defined as "the attitude that an agent will help achieves an individual's goals in a situation characterized by uncertainty and vulnerability" [11]. In the case of a decision aid, trust is "… the extent to which a user is confident in, and willing to act on the basis of the recommendations, actions, and decisions of an artificially intelligent agent" [12]. This can be determined by a stake with a probability of an adverse outcome [13]. Two different notions can define trust: self confidence (egocentric) and trust in the system (exocentric). It is their ratio which indicates the level of acceptable risk (internal and external) for the operator. Then, we can consider trust like a risk which is accepted to prevent other risks [4].

4.2.4.3.1 Trust: a Regulator of the Cognitive Compromise

The operator confidence seems to evolve with the mechanisms of acquisition and particularization of his know-how [14]; the ease for detecting the behaviour of the system and its supporting state indicators increase this confidence [15]. When confident, the operator tends to automate certain specific know-how with regards of his task. This behaviour, associated with a certain simplification and loss of flexibility of the system management, structures and facilitates the causal analysis. The operator makes "more" (in term of performance) with "less" (in term of knowledge) [4]. However, the flexibility of adaptation to the context, resulting from confidence, cannot be directly associated with the know-how. Indeed, confidence is more related to an "ability of management" than with a know-how control. The degree of confidence in a system allows the operator to explore a more or less wide field of his cognitive compromise with respect to certain know-how, and then allows him to increase his possibility of actions on the situation. This flexibility of the cognitive compromise authorizes, from time to time, the operator to take more risks (a lower control) in exchange of a greater adaptability in his task. This risky behaviour obeys to a principle of homeostasis, in accordance with the modification of the environment [16]. Then, we can define a judgement of confidence like a metacognitive activity [17,18,19]; confidence is a regulator of the operator's level of control. In the case of a low confidence, the operator tends to select a conscious and logical control mode based on his metaknowledge, which is associated with a great workload. On the contrary, a high confidence involves a reduction of the level of control, with an increasing production of routine errors in the case of overconfidence [4,13].

4.2.4.3.2 Trust and Automation

Confidence of an operator in an automated system determines its behaviour toward the system [20,11,21,7]. Lee and Moray [22] suggest that operators use automatic modes in accordance to their previous level of confidence, the probability of failures and their skills in manual control. Decisions to switch over from one mode of command to another can be predicted by the ratio between the level of confidence in the system and the operator's self-confidence [23,24,25]. Therefore, the choice of a manual control shows a confidence in the manual mode better than in automation. This choice is made on a subjective evaluation of the reliability of the system and on the own skills of the operator. Indeed, an operator will not use a reliable automatic system if he does not trust it. However, in the case of system which presents failures, the operator can judge his own capacity to manage it manually less reliable and riskier than in an automatic mode due to workload increase [26,27]. Then, the operator prefers to switch to an automatic mode while reinforcing his level of supervision. This can be confirmed by the fact that the level of detection of failures by the operator varies conversely with the reliability of automation [28].

In the first interaction, we note, without failures, a quick raise of a(n) (over)confidence of the operator towards the system [29] especially in the case where decisions are taken from visual information [17]. This confidence remains until important failures happen. Indeed, occasional failures do not induce a change of the control mode as long as theses are bearable for the operator with a lower cost in mental workload. Nevertheless, Lee and Moray [22] have shown that whatever problems encountered confidence in automation settles slower than it decreases.

We note that certain researchers consider that man, in his interaction with an artificial system, reproduces the same behaviours of management of trust as those observed in social situations between individuals [30,31,32,33] and this in spite of the fact that technological artefacts do not have motivations. These researchers talk even about "personality" of the system [34] and about its links with the operator's personality.

4.2.4.4 Conclusions

The difficulties (exploration of the environment and visual searches) associated with time delays lead the operator to reconsider his confidence about the system, often with a negative view. It's not in favour of a strict control by the operator, but rather for supervision and task sharing between the operator and the system. Nevertheless, we have to be careful to not impoverish the operator's activity and then consequently his understanding of the process. In the context of a hermetic system (for the operator), the activity of supervision tends to decrease. Indeed, the use of automation and then the difficulty of control are associated, in a timely manner, with a reduction of skills and the ability to supervise the system [35]. Recovery of errors by the operator is then particularly affected.

With these problems must be added risks about the implication of the operator towards the UMV in his control/supervision. Indeed, spatial and temporal distance between the command station and the aircraft lead the operator in a no interpretation status of the bonds between these two entities. Thus, the intermediary space between these two entities is considered like a black box where the outputs do not seem to be related to the inputs of the operator. This space tends to be an independent operative intermediary between the operator and the UMV. This creates a gap between these two entities which move in two different spatial ant temporal universes, and then leads the operator to work only in the universe which can be directly controlled. Then, the operator will consider his task only toward an external artificial representation of the UMV (the screen in the command station) and not in relation to a real, and distant, massive aircraft.

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4.2.5 Future Research

As knowledge, technology, and autonomous UMV system capabilities progress, HSI research efforts must also continue to address user-centered design aspects of information management for C2. Five pertinent areas of enabling technology research are discussed below, including, multi-modal user interfaces, augmented cognition, collaborative tools, chat applications, and supervisory control of autonomous UMV swarms. See the "Advanced UMV Operator Interfaces" chapter within this publication for additional design concepts.

4.2.5.1 Multi-Modal Interfaces

Continued multi-modal interface research is needed to further understand HIP and how best to leverage cognitive resource and attention pools utilized in processing sensory inputs, decision making, and response execution. The concern is that HIP benefits from presenting information multi-modally could be tempered if the costs for modality coupling and switching are high. Another vein of research is an examination of the potential benefits of multi-modal interfaces to mitigate the effects of visually induced motion sickness in provocative environments while allowing the operator to remain effective in performing C2 tasks. Multi-modal user interface research should also investigate the potential for supporting reduced manning concepts and personnel selection criteria for effective use of multi-modal systems. Finally, in conjunction with a deeper understanding of how multi-modal interfaces leverage HIP concepts, research should also be undertaken to compliment the augmented cognition concept discussed below. In particular, the creation of modality based user interface augmentation guidelines for cognitive bottleneck resolution in response to real time assessment of operator workload and the HIP resources overburdened.

4.2.5.2 Augmented Cognition

Augmented cognition is a neuroergonomics enabling technology concept that leverages HIP models, user interface augmentation concepts founded in HIP theory (e.g., multi-modal user interfaces), and physiological sensor technologies. The goal of augmented cognition is to develop a cognitive feedback loop between operator and system that allows the system to sense when an operator is experiencing unacceptable levels of cognitive workload, mental fatigue, and/or stress. When the aforementioned contributors to cognitive performance decrement are detected, an augmentation manager appropriately alters the user interface or information presentation modality to mitigate cognitive performance decrements.

From an applied perspective, the goal of augmented cognition is to increase the amount of information that operators can process and utilize in decision making, reduce manpower requirements, and improve selective attention during stressful battlefield conditions. These applied goals are related to autonomous UMV C2 by directly impacting the number of automated UMVs an operator can control and providing an effective means for enhancing cognitive processing and information management. Augmented cognition research efforts relating to autonomous UMV C2 [1] have utilized a suite of physiological sensors (pupil size, EEG, ECG, EOG, EMG, and functional near infrared (fNIR)) and statistical process control techniques to assess an operator's cognitive state, while employing an array of user interface augmentations to mitigate high cognitive workload contributors. Barker [1] conducted a series of experiments to address cognitive bottlenecks in working memory, executive function, sensory input, attention, and response generation. The experiment results demonstrate that aiding from closed-loop augmented cognition significantly improves autonomous UMV operator performance on both primary and secondary C2 tasks. The primary tasks that showed improvement were associated with ingress and attack phases for suppression of enemy air defences (SEAD) mission where the operator was controlling one, two, or three strike packages consisting of four UMVs. The secondary tasks that showed improvement were detecting and responding to vehicle health alerts.

While research in the domain of augmented cognition is based on a solid theoretical foundation, substantial work remains to validate the efficacy of the concept at both basic and applied levels. Future research is also required to improve physiological sensor capabilities, packaging, and optimal placement. In conjunction with sensor development is the improvement of techniques for processing the sensor data and selection of appropriate user interface augmentations. Augmented cognition is a promising concept that could be an enabling technology breakthrough for autonomous UMV C2 as the associated body of knowledge continues to expand and mature.

4.2.5.3 Chat Applications

The use of chat applications and instant messaging were discussed above as potential tools to enhance a variety of collaborative C2 scenarios. They are revisited in this section because they may result in an unexpected consequence of the convergence of network centric technical capabilities and societal trends. Cummings and Guerlain [2] used chat during a decision aid study as an operationally valid secondary task to measure workload. Unexpectedly, they found that the chat application and the information contained in the chat messages dominated operator attention allocation while performing time sensitive retargeting of tactical tomahawk missiles. Cummings and Guerlain's [2] intent was to create a realistic secondary task that required spatial reasoning skills in a chat application that was familiar to naval personnel. The chat application conveyed messages containing basic information about missile status, instructions for action, or queries for information from superiors about past, present, and future elements of missile and target status. Interestingly, Cummings and Guerlain's [2,3] found that participants became fixated on the chat application despite explicit instructions that time critical retargeting was the highest priority task and answering chat queries was the lowest priority task. In addition, participants were told that incoming chat messages were generated by a scripted computer program and their responses were not being read by a human. In spite of stressing instructions to only attend to chat when no other tasks were occurring, many participants responded to chat queries before attending to the more pressing time sensitive target problems. Cummings and Guerlain [2,3] suggest that the over-attention to the chat application degraded the overall task performance of some participants, which could have costly operational consequences.

The findings of Cummings and Guerlain [2,3] indicate future research may be needed to understand the predilections of an e-enabled warfighter population that regularly uses social connectedness applications, such as chat and IM, in their work and personal lives. Inevitably, current and future warfighters responsible for C2 of UMVs will bring with them generational culture biases where compelling personal connections are established via e-enabled medium. As network centric technical capabilities evolve and incorporate common place commercial applications, future research should be directed at understanding the societal impact of these technologies on the military community and the possible impact on training, tactics, and procedures as well as warfighter performance.

4.2.5.4 Decision Aiding for Autonomous UMV Swarm Control

Autonomous swarming UMV networks will create new aspects of operator decision making complexity in C2. One of the primary advantages of autonomous UMV swarming networks is the ability to process large amounts of sensor data in short periods of time to optimally achieve an intended effect. Humans will continue to be needed in autonomous swarm networks to ensure safety and monitor progress toward an intended effect as part of the supervisory control and decision making loops. However, Cummings [4] notes that because of the revolutionary nature of swarming technology, futuristic operator interaction with complex autonomous UMV swarms is not well understood, and more research emphasis needs to be placed on operator requirements, strengths, and limitations for supervisory control. Cummings [4] suggests that future research in this domain should include an investigation of the interaction of increasing vehicle autonomy on human supervisory control, the effect of increased levels of automation in decision-making, and how situation awareness is affected by increasing levels of vehicle autonomy and automated decision making. The crux of the future research issue is to devise an autonomous UMV swarm – operator feedback loop that allows the operator to understand what, how, and why a swarm behaves like it does [4].

While current and past research has focused on determining levels of automation that promote effective operator-system interaction [5,6,7,8,9,10], little has focused on the C2 domain, and virtually no research has been done on operator-autonomous swarm interaction. Cummings [4] notes that with the creation of

autonomous UMV swarm networks that communicate with both humans and each other, the supervisory control problem space increases in scope and complexity. From a future operator decision aid design perspective, the implication is that it will be paramount to determine the impact of automation levels for decision making, the effects of different collaboration levels between UMVs, the interactions between the two automated systems (i.e., decision aids and swarming UMV networks), and how best to represent to the operator multi-objective cost functions that should either be minimized or maximized [4]. From a high level perspective, future research on supervisory control and operator decision aids for autonomous UMV swarms should focus on the impact of increasing vehicle autonomy on supervisory control, the effect of increased levels of automation in decision making, and how situation awareness is affected by the increasing levels of UMV autonomy and decision making automation Cummings [4].

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4.3 MIGRATION OF OPERATOR CONTROL: HUMAN FACTORS AND TEAMING ISSUES

4.3.1 Background

As noted by Gawron [1] specifically with regards to uninhabited aerial vehicles (UAVs), the advent of uninhabited military vehicles (UMVs) has created a host of new human factors challenges which arise primarily because the vehicle and the operator are no longer necessarily co-located [2]. Perhaps one of the most unique of these UMV specific human factors challenges concerns migration of operator control. While migration implies movement, the construct of control migration used in this work will be similar to that described by Kahne [3] and includes changes in the locus of control within functional, temporal, or physical domains. For instance, in current long endurance UAV operations, control may be transferred between operators in a control station (e.g., crew changeover), between control stations (e.g., vehicle handoff), or among members of a crew (e.g., task execution) [4]. Although migration of operator control has been a factor in several UAV mishaps [5,6], there are currently no relevant studies in the literature addressing this issue in either UAVs [4] or other UMV systems. For autonomous UMVs requiring only supervisory control, studies of air traffic control (ATC) can serve as an analog supervisory control domain [7]. However, while ATC issues instructions to aircraft, ATC's role is ultimately advisory rather than mandatory since legal responsibility for the safety of the aircraft and its occupants rests with the pilot [8]. Thus, this section will necessarily be more of a theoretical discussion of migration of operator control rather than a review of empirical evidence. In particular, migration of operator control in UMVs will be explored as a novel application of the fields of team processes and team communications. First, the current state of knowledge regarding migration of operator control in the most mature UMV technology (e.g., UAVs) will be reviewed with the understanding there are logical applications to future ground or maritime UMVs as well. This will be followed by discussions of the potential reasons for and the advantages and disadvantages of migrating operator control, the impact of migrating operator control on team dynamics, important issues which need to be resolved, and potential strategies to address or mitigate those issues.

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4.3.2 Migration of UAV Operator Control

4.3.2.1 Levels of Control

Standardization Agreement (STANAG) 4586, Standard Interfaces of the UAV Control System for North Atlantic Treaty Organisation (NATO) Interoperability, defines five different Levels of Interoperability (LOIs) or degrees of control for UAVs (A. Kirschbaum, personal communication, August 17, 2005):

Level 1: Reception and transmission of secondary imagery or data.

Level 2: Reception of imagery or data directly from the UAV.

Level 3: Control of the UAV payload.

Level 4: Control of the UAV, without takeoff and landing.

Level 5: Full function and control of the UAV to include takeoff and landing.

Control complexity increases from level 1 to level 5 with each subsequent level including the capabilities of the former level(s) (Figure 4-3). Implicit in this control taxonomy is the understanding that a variety of transfers between LOIs may be necessary during a single UAV mission. STANAG 4586 describes these LOIs without reference to a specific UAV category. Nor does the standard clearly state if these LOIs apply only to the dedicated UAV control station or if they also apply to downstream users of the information derived directly from the UAV. Certainly allowing a user more control of the system has the potential to enhance mission execution by decreasing the number of intermediary personnel. However, the higher the LOI, the more costly the equipment and the more specialized the training required [1].

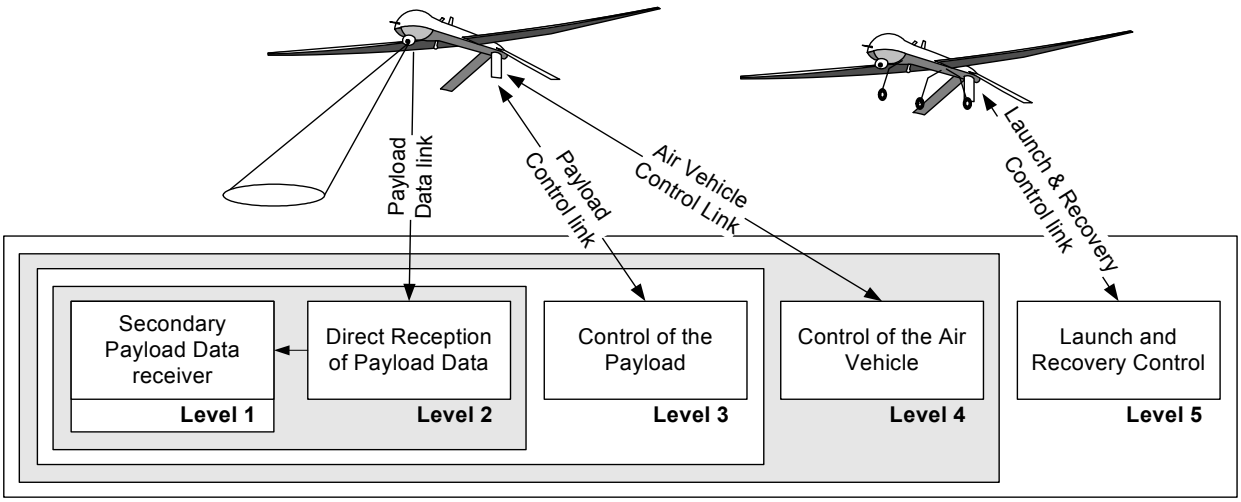

Figure 4-3: Levels of UAV Interoperability and the Respective Communication Links.

4.3.2.2 Types of Control Migration

4.3.2.2.1 Changeover

A changeover is the migration of vehicle or payload control from one (group of) operator(s) to another (group of) operator(s) at the same location. It is possible during a changeover to have a face-to-face debrief. Also, since the same equipment is used, there is no need for system changes or data transmission link reconnections. Additionally, a changeover will generally not require coordination with ATC or other external command and control (C2) agencies. Types of changeovers include:

- Time transfer: Time transfer implies the operators are identical in skill and function and control is transferred because the endurance of the vehicle exceeds that of the operator(s). Very long UAV missions may require several time transfers.
- Function transfer: Function transfer implies the operators must accomplish different tasks during the same mission, possibly in another system-mode or even at a different part of the system. For example, an operator may merely perform navigation and safety monitoring tasks in coordination with ATC during the ferry to the theatre of operations (TOO), but once in the TOO, may change to a more payload driven way of operations (Figure 4-4). This form of transfer can be combined with a changeover.
- Skill transfer: Skill transfer implies the operators are trained differently and the transfer is required as the vehicle performs different tasks. This kind of transfer may be performed when less experienced operators operate the vehicle or payload for simple tasks while more skilled operators take over for complex tasks.

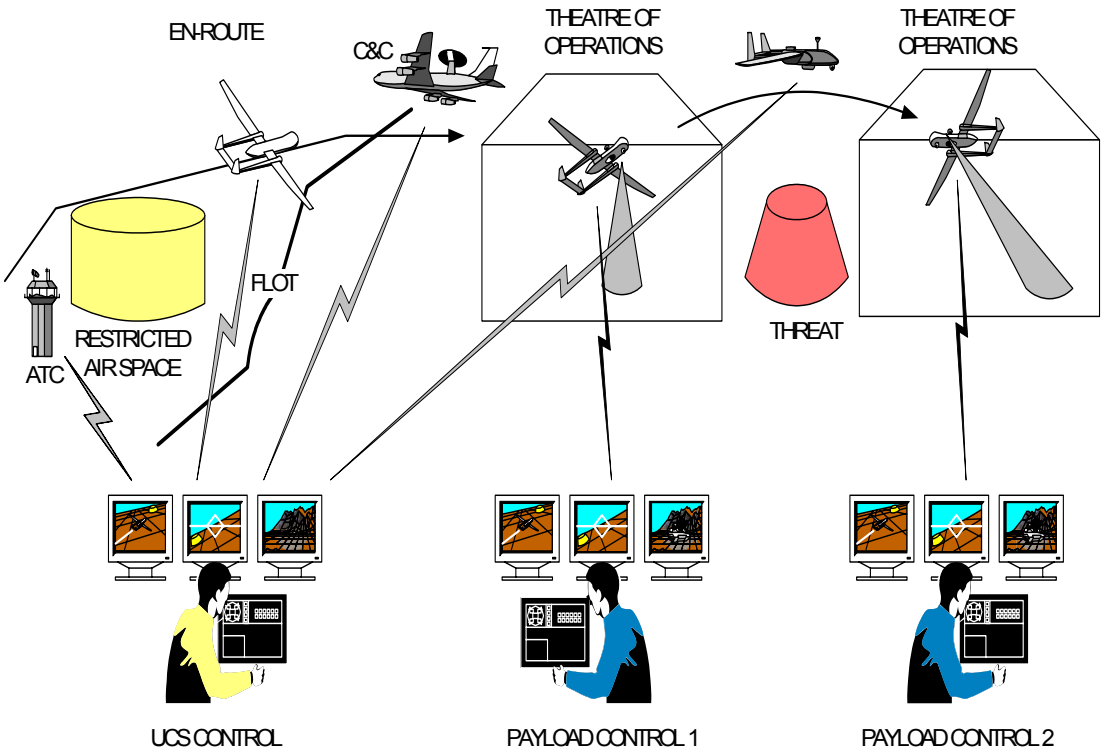

Figure 4-4: Functional Transfer and Time Transfer of the UAV during Different Mission Phases.

A handoff or handover involves the migration of vehicle or payload control from one location to another location. Often the term handover is used when the transfer is performed between two similar control systems (e.g., two identical control stations). In contrast, the term handoff is used when the transfer is performed between two dissimilar control systems (e.g., changes between LOIs).

4.3.2.2.2 Vehicle versus Payload

Both a changeover and a handoff may be used to transfer control of both the vehicle and payload or solely the payload. A vehicle transfer implies operators transfer control of the vehicle to include the following: a) vehicle command and control, b) navigation, c) voice communications, d) vehicle safety and emergency responsibility, e) payload control, and f) data transmission link control and monitoring. In contrast, a payload-only transfer implies operators retain control of the vehicle (items a-d) and only transfer control of the payload. Payload-only transfer appears less complex than vehicle transfer because overall responsibility for the vehicle does not change. However, if a large area must be covered or objects of interest are mobile, a high degree of coordination is required between the vehicle and payload operators in order to keep the UMV path within sensor constraints. This may significantly increase the workload of both operators and have a negative effect on the operators' situational awareness (SA).

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4.3.3 Reasons for Migrating Operator Control

4.3.3.1 Limitations Necessitating Control Migration

4.3.3.1.1 Temporal Limits

Many current human-machine operations are continuous in character and the nature of these operations often precludes a temporary shutdown because of economical or other constraints [1]. Such operations also have the potential to create situations in which people are driven to work continuously. This has certainly been the case in military operations where technological advances in night vision devices and other sensors coupled with a global battle space has led to a doctrine of continuous, around-the-clock operations [2,3]. Thus, current military endurance UAV systems operate at distances requiring beyond-line-of-sight communications and can remain airborne for nearly 1 – 2 days. Future military and civil UMV systems are projected to operate for durations of days to months at a time [4,5,6].

A critical problem for such endurance UMV systems is the predictable decrements experienced by individuals continuously performing cognitive tasks for sustained periods [1,3]. In a study comparing the effects of fatigue versus alcohol intoxication, Dawson and Reid [7] found the hourly performance decrement for each hour of wakefulness between 10 and 26 hours was equivalent to the performance decrement observed with a 0.004 percent rise in blood alcohol concentration. Therefore, after 17 hours of sustained wakefulness, cognitive psychomotor performance decreases to a level equivalent to the performance impairment observed at a blood alcohol concentration of 0.05 percent. This is the proscribed level for alcohol intoxication in many western industrialized countries [2,7] and exceeds the 0.04 percent limit established by the Federal Aviation Administration for aircrew [8]. Mullaney, et al. [9,10,11] conducted studies of continuous performance on

monotonous tasks requiring sustained attention and found such performance produced rapid fatigue effects after only 6 hours. More than half of the study participants experienced psychological disturbances such as mild hallucinations, illusions, disorientation, and derealizations, mostly after 18 hours. Finally, the operational impact of fatigue-related performance decrements was demonstrated by an Air Force Safety Center study which found fatigue was present in 12.7 percent of the most serious class of Air Force mishaps occurring during fiscal years 1972 – 2000 [12], costing the Air Force an estimated 54 million dollars each year [2].

While it is obviously unreasonable to expect a single operator to control a UMV with an endurance greater than 1 day, it is also evident operators will need to be changed during UMV operations spanning more than the majority of a day. Summarizing NASA's experience testing UAVs, Del Frante and Cosentino [13] stressed the importance of adhering to established crew rest requirements, implying UMV operations are not immune to fatigue-related operator performance decrements. Additionally, studies of personnel working 8, 10, and 12 hour shifts [14,15,16,17,18] have shown increased fatigue and poorer performance with 12-hour versus eight or ten hour shifts. Collectively, these studies suggest migration of operator control is a necessity as UMV endurances routinely exceed 12 hours, although optimally it should be considered after 8 – 10 hours.

4.3.3.1.2 Physical Limits

As previously mentioned, some military endurance UAVs currently operate at great distances from the control station, necessitating beyond-line-of-sight communications [5,6]. As satellites or other UMVs are used to relay signals over the horizon, variable time delays or latencies of one or more seconds are introduced. However, latencies greater than one second mean real-time feedback necessary for effective manual control is not available [19]. Additionally, many UMV operators are dependent on real-time imagery from cameras mounted on the remote vehicle in order to manually control the vehicle [20]. This requires data transmission links between the vehicle and control station with high bandwidths and low latencies, but increasing distance between the vehicle and control station, especially beyond line-of-sight, necessarily forces constraints on data link bandwidth and latency [20,21,22]. Such data link constraints can result in limited temporal resolution, spatial resolution, color, and field of view of imagery irrespective of onboard sensor capabilities [20,23]. With great enough distances, the frequency and immediacy of transmitted images may decrease to the point where direct manual control of the vehicle is significantly degraded [21,24]. Besides vehicle control, experimental evidence has also shown visual tasks such as target detection and identification, tracking, and orientation are affected by degraded image quality, slow update rates (< 2 Hz) and high latency (> 2 sec) [20,25].

Increased automation (e.g., supervisory control) and predictive displays have been utilized to mitigate the effects of control latency [24,19]. However, there are situations where manual control modes may be preferred over supervisory control or a fully automated vehicle [20]. In such situations, an alternative strategy may be to handoff control to more proximate control stations. This approach has relative merit over supervisory control in situations where concerns over control latency and quality of visual imagery or sensor information are critical, such as in highly dynamic and changing environments where near-real time data is required for complex decision-making [21,20]. These situations might include weapons employment [24] when there is a risk for fratricide or responding to a malfunctioning or damaged remote vehicle. Additionally, some current military UAVs by design must be manually controlled during takeoff and landing [21,6,20]. In these circumstances, a control station needs to be located in line-of-sight distance of the airfield to minimize data transmission delays and optimize manual control. However, once airborne, control is handed off to a geographically remote control station where the UAV is operated via supervisory control, thereby minimizing the equipment and personnel which must be sent to a potentially vulnerable forward base of operations.

4.3.3.1.3 Functional Limits

Migration of control within a crew may occur when a UMV system is designed such that control is functionally divided between non-equivalent controllers. For instance, current military UAVs are typically operated by at least two operators with one responsible for vehicle control and the other for payload control [21,20]. While the payload operator usually does not directly control the vehicle, it may be possible for this individual to exercise indirect control of a UMV if it is designed to autonomously adjust its path to stabilize camera or sensor images. Functional migration of control also occurs in some military tactical UAVs (TUAVs) where responsibility for takeoff/landing and en route control is divided between two operators. In this situation, the external pilot (EP) interacts with the TUAV while in direct visual contact at the site of takeoff or landing. In contrast, the air vehicle operator (AVO) is inside a control station and interacts with the TUAV through an interface of sensor displays and controls during the en route phase of flight [26,6,27]. While control is functionally divided in part out of necessity because of task-specific human-machine interfaces (HMIs), Barnes et al. [26] also demonstrated differences between EPs and AVOs with regards to operator abilities across multiple cognitive skill sets.

4.3.3.2 Advantages of Control Migration

4.3.3.2.1 Mitigate Fatigue and Optimize Operator Vigilance

In highly automated systems such as UMVs, much of the operator's task load is supervisory in nature, consisting mainly of passive monitoring of system parameters and remaining alert for malfunctions [28,20]. This trend towards placing the operator in the role of passive monitor has continued despite years of vigilance research demonstrating such roles make maintaining a constant level of alertness exceedingly difficult [29,30,31,32] and predispose to "hazardous states of awareness" [33]. Studies of vigilance tasks have consistently demonstrated a vigilance decrement beginning as early as 20 – 35 minutes after initiation of a task and characterized by declining numbers of correct responses and/or increasing response times [29,3,19]. One study found declining detection rates after only 2 – 3 minutes of task performance, with target detection rates eventually plateauing at 70 – 80 percent of initial rates [34]. Prolonged vigilance work generally invokes subjective feelings of boredom and monotony and invariably induces decreased levels of physiologic arousal. Boredom in particular can become apparent within minutes of the onset of a monotonous task and is associated with decreased performance efficiency and increased drowsiness. However, when coupled with the need to maintain high levels of alertness, vigilance tasks can be perceived as quite stressful [3,35]. This stress predisposes the operator to short term fatigue which typically manifests as long response times, missed signals, and brief interruptions in performance due to gaps or lapses in attention [36] as well as increased decision errors or decreased thruput (e.g., maintain accuracy at the expense of performance speed) [3]. Thus, it should be expected that tasks requiring the sustained attention of UMV operators will be susceptible to degraded performance and increased risk for operational errors [28].

Although initial research [1,37] with complex monitoring tasks typical of the ATC task environment suggested vigilance decrements did not occur, more recent studies are supportive of the vigilance decrement in both simple and complex monitoring tasks [29,39,36,40]. The validity of these concerns in UMV operations was demonstrated in a study of Army UAV operator performance under two experimental conditions involving 8 – 10 hour versus 3 hour flights [41]. Target detection and recognition performance as well as crew reaction times were significantly degraded during nocturnal operations involving the longer flights while no nocturnal changes were observed for the shorter flights. Likewise, two studies [36,40] using an ATC task found the time to detect and the frequency of missed traffic conflicts increased significantly over the course of just 2 hours. These vigilant decrements were attributed to increasing lapses in attention rather than a generalized fatigue effect.

One of the best ways to overcome these effects is change, whether using work breaks, rest pauses, or split shifts, although the benefits of rest pauses may derive more from subjective factors such as relief of boredom [3]. Warm [42] in particular recommended continuous vigilance monitoring tasks be kept to less than 4 hours in duration. Regardless of the method of change, it will necessarily involve the migration of control to another operator, whether in the same or another control station. Thus, migration of operator control plays a potentially critical role in the maintenance of optimum operator performance and decreasing risk for operational errors.

4.3.3.2.2 Operator Functional Specialization

Unlike manned vehicles where crew size is limited by vehicle payload constraints and all operator functional capabilities must be resident in the onboard crew, UMVs offer a distinct advantage of allowing these functional capabilities to be distributed over a multitude of potentially geographically dispersed specialists. In essence, a UMV crew is limited only by data transmission link accessibility. Given the massive amounts of information currently down-linked from UMV systems [28] and the information processing constraints necessarily imposed by the sequential decision-making of human operators [43], it is key to distribute this information so it can be more efficiently processed for mission accomplishment [28]. This point was highlighted by a study of human systems integration (HSI) issues in military UAV mishaps which found an association between failures in the cognitive domain and operational errors [44].

Beyond the issue of information processing, UMVs offer the opportunity to employ task specialization beyond the level hereto seen in traditional manned vehicles. The potential need for task specialization in UMV operations can be understood given the current military experience with UAVs in which training and attentional issues are frequent causal factors in human error-related mishaps [45]. As noted by Barnes et al. [26] in their study of Army UAV operators, experience improves operators' cognitive throughput, allowing them to devote limited attentional resources to future problems while automatically attending to immediate perceptual and motor tasks. This was echoed in NASA's lessons learned testing UAVs [13] that "even more important than practicing the emergency procedures is practicing the normal procedures to the point that they are second nature" so anomalies are addressed with increased attention. Thus, experience serves to increase an operator's cognitive efficiency in problem solving by effectively increasing attentional resources [19]. Unfortunately, the cognitive efficiency obtained via experience is specific to the tasks experienced and not broadly generalizable [26].

Given the task-centric nature of expertise, consideration should be given to the creation of specialty teams to intervene and handle uncommon or off-nominal events. Such teams could rehearse infrequent tasks and explore potential outcomes, thereby developing proficiency in situational problem solving prior to encountering the actual event. For example, rather than training all operators to handle emergencies, specialty teams could be trained to take control of the vehicle and troubleshoot a malfunctioning or damaged UMV. These emergency teams could operate from remote control stations equipped with enhanced displays to aid diagnosis and allow predictive simulation. Such methods have been used successfully in the U.S. space program [28].

Functional specialization may also be utilized in non-emergent, nominal situations to optimize the central role of the human decision-maker within the system. In traditional manned combat vehicles, the local operator has the responsibility to authenticate targets and trigger weapons because they are presumed to be in the best position to assess the situation and make timely decisions. However, UMVs allow this function to be migrated to other team members possessing higher levels of technical or combat expertise such as a target detection specialist or experienced mission commander, thereby improving the confidence level of information

presented to controlling authorities [28]. Additionally, functional specialization allows for increased training program efficiency since all personnel don't need to receive equal training. The FAA has explored this issue with regards to training air traffic control specialists [46] and the Air Force has adopted this approach in training MQ-1 Predator operators on takeoff and landing.

4.3.3.2.3 Workload and Multiple Vehicle Control

There currently is a limited body of human factors research suggesting one operator may control more than one UMV under relatively idealized conditions to include closely coordinated and correlated vehicle activities, a stable environment, and reliable automation [38,47,48,6]. However, research has also demonstrated that operator performance controlling a single vehicle is significantly degraded when heavy demands are imposed by payload operations [41,49,25]. This would suggest the ability of an operator to attend to multiple UMVs may be severely compromised under non-idealized conditions, especially if one vehicle is malfunctioning or damaged [6]. Additional human factors research is available examining situational awareness in ATC, an analog for supervisory control of multiple vehicles. Endsley and Rodgers [50] found air traffic controller accuracy was significantly impacted by the number of aircraft being controlled and situational awareness declined dramatically when the number of aircraft exceeded 8 – 10. This is consistent with the magic number "7 ± 2" in memory research [51] which states there are finite limits on human information processing beyond which people tend to forget. Two studies [52,22] examining air traffic controller performance when passively monitoring aircraft under free flight conditions found a significant decrement in situational awareness when controllers had to handle 17 versus 11 aircraft. Additionally, a study examining control of multiple retargetable missiles [38] found operators could effectively control 8 – 12 missiles, but performance degraded with 16 missiles. The preponderance of the evidence thus suggests greater than 12 vehicles potentially represents a cognitive saturation state for controllers interacting with semi-autonomous vehicles requiring only the setting of new goals [53].

Given the suggested limits to an operator's ability to manage multiple UMVs, migration of control may be utilized as a workload mitigation strategy. For example, an operator controlling multiple UMVs under high workload conditions (e.g., multiple vehicle requests for operator attention) could transfer control of one or more UMVs to other operators under low workload conditions, even as part of normal operations. In cases where a single UMV requires sustained attention because of a backlog of vehicle requests for operator attention or off-nominal operating conditions, control of this high workload UMV could be transferred to an on-call operator or supervisor akin to current ATC practices. The ability to transfer control of UMVs based on workload prevents a single operator controlling multiple UMVs from having to adopt triage-like procedures for handling multiple attentional demands [28].

4.3.3.2.4 Payload Control

As already alluded to during the discussion of multiple vehicle control, performing payload tasks can significantly increase operator workload and degrade operator performance. In current military reconnaissance UAVs, vehicle and payload control are typically divided between a vehicle operator and a payload operator [21,25]. Van Erp and Van Breda [25] concluded such a crew structure was reasonable in light of findings that consolidating vehicle and payload control within a single operator substantially degraded performance. Likewise, Barnes and Matz [41] studied a UAV control station configuration which required a single operator to perform both aviation and target acquisition functions. They found operators became focused on the targeting function to the detriment of situational awareness and vehicle control, leading the authors to question the wisdom of using a single operator. Two additional studies demonstrated attentional fixation and cognitive tunneling during target analysis which degraded performance on other tasks irrespective of level of automation or use of auditory cueing [47,49]. The task of manipulating a camera image, analyzing targets,

and keeping track of cardinal directions appears to be sufficiently challenging that timesharing with other tasks such as vehicle control becomes virtually impossible. Finally, Van Breda and Passenier [54] noted operator performance was poor when utilizing "double-stick" controls where one joystick controls airframe heading and speed and the other camera heading and pitch. However, this is not surprising given such control arrangements predispose to perceptual confusion which increases the potential for action slip errors [19].

Nevertheless, for optimal flexibility and cost effectiveness, it is desirable to allocate both vehicle and payload control to one operator [54]. It may therefore be necessary to delineate circumstances under which vehicle and payload control may be safely performed by a single UMV operator and when control of the payload should be transferred to another operator [6]. This may be decided prior to a mission or payload control may need to be transferred during a mission in response to a dynamically evolving situation. As previously discussed, a UMV operator's ability to perform payload-oriented visual tasks such as target detection and identification, tracking, and orientation is impaired by low temporal update rates and long transmission delays [20,25]. If vehicle control is adequate for the task using some form of supervisory control, it may only be necessary to handoff payload control to a more proximate control station, potentially eliminating the need for full control stations in forward locations. Additionally, the ability to handoff payload control to those directly requesting the camera imagery or sensor data (e.g., target detection specialists or fielded forces) could increase the efficiency of data collection and eliminate the need for coordination with an intermediate payload operator. At the extreme, control of weapons could be transferred to the forces requesting their employment, hopefully decreasing the risk for fratricide.

4.3.3.3 Disadvantages of Migrating Operator Control

4.3.3.3.1 Situational Awareness

While there are good reasons to consider utilizing migration of operator control in UMVs, it is important to also explore the potential pitfalls. Indeed, migration of control may well constitute a critical and potentially high workload phase for UMV operators [6]. For example, several military UAV accidents have occurred either directly during or indirectly as the result of changeovers or handoffs [6,55,27]. In handing off control between stations, mishaps have resulted when the station receiving control was improperly configured [27]. During changeovers, mishaps have resulted because of the new operator's decreased systems awareness [55]. More broadly, there is also concern for an acute decrement in crew situational awareness when control is transferred to a crew not currently involved in the ongoing mission [55]. Kidd and Kinkade [1] demonstrated the existence of such an operator change-over performance decrement in the ATC environment. Controller performance was markedly decreased over the first 5 minute period following assumption of controller duties. This change-over performance decrement was mitigated by about 50 percent if either parallel control or auditory-plus-visual monitoring was employed as a pretransition condition. Another study examining operational errors in ATC [56] found errors were most frequent during the first 15 minutes after assuming controller duties and nearly half occurred within the first 30 minutes on position. Likewise, a study of Army UAV operators [41] found operators preferred longer over shorter rotations because they perceived the longer rotations allowed for better situational awareness of the tactical environment.

4.3.3.3.2 Complex Teaming Situations

Migrating operator control can create distributed crews with dynamically changing membership which may have significant associated costs in terms of the increased complexity of crew coordination and communication [57,6]. Breakdowns in team performance, cooperation, and communication have been shown to be a contributing factor in military UAV mishaps [45]. Complex teaming situations dictate the need for highly efficient, structured, and reliable communication. Unfortunately, the nature of human-human and

human-machine teams in high stress environments tends to create an unfavorable climate for successful communication. With respect to human behavior, emotion, information overload, and a lack of situational awareness comprise a few of the factors which impede the production and processing of messages, resulting in low fidelity communication.

Supporting complex teaming situations is further complicated by the densely bureaucratic nature of military and governmental bodies. The culture and structure of these types of organizations has historically been characterized by rigid, formal, and delayed communication. Large, structured networks constrain communication, which results in delayed information processing and a lagging response to environmental stimuli. A change in organizational structure from a traditional management hierarchy to a self-organizing system of self-managed, mixed-entity teams can improve the military's ability to respond to critical C2 situations.

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4.3.4 Effects of Control Migration on Concept of Teams

4.3.4.1 Teams Versus Groups

A group refers to a small set of organizational members comprising three to fifteen actors who regularly interact for the purpose of a common goal. All teams qualify as groups; however, all groups do not fulfill the criteria required for classification as a team. Teams are behaviorally distinct from groups on the dimensions of performance requirements, interdependence, and accountability. “A set of two or more individuals who are expected and required to interact dynamically, interdependently, and adaptively to accomplish their goals, but do not are still a team – they are simply an ineffective team” [1]. The existence and prominence of teaming in organizations is a significant distinguisher of organizational structure and culture.

4.3.4.2 Types of Teams

Teams may be classified according to four general structures: traditional work teams, long-term project teams, network design structures, and parallel teams [2]. These structures may be further characterized by formality, temporality, purpose, and membership. Therefore, teams may be distinguished from one another in terms of formal designation within a system, lifespan of the team, tasks and functions, designation of goals, interchangeability of skills, and the extent to which team members possess membership on multiple teams. An additional aspect is the notion of distribution; do team members reside locally or remotely within and/or external to the organization? This is a critical factor because a distributed or virtual team demands highly flexible, coordinated, and specific communication. Watson-Manheim and Bélanger [3] noted the dependence of virtual teams on communication technologies for accomplishing goals, yet these same teams experienced significant problems with communication-based work processes.

As the relationship of human and computer interaction evolves, the notion of what has constituted a human-member team must be changed to include nonhuman entities (e.g., autonomous UMVs). This broadening of relationship definition can still be loosely characterized within the traditional definition of team.

The migration of operator control to autonomous agents is grounded in the need of team entities to achieve mission success. Because teams have greater performance than work groups, this fulfills the criteria of meeting performance requirements. Consequently, optimal mission performance with respect to migration of operator control is dictated by the interdependence of humans and machines. Successful decision making is determined by the cooperation and coordination of all team entities. The third criterion is illustrated by the shared accountability of man and machine in mission success. Have the appropriate exchanges occurred for operator control from human to machine and vice versa?

Successful team function is dependent upon team member collaboration, trust, and technology. One aspect of how communication is important is its role in information behavior. Sonnenwald and Pierce [4] determined the why, what, and how were relevant concepts for group work contexts in C2 environments. "C2 team members need to collect, synthesize and disseminate information to create an understanding of the current battlefield situation and to anticipate future battlefield events". One should also consider the who and when. Therefore, military teams can be understood as functional organisms, coordinating work processes among team actors to achieve macro and micro level system goals within specified timeframes.

Coalition operations require the coordination of dynamic and culturally-diverse teams. Regardless of whether the teams comprise humans, UMV members, or both, the principles of intercultural communication may apply. Cross-cultural differences may present challenges for facilitating intra-team and inter-team coordination. These differences can be evident in team member attitudes and behaviors, and more recently, have been attributed to primary differences in group cognition and behavior [5]. Collectively, these variables can cause undesirable or hazardous behavior during team operations. Team interactions should be structured to manage uncertainty and anxiety for face-to-face and virtual contexts.

4.3.4.3 Distributed and Dynamically Changing Teams

Virtual teams are groups in which the members are geographically distributed but technologically connected to support asynchronous and/or synchronous communication for the purpose of coordinating behavior and goal achievement. In this context, technology platforms are critical foundations for forging network relations and permitting teamwork. Virtual teams provide an organizational structure contrary to the high-level hierarchies of military and government bureaucracies. The result reflects a flattened, lean, fluid, specialized and responsive network.

Qureshi and Vogel [6] identified three types of adaptive social processes virtual teams experience: technological, work, and social adaptation. The adoption of new technologies for communication, the application and integration of technologies to team member ways of working, and the emergence of social norms related to technology affect the way virtual teams adapt to the environment. Virtual teams are communication and technology intensive. "The challenge for virtual teams is in allocating tasks based on knowledge and skill in an environment that is often dispersed across space, time and organizations". This environment is further complicated by the communication demands of culturally-diverse team members. Lee-Kelley, Crossman, and Cannings [7] suggest a "focus on attributes of persons, situational expressions of these attributes and the relation of personal attributes toward others in the work group, may be used to explain some of the relational issues that spatial and temporal separation in the virtual team may create". Managers and organizational designers should consider the additional complexity of cultural diversity and how it impacts relational issues among team members.

In developing communication protocols for UMV teams, the dimensions of virtual organizations proposed by DeSanctis, Staudenmayer, and Wong [8] may be useful. The characterization of space (e.g., spatial dispersion

of organizational members), time (e.g., the degree of asynchronous operation), culture (e.g., norm, value, behavioral variability), and boundary (e.g., organizational dispersion) provides a framework for developing communication standards. As previously noted, virtual teams have similarities when compared with traditional team structures; however, because of the heightened dependency on information communication technology (ICT), understanding the organizational processes at the supra and micro system levels becomes more critical for virtual teams. Only when this knowledge is obtained and observed can virtual teams be effectively and properly supported. For example, the transfer of UMV system control from operator to operator is a team process. By understanding the vigilance issues, the constraints of operator control transfers, and other environmental variables, ICT can be optimally structured.

4.3.4.4 Dimensions of Team Performance

4.3.4.4.1 Organizational Culture and Structure

Organizational processes occur at every system level: the individual components, the environmental context, the system goals, and the organizational resources (e.g., people, technology, etc.). When a keen understanding of the inner workings of a system is established, leaders occupy an educated position to plan and manage change. Ali, Pascoe, and Warne [9] reinforced findings from the literature regarding the role of organizational culture in effective social learning and organizational change. Organizations which sustain an environment of member empowerment, forgiveness, trust, individual and organizational commitment, information sharing, openness of decision-making, and cultural cohesiveness enable effective social learning. Organizations which uphold these values create environments where members are able to engage in quality learning. Open communication is a primary catalyst for achieving organizational learning [10]. “Social control is particularly valuable when the need for sharing tacit knowledge increases over socially impoverished channels of virtual communication, where conflict may escalate due to teamwork issues engendered by cultural difference in communication and problem-solving styles and approaches” [11].

Organizations must maintain high levels of adaptability to achieve an optimal level of survival/success. “An adaptive structure requires organizations to develop dynamic capabilities to modify current practices in response to dynamic changes in the environment” [11]. Many have applied a deterministic approach to communication technology, and view technology as the source of impact in a social network. A social network approach indicates the converse. According to a social construction perspective, the relationship of technology and structure is indicated by a simultaneous affecting of each other [12]; “the composition of content and context are not predetermined by technological design or by the prior existence of certain social groups”.

Cultural differences may exist across team members on the dimensions of learning style, thinking style, teamwork experience, functional expertise, uncertainty threshold, and intelligence (e.g., analytical, practical, and creative) [11]. These differences may create barriers to building trust and consequently retard the development of team cohesion [7]. To further complicate team functioning, language usage can result in inaccurate, ambiguous communication.

High performing virtual teams tend to have members with experience in multicultural environments. “The difficulty of getting a group of disparate people to come together and work effectively cannot be over emphasized” [7]. One approach to managing intercultural communication is to minimize adverse behaviors by building trust among culturally-diverse team members and across teams. “The status report genre, bug/error notification genre, update notification genre, and phone meeting management genre system emerged as key communication structure that both reflected and shaped members’ temporal and work practices” [13].

This reflects the suitability of structuring communication and work processes for improved coordination in distributed teams. The enactment of work routines provides stability for team structures. Team stability is positively affected by homogeneous rules. Heterogeneous rules are associated with increased novelty and team adaptation [14]. Therefore, it is advisable to conceive of the appropriate levels of stability for C2 teams and balance heterogeneous and homogeneous behavioral rules accordingly.

4.3.4.4.2 Satisfaction

The team is important to an organization because its effectiveness determines organizational mission success and member satisfaction. The literature has numerous examples of research supporting the relationship of member satisfaction and member productivity. With the transition to increasingly autonomous UMVs, some might dismiss team member satisfaction as irrelevant. However, as long as HMI is present, satisfaction remains important for the human elements of the team. High satisfaction of team members varies directly with team commitment and committed team members are critical for operational success.

4.3.4.4.3 Qualitative Composition of Teams

Teams are comprised of organizational members; each member presenting emotional, psychological, and behavioral differences. One dimension of personality is the typing of individuals as A or B (TABP). Keinan and Koren [15] established a significant relationship between team member personalities and group performance. “Our findings show that when the task is competitive, the effect of TABP on performance differs from when the task is noncompetitive.” Teams primarily comprising type A personalities are directly associated with improved team performance for competitive tasks and are generally more productive than those teams with a majority of type B personalities.

But, the literature is generally contradictory in the area of group composition. For example, homogeneous teams have been reported as both positive and negative on the measure of performance. It has been argued trait similarity increases team member attraction; this positively affects relational satisfaction and team performance. Conversely, research has also documented the positive relationship of dissimilar group membership and team performance. Theoretically, members with varied opinions, knowledge, and experiences will provide a greater quantity of unique problem resolutions resulting in optimal performance for complex environments.

Teams comprising fundamental knowledge, skills, and abilities (KSAs) are better equipped to fulfill mission goals. KSA requirements are not completely transferable from in-person teams to virtual teams and vice versa. The densely computer-mediated communication environment of the virtual realm requires a heightened adeptness at managing digital conflict, text-intensive interactions, and media selection [16].

4.3.4.4.4 Trust

Virtual teams are not immune to the requirements for success that traditional teams face. Team effectiveness is determined by connecting with key team members for information sources (e.g., knowing who to call for specific questions), using appropriate communication media (e.g., e-mail, telephone, listservs, intranets, etc.), and establishing a positive organizational culture. Watson-Manheim and Bérlanger [3] found virtual teams are highly influenced by establishing organizational norms for communication media choice, providing appropriate training, and managing team member relationships.

4.3.4.4.5 Training

The literature indicates teamwork does enhance performance; therefore, teams can benefit from focusing on improving member relations. Training is a primary vehicle for creating a positive teamwork environment. This may include building skills in coordination [17]. Team members, human or machine, must acknowledge communication, provide meaningful information at appropriate time intervals, use standardized language, use feedback mechanisms, address conflicts, recognize uncertain and complex environments, and identify problems. Teams will likely benefit from training in conflict management, uncertainty avoidance, learning to select appropriate communication channels, and how to design appropriate messages. Indeed, training is an important and viable component of performance enhancement programs. Stout, Salas, and Fowlkes [1] suggest "that team training equates to providing trainees with necessary KSAs (e.g., team competencies) to engage in cooperative behavior and to efficiently interact with one another to attain effectiveness". In their study of training effects in complex environments, pilots who were trained in teamwork behaviors were better prepared to deal with complex problems using team competencies.

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4.3.5 Important Issues in Control Migration

4.3.5.1 Interoperability

Implicit in the concept of migration of operator control is the assumption that there is complete interoperability of both systems and personnel. Current work on the NATO UAV interoperability effort (e.g., STANAG 4586) aims to address issues of system interoperability specifically with regards to the data link interface between the control station and vehicle and C2 interfaces between the control station and external command and control, communications, computers, and intelligence (C41) systems. However, despite these efforts, migration of operator control is currently regarded as one of the most complex and risky phases of UMV operations. For example, many system parameters may be changed and difficult procedural and technical issues can be involved. This phase typically requires meticulous planning and allows almost no flexibility in execution. Migrating control between dissimilar systems is particularly difficult because of issues of system synchronisation. Migration of control between operators and systems at physically dispersed locations may require initiation and alignment of systems, one or more data and communications links, and possibly even cryptological equipment. It may also require coordination with external C2 agencies. This situation may be made more complex if a face-to-face debrief is not possible. Additionally, the control system will need to be designed to allow for system synchronisation and facilitate operators achieving an adequate level of situational and system's awareness so a handover can be safely performed. However, standards and safeguards are particularly lacking for the latter issue.

4.3.5.2 Procedures for Migration of Control

Using the example of current UAV systems, migration of operator control needs to be coordinated prior to the actual event. This means the specific procedures and information to be exchanged should be identified during the mission planning process. The procedures should be available in checklist form and should have been previously validated to minimize the unintended effects of operator input errors as well as be applicable to

both nominal and off-nominal situations. Information exchange can be facilitated by the preparation of a mission folder containing the flight plan, tasking, handover location, datalink parameters (e.g., frequencies and cryptological settings), other system settings, and emergency or contingency plans. Additionally, there needs to be processes implemented to ensure this information is updated to reflect actual mission circumstances. Since migration of operator control demands a high level of crew coordination, all involved personnel should have initial and recurrent proficiency training in control transfer procedures as well as crew coordination. The latter may be particularly applicable for personnel without prior aviation experience. Finally, systems should be designed to provide immediate and unambiguous feedback to operators regarding the state of control transfer, whether gaining or releasing.

4.3.5.3 Team Situational Awareness

4.3.5.3.1 Levels of Situational Awareness

Team situational awareness has been described as the process by which a knowledge-heterogeneous team develops a dynamic shared mental model in accordance with the demands of making predictions about a dynamic team task environment [1]. Recent research has demonstrated in turn that team performance directly correlates with team members' levels of SA [2]. Accordingly, in order to safely migrate operator control, it is imperative the operator gaining control have at least the same level of SA as the operator releasing control [3]. Endsley [4] has described three levels of SA: perception of the elements in the environment (level 1 SA), comprehension of the current situation (level 2 SA), and prediction of the future status of one's own situation and the surrounding elements (level 3 SA). Operators should strive for the highest level of SA (e.g., level 3 SA) prior to assuming control of a UMV [5]. SA may need to be achieved at the system, operational, and mission levels. For a UAV mission, this may include SA of a very broad array of issues to include:

- System status: Fuel status, power settings, active and non-active systems, payload status, settings, etc.
- System degradations: Missing functionality and its consequences for flight continuation, vehicle performance, achievement of mission objectives, etc.
- Datalink status: Coverage, frequencies, cryptological settings, antenna alignment, etc.
- Vehicle parameters: Position, speed, attitude, intentions, and future flight path.
- Airspace: Restricted areas, danger zones, and both current and predicted weather.
- Position of other elements in the environment: Traffic, threats, cooperative elements, and coalition assets as well as their intentions and predicted future status.
- Mission objectives: Tasking(s), commander's intent, target information, downstream user requirements, intelligence situation and prognoses, etc.

Obviously, level 1 SA is easier to obtain and requires less effort than level 3 SA. However, the more complex the situation, the more important it becomes to achieve level 3 SA, and thus the more complicated the process for migration of operator control.

4.3.5.3.2 Sharing Situational Awareness

Current research has yielded conflicting results on the existence of detrimental effects of geographic dispersion on team processes, team knowledge, and team situational awareness. However, co-located teams appear to more readily carry out planning and adaptive behaviours and generally communicated more than distributed teams [6]. Consequently, it appears important to facilitate information sharing during UMV

handoffs, which may be accomplished in several ways. It can involve voice communication, text message exchange, graphical display exchange or alignment of system information (including graphics and status). The human interaction in these exchanges can vary greatly. However, this is also true of the potential for human error during the exchange. The more complex the situation, the more operators will have to rely on automation to help them attain SA considering control transfers have to be performed within a certain timeframe. Therefore, there is a need to design the HMI for the operator in such a way to minimize the workload during transfer of control. As an example it could help the operator to focus the attention to changed mission folder items compared to the original situation.

4.3.5.4 Priorities in Sharing Information

Teams need environments which facilitate efficient and effective C2 information sharing. Communication principles for data and knowledge exchanges can be applied at the human and human-computer levels in C2 contexts. Information priorities may be classified in a communication taxonomy for UMV operator teams. When team members trust each other and the team infrastructure, are educated about organizational structure and processes, and understand information processing, fluid communication is enabled.

Teams will likely benefit from training in information salience, conflict management, uncertainty avoidance, learning to select appropriate communication channels, how to design appropriate messages. Team members should be advised on the relationship of communication to relationship building within dynamic, complex, and stressful situations. Indeed, team members need to quickly identify individual and team information needs, fulfill the needs, and disseminate, synthesize, and integrate that knowledge into mission activities. Consequently, situational awareness requirements can be addressed by supporting social networks with access to databases, human capital, and technology.

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4.3.6 Future Challenges

Teams play a critical role in complex military operations necessitating multi-operator environments [1]. Although one project evaluating teams in a UAV C2 environment found no performance differences between co-located and distributed teams, subtle differences in team processes and individual task knowledge were found suggesting the equivalence in team performance was achieved via modified team process strategies [2]. As Cooke et al. noted [2], "these results begin to suggest the importance of considering long-term process behaviors that can accrue over time ultimately impacting team performance in [a] command and control task". Unfortunately, the limited empirical evidence to date on team performance in distributed environments presents a significant challenge in itself. Thus, the potential future challenges posed by migration of operator control in UMVs can best be anticipated by looking to the current state of knowledge in the fields of team processes and team communications.

The presence of interpersonal and task conflict may be perceived as negative; however, its relation to team performance is a positive, direct relationship. For example, intragroup task conflict creates opportunities for team members to better understand a problem through team discussions. As a result, team members are more likely to voice dissenting or novel opinions. To balance and maximize the useful exchange of ideas in team processes, it is advisable to accept a moderate level of task conflict, but to train members in conflict management techniques or to create a problem solving protocol. A moderate level of task conflict tends to be positively associated with team commitment, solution satisfaction, team trust, and enhanced performance.

Interpersonal conflict refers to value, goal, or need differences among organizational members. This type of conflict is frequently characterized as a personality incompatibility. This negatively affects team trust and performance. In this conflict, member focus is directed to non-productive behaviors and stress and emotion levels are heightened. Again, team training in interpersonal communication skills may be valuable for avoiding and minimizing this type of conflict.

Alternatively, performance feedback may moderate group task conflict, where past issues involved in group activities are revisited as a result of the feedback. For example, teams with positive relations tend to recover and build on negative performance feedback. Teams with the same performance feedback and a history of negative relations, however, tend to further degrade in quality of interactions and performance.

As part of the restructuring of military hierarchies to self-organizing teams, it may be advisable to move away from a process-outcome view of groups. Peterson and Behfar [3] suggest "teams are at particular risk of experiencing extremely high relationship conflict and poor future performance when two conditions are simultaneously met; teams that do not establish trust before they receive negative feedback are especially vulnerable to ongoing relationship conflict, and likely to perform poorly".

Ideally, team members should manage the intensity level of the conflict. Balance the benefits of increased critical reasoning by allowing a minimal level and avoiding the negative impact of destructive team interactions at high intensity conflict. De Dreu and Weingart [4] "support the information processing perspective that suggests that whereas a little conflict may be beneficial, such positive effects quickly break down as conflict becomes more intense, cognitive load increases, information processing is impeded, and team performance suffers".

Much of the literature is based on qualitative, self-report data. The dramatic consequences in the C2 environment require building upon the findings of case studies and building experimental evaluation of those observations concepts. Organizational leaders need to evaluate the social norms, behavioral norms, cultural norms of team members, task work, and team goals within the context of dynamic environments to better structure, support, and develop team operations. In a virtual team environment, operational protocols can be designed in accordance with the unique characteristics and requirements of the team members. The behavioral tendency for a performer to allocate attention from concurrent tasks to the high priority task to maintain standards of performance [5] is valuable information for communication system design. For example, verbal interactions among remote and co-located participants were found to be significantly retarded when participants were engaged in challenging tasks [6]. There were no significant differences in task SA and performance for the remote and in-person communicators; however, verbal communications degraded SA for both conditions.

Some general recommendations to consider for future work and research include:

- Conceptualize work process and structure as sequences of communicative actions which coordinate the activities of members [7,8].
- Develop trust and cohesion by incorporating face-to-face meetings early in the team creation process.
- Organizational roles should be clearly defined across team members/agent and task responsibilities at the individual level (human and technology).
- Evaluate which tasks are appropriate for virtual teams.
- Tasks should be clearly communicated and unambiguous. For complex tasks, provide access and availability for increased communication and collaboration.
- Create ways for social ties to be nurtured in virtual teams.
- Provide training for team members in communication skills:
  - Interpersonal,
  - Organizational,
  - Intercultural,
  - Uncertainty reduction,
  - Communication protocol development/use, and
  - HMI communication.
- Develop communication protocols which reflect environmental contexts, media constraints, information complexity, task and socially-related interactions, and technological capabilities.
- Develop systematic, empirical research programs to test the behavior of human and human-machine virtual teams in C2 environments. This data is important for determining appropriate cultural and structural changes to allow co-located and virtual teams to succeed.

Additionally, McCarley and Wickens [9] reviewed the literature and summarized current UAV specific human factors research shortfalls, several of which are directly applicable to the topic of migration of operator control in UMVs:

- Develop and test formal procedures for the transfer of control between teams of operators.
- Develop and test HMIs, automation, and procedures to ensure operators have adequate system awareness when assuming vehicle control.

- Delineate circumstances under which responsibilities for vehicle and payload control may be safely performed by a single operator versus circumstances where responsibility should be distributed over two or more operators.
- Delineate circumstances where a single operator can safely simultaneously control multiple UMVs.

The potential benefits and promise offered by UMVs in a multitude of applications have captured the attention of both the military and commercial sectors. When technology changes rapidly or new and radical designs are introduced, previous human factors data may no longer be valid. It is therefore imperative to address the human factors and teaming issues arising from the advent of migration of operator control so the full potential of UMVs is realized. It should be obvious that rather than eliminating human factors concerns, UMVs have instead opened a new and critical chapter in human factors research.

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4.4 MANPOWER AND SKILLS

4.4.1 Selecting UMV Crews

4.4.1.1 Introduction and an Alternative Crew Selection Method

As part of System of Systems and the Human Factors of Command and Control, personnel selection must be considered. This assumes that humans will always be part in the command and control of UMVs at some level of abstraction.

UMVs are new technologies for most militaries around the world, and potentially require new jobs, positions, occupations, and units to command and control these assets. On the other hand, militaries have similar manned vehicles with similar payloads. The personnel that operate these vehicles are highly skilled and knowledgeable, and these skills and knowledge are potentially transferable to operating UMVs. Moreover, if UMVs were highly "intelligent" or "autonomous" then perhaps only general skill and knowledge levels would be required to operate the vehicles and their payload. The transfer of skills and knowledge, and the requirement for general skill and knowledge levels will contribute to Force Multiplication by drawing from an existing, broader pool of people that can operate UMVs.

For example, a pilot, a tank driver, and an Officer Of the Watch might be well suited to fly, drive, and sail UAVs, UGVs, and USVs, respectively. These are positions with the expected high level of expertise. Moreover, a navigator, a gunner, and an Operations Room Officer may have enough general skill and knowledge to be able to quickly become expert UMV operators.

The Canadian Forces Experimentation Centre (CFEC) is exploring a new method for selecting crews that involve matching tasks and knowledge statements within a Canadian Forces – wide task and knowledge database to predicted tasks and knowledge statements derived from a composite scenario that involves the new technology – in this case, multiple UAVs. As more matches that are made for each position in the database, the more likely that that position or occupation would perform well as part of the crew for that UMV. This method represents a substantial departure from common crew selection methods that are often based on career progression, legal considerations, availability, and ownership of the new asset. The new method has four steps as follows:

1) Decompose a composite scenario involving new technologies into a hierarchy of goals.

   There are many techniques to perform mission analysis and function decomposition (e.g., MIL HDBK 46855). The technique used in this case is based on Perceptual Control Theory applied to function and task decomposition [1]. The result is a Hierarchical Goal Analysis (HGA) where the scenario is described in terms of desired system goals. At some level of the hierarchy, the goals are assigned (allocated) to humans and machines. Further research is required to systematically develop individual jobs based on predicted workload and/or grouping tasks into roles and responsibilities.

2) Propose and link the new job elements (task and knowledge statements) to the goals.

   Job elements can be associated with the completion of those goals assigned to humans. The job elements are not limited to task and knowledge statements, but may include the other elements (such as intelligence, aptitude, personality, health, gender, etc.) depending on the level of fidelity required. However, there are some indications that current tasks may be a first order predictor of new job performance.

3) Compare the new job elements to the CF job element inventory.

   This methodology for selecting crews depends on having a task and knowledge statement inventory so that the new task and knowledge statements can be compared to those in the inventory. The mathematical equation for the comparison has been referred to as a Job Similarity Index (JSI). The simplest matching algorithm, or JSI, is as follows:

$$\text{JSI} = \tfrac{1}{2}\frac{\text{number inventory tasks that match new tasks}}{\text{total number of new tasks}} + \tfrac{1}{2}\frac{\text{number of inventory knowledge that match new knowledge}}{\text{total number of the new knowledge}}$$

   As JSI approaches one, then the current job would match the new job. The hypothesis is that the job performance is directly related to the JSI value. That is, those personnel who have a high JSI will perform well in the new job and will require minimal training, since they perform most of the tasks in their current job and have most of the knowledge from their current job that are required for the new job.

4) Select positions based on the best match.

4.4.1.2 Experimental Design

CFEC conducted an experiment to evaluate this crew selection method and to determine whether JSI predict job performance. Military participants were asked to participate in a 6-hour experiment that involved the command and control of five UAVs in support of an intelligence, surveillance, and reconnaissance mission as the UAV crew searched for a terrorist boat amongst 14 other fishing boats of a similar classification.

Each participant provided demographic information as well as wrote the Wonderlic General Cognitive Ability (GCA) test. The participant performed a one-hour UAV mission in DRDC – Ottawa's synthetic UAV Research Test Bed: 20 minutes in each position as the Vehicle Operator (VO), Payload Operator (PO), and Mission Commander (MC). Two other experimental staff members played the alternate positions, thus a crew of three was formed. Following the first run, training was conducted in the form of a question and answer period. A proficiency test was administered, and then the participant repeated the hour scenario again. The measured variables included demographic information, GCA, task completion, assessed performance, Situational Awareness, and proficiency test results, while JSI was calculated using the above formula for each participant.

The primary performance measures were subjective observations about a number of tasks. Two observers rated performance on the task from one (low) to five (high). A zero meant that the task was not performed. Another measure of performance was a situational awareness (SA) map tasks where the subject was asked to recall the friendly, neutral, unknowns, and unfriendly radar returns and draw them on a map. Their answers were compared to ground truth, and high scores were given when the two maps were similar.

The data analysis was designed to show whether performance and JSI are related. Figure 4-5 is a fictitious example showing the scatter of data. Excel™ was used to calculate trendlines as well as the normalized mean distance (m.d.) between the data points and the trendline. If the trendline has a positive slope, then performance and JSI are related. If the slope is zero, then there is no relationship. If the slope is negative, then the two variables are inversely related. As the mean distance approached zero, then the points would fall onto the trendline and there would be high confidence that the data and the trendline were correlated. As the mean distance approached 100% of the maximum possible mean distance then there would be low confidence that the data and trendline were correlated. Note that this is a preliminary analysis in order to obtain generic impressions of the variables' relationships.

Figure 4-5: Anticipated Results Showing that Performance is Directly Related to JSI.

4.4.1.3 Results and Discussion

Figure 4-6 shows the preliminary results in graphical form. The first graph indicates that task completion does not depend on JSI. That is, all participants were able to complete 97.7% of the UAV tasks regardless of the percentage of tasks and knowledge they had in their current occupations. The mean distance between the trendline and the data was 1.3%, which gives us a very high degree of confidence that the data are correlated with the trendline.

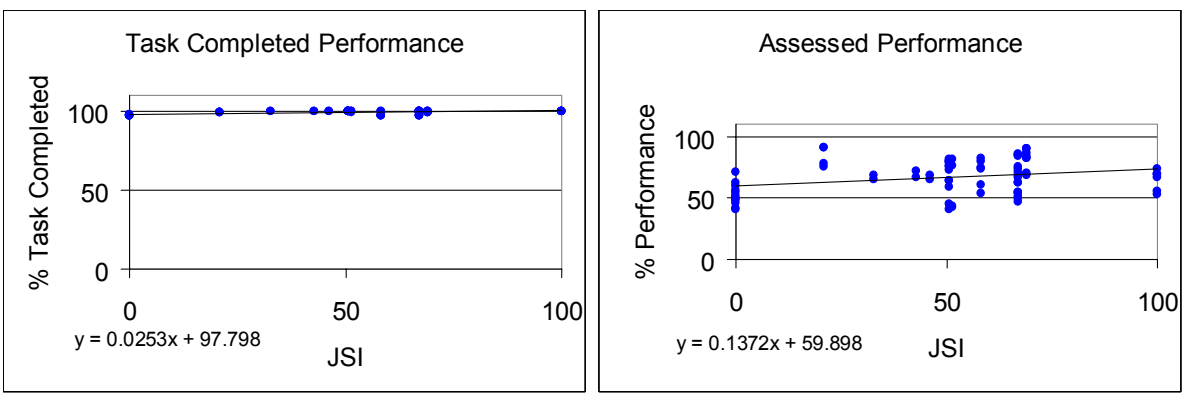

Figure 4-6: JSI versus Performance Results.

The second graph indicates a slight positive relationship between JSI and the assessed performance results (i.e., slope = +0.13). However, our confidence that the data and trendline are correlated is lower because the mean distance increases to 10%. Note that the intercept value is 59.9%. That is, even participants who do not perform any of the UAV tasks or have any of the required UAV knowledge, still have a general level of tasks and knowledge that they can achieve 60% performance. Anecdotally, only after several minutes of training on the system, the performance rises (training proficiency test average mark = 74.2%). Also, the other two crew members (a private and a corporal) became experts at all the positions well within 3 hours. Clearly, this simple composite scenario required a general level of tasks and knowledge in order to achieve adequate performance. (N.B. the scenario was validated by experienced CF Aurora crew members whose job is maritime surveillance and reconnaissance).

Table 4-1 summarizes the relationships between JSI and other variables measured in this experiment, and Table 4-2 summarizes the relationships between the variables and assessed performance. A detailed analysis would require a multiple regression as well as a test for significance. Also, one must determine the minimum slope value by which it can be said that JSI is related to performance, as well as the maximum mean distance that would still indicate a high confidence level. Never-the-less, there are indications that JSI predicts performance to some degree. However, this scenario was simple enough that a broader pool of participants with general tasks and knowledge could complete 97.7% of the tasks at a performance level of least 60% with minimal training and a fairly robust human-computer interface.

Table 4-1: JSI versus Measured Variables

x-axis	y-axis	Slope	Intercept (%)	Mean distance (%)
JSI	Reference	0	100	0
JSI	Proficiency Test	-0.14	81.2	14.7
JSI	Situational Awareness	-0.10	60.3	16.1
JSI	**Task completed**	**0.03**	**97.9**	**1.3**
JSI	GCA	0.08	49.2	6.9
JSI	Assessed Performance	0.14	**59.9**	10.0
JSI	Years of Service	0.19	21.1yrs	11.0
JSI	Service	NA	NA	NA
JSI	Reference	1.00	0	0

Table 4-2: Measured Variables versus Assessed Performance

x-axis	y-axis	Slope	Intercept	Mean distance (%)
Reference	Performance	0	100	0
Years of Service	Performance	-0.28	73.0	11.5
Proficiency Test	Performance	0.06	62.3	11.7
JSI	Performance	0.14	59.9	11.1
Service	Performance	0.15	57.1	10.6
Situational Awareness	Performance	0.39	46.1	9.7
GCA	Performance	0.48	41.2	11.0
Reference	Performance	1.00	0	0

4.4.1.4 Concluding Remarks

There are indications that JSI can be used to predict job performance to some degree. However, there are other factors that influence job performance including the simplicity of the job in combination with a good human-computer interface. As UMVs become more “intelligent” (i.e., operating at high levels of automation), then operators will only need a general level of job elements in order to work the systems at relatively high performance levels. The results seemed to indicate that, depending on the scenario and equipment used, one could select from a larger population of current military personnel.

The alternative method for crew selection is not tied to any particular application, and is hoped to be an objective way of selecting crews particularly when no job incumbents exist. This would be the case for most UMV systems coming online. As countries world-wide begin to build their UMV units, they will need a method for staffing the units either with existing personnel or new recruits if specific skill sets are not found within the organization. The method yields task and knowledge statements for a given scenario, yet the method itself can be applied to any scenario.

The method requires an existing database for the task and knowledge statement lexicon for step 3. That is a common lexicon for tasks and knowledge statements is required. Even between environments (air, land, and sea) a single task may have several meanings. For example, secure a building may mean surround the building with troops for army personnel, close all doors, windows, and hatches for navy personnel, and purchase or lease a building for air force personnel. Initial discussions have started in developing an Intelligent Agent solution that would help "translate" between environments' lexicons. The next step would be to expand the tool so that it could "translate" between interagency and multi-national task and knowledge lexicons, if they existed.

This study showed that the operator to vehicle ratio is moving in the desired direction for Force multiplication. That is, the operator to vehicle ratio in this case was 3 to 5, and the operators only required a general level of task, skills, knowledge, and training. In the absence of incumbents for UMVs, this crew selection method promises to be a viable alternative that would cross not only environmental boundaries, but also multi-national and interagency boundaries. Thus the method is compatible with system of systems and interoperability thinking.

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4.5 UNINHABITED MILITARY VEHICLE OPERATOR TRAINING

4.5.1 Training of Decision Making Skills Based on Critical Thinking

An important aspect of decision making skills in real-world situations how to decide on a course of action even though available information may be uncertain or incomplete, or relevant information is simply missing. Since there typically are no clear cut answers in situations like this, any augmentation of the decision-making process in the form of training has to focus on how the decision makers interpret the information at hand. For example, how to consider the relevant factors, make plausible assumptions, and identify conflicts in the information. Several studies have shown that these decision-making processes can be augmented by improving the decision makers' critical thinking for self-critiquing, through training [1] and decision support systems [2].

There are several theories of critical thinking, but the one of most interest here is critical thinking as a dialogue that has been developed by Marvin Cohen and associates in a series of papers [3,4,5]. According to their theory, critical thinking is a series of questions and answers that serves to investigate alternative positions of what the available information may indicate. Three roles are involved:

1) The proponent who defend a position by introducing more reasons that are only consistent with the current position;

2) The opponent who asks for missing reasons or introduce rebuttals that cancels reasons or their effect on the conclusion; and
3) The facilitator who regulates the process in terms of the relevance of reasons and whether the dialogue achieves the overall goals [4,5].

Often, the opponent tries to expose uncertainties in the proponent's position which may be incomplete when some relevant reasons are missing [3]. The reasons that the proponent introduces as a response to the incompleteness may then conflict with existing reasons by also supporting alternative positions. One or several reasons must then be revoked or assessed in terms of reliability since only one position can be chosen. Thus, the critical dialogue between the proponent and opponent encourages introduction of reasons that have not yet been considered by the other. These reasons are then used to assess positions in terms of their plausibility, correspondence between reasons and observations, coherence of reasons, and the uncertainty of the position based on the number of alternative possibilities where the position would be incorrect [5]. Consequently, the decision quality improves over time as the partners learn more about the positions' strengths and weaknesses. The critical dialogue is applicable to both team and individual decision-making by switching between the roles [6].

An important aspect of the critical dialogues is that they can be adapted to the available time until a decision has to be made. There are several dialogue types, such as persuasion, inquire, information seeking, negotiation, deliberation, and eristic [7], that vary to which extent assumptions are questioned. The decision makers can therefore control the amount of questioning and number of possibilities to consider by choosing the best dialogue type depending on the context. Since the critical dialogues uses the available information within the constraints of the situations, there is no conflict with the assertiveness and rapid responses that is often required in military domains [4]. Should the decision makers be in severe time pressure, they may also choose to adopt a more recognitional decision making strategy instead of using critical thinking [8]. The ability to adapt the decision process depending on the context is often an important aspect of expertise. For example, studies by Freeman, Cohen, and Thompson [9] and Cohen, Adelman, and Thompson [10] show that experienced commercial airline pilots adapt their decision process for diversion to an alternate landing site depending on the available time and uncertainty about the need for diversion. Less experienced pilots did not show the same responsiveness.

Training of critical thinking attempts to encourage a dialogue that clarifies disagreements and weaknesses in positions. For example, Cohen et al. [5] describe a training program that explains the three roles, how to perform a critical thinking dialogue (adapted from von Eemeren and Grootendorst [11]), and general rules that encourages a critical dialogue. After first developing their own positions, the teams identify important disagreements and how to resolve them by challenging, defending, and modifying positions until the parties agree or there is no more time for discussion. The effect of the training program was investigated using Army officers that performed tactical decision making games. The critical thinking training increased the generation of new options and the number of reasons for positions. A similar type of training program has also been evaluated for situation assessment of enemy intent [1,12], and planning of a course of action for tactical decision-making games [10]. This training is based on the improving the coherency of stories that explains the available information. The training consists of four segments for story creation and evaluation, characteristics of task specific stories, how to manage conflicts and generate alternative interpretations, and when critical thinking is appropriate. Mental strategies, such as the Devil's Advocate or the infallible crystal ball, are used to encourage critical examination of positions and reasons. These critical examinations occur naturally in the critical dialogue due the different roles. Overall, the training increased the usage of relevant information and identification of conflicts and assumptions that required further investigation. These changes in the decision

process often improved the final decision. The positive effects of critical thinking training are not surprising since many aspects of the training are based on differences between how experienced and less experienced officers handle similar types of situations [12]. Similar effects of experience have also been found for how commercial airline pilots evaluate options for diversion due to bad weather [9,10]. In addition to adapting the decision process depending on the available time, experienced pilots also requested more information to address sources of uncertainty. Although Cohen, Adelman and Thompson [10] propose a strategy for training critical thinking skills of commercial airline pilots, no training program has been developed or evaluated for option evaluation, however. Finally, the training can be administered using conventional presentations or self-administered individual homework assignments and use advanced simulation techniques for illustration of scenarios.

The preceding discussion shows that critical thinking can enhance decision making in many domains where there is only partial and uncertain information. It is therefore reasonable to expect that critical thinking will also be important for control UMVs when they are employed tactically as a part of or in close cooperation with manned forces. While lower costs and reduced risks for military personnel make UMVs suitable for the dull, dirty, and dangerous missions, they also have several characteristics that affect their operation. Critical thinking appears to be a useful approach for assessing how these characteristics can affect mission accomplishment within the current context. Table 4-3 summarizes a brief review by Svenmarck [13] of some critical characteristics that may be important for control of UMVs. One important characteristic of UMVs that is often mentioned in the literature is the lack of situation awareness from the limited field-of-view of sensor information for control of tele-operated vehicles. The result is often spatial disorientation, lack of awareness of surrounding obstacles, and difficulty of interpreting the overall situation. Further, tele-operation for navigation and control of the sensor suite are in reality separate tasks that can not be performed simultaneously [14]. Both tasks are also hampered by the significant time delays in communicating sensor information and control commands [15]. The combination of tracking difficulty and a preference for endurance typically makes UMVs slower than manned systems. Often, several operators are therefore required to control and manage the UMVs due to the demands on attentional and cognitive resources. Overall, however, the demands are considerably less than when performing the same missions manually without UMVs, which improves the endurance. The effect of these characteristics versus the benefits of less risks and efforts of military personnel can only be assessed by the operator using the available information about the situation. Consequently, a reliable decision making process, such as critical thinking, is essential for maintaining control of UMVs.

Table 4-3: Summary of Characteristics that Affect how UMVs are Employed Depending on the Mission Context – the characteristics are listed as a relative comparison of performing missions with UMVs vs. without UMVs

Pros	Cons
• Costs less than military personnel • Can perform more risky missions • More precise weapons management • Less physically and mentally exhausting for operators	• Provide limited information • Time-delay in control and sensor information • Tele-operation requires attentional and cognitive resources • Tele-operation often require more than one operator • Limits interpretation of the situation • Vulnerable • Have a higher failure rate • Not optimised for stealth • Can be slow to deploy • Vehicles that are not fully automated must remain within radio coverage for control. Currently, the radio coverage is often limited, especially in built-up areas • The radio communication is vulnerable to detection and electronic warfare

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4.5.2 Embedded Training for UMV Crews

4.5.2.1 Introduction

Earlier in this SoS chapter, it was stressed that Network Centric Capabilities interweaving sensors, humans and decision aids will increase sources and quantities of information. These advances will place heightened cognitive demands on UAV operators performing C2 tasks. While the C2 structure for the future battle space may not be different from current operations, the ability to fluidly push and pull information over long endurance missions is vastly improved. This poses new challenges for teamwork in UAV operations, particularly when it comes to migration of operator control, team co-ordination and co-operation, team situation awareness and sharing of information. These challenges emphasize the need for novel training concepts for UAV crews.

One of the concepts that emerged from social psychology is training of team decision-making using the 'critical thinking' paradigm [1], which was dealt with in the previous paragraph. In the current paragraph, a human systems engineering approach to team training is dealt with, proposing Embedded Training (ET) as a possible solution. ET for UAV crews basically addresses the aforementioned challenges encountered in teamwork by providing a team training environment that matches the conditions of the future battlefield,

using the actual UAV system in combination with virtual features of the environment, such as threats, targets and other players.

During deployment of a single tactical or strategical UAV system (which may contain more than one air vehicle) for ISTAR type missions typically a team of 50 personnel (in the order of magnitude) is involved in the sustained operation. These personnel consist of operations personnel (mission commanders, air vehicle operators, payload operators, data analysts), maintenance personnel and command personnel, who work in shifts to maintain a continuous operation. For the purpose of ET we will mainly concentrate on what we call the core team. The core team consists of those operators that are responsible for mission C2 tasks and planning, air vehicle control, payload operation and immediate data analysis. More loosely defined we can say that the core team is active during the mission and present in a Ground Control Station (GCS) or in a GCS collocated with a data analysis cell. The core team's primary purpose is guaranteeing mission effectiveness and safety.

Each of the core team members has a specific role and a dedicated working position in the GCS or data analysis cell. For operational training of the core team members it may seem attractive at first sight to be attainable to train the skills, knowledge and attitudes (SKAs) for the separate roles, using specialized training for each role. However, the effectiveness of the core team as a whole depends to a large extent on the teamwork of the members, more than on individual SKAs. This is not hard to understand, since the dynamics of ISTAR type missions require a precise co-ordination between mission planning, air vehicle control, payload operation and image analysis/interpretation. Therefore emphasis should be placed on training the SKAs that are associated with teamwork.

In a typical scenario, the mission commander indicates the points of interest and their priorities, and takes into account the tactical situation and safety constraints. Eventually this results in a mission plan, consisting of a flight plan and sensor plan. The air vehicle operator controls the air vehicle according to the flight plan and the payload operator controls the on-board sensors according to the sensor plan. Data-analysts (photo interpreters, SAR analysts or ELINT analysts) analyze, interpret and report the data to further echelons. Since each on-board sensor has an optimum flight profile and altitude, the use of a specific sensor has consequences for the flight path of the air vehicle and vice versa. During the flight the operators have to deal with unplanned situations such as threats to the air vehicle, changing weather conditions, military and civil air traffic, targets of opportunity, changes in the target list and 'sensor-to-shooter' co-ordination, including communications with other entities in the network. Consequently, the mission plan must be frequently adapted while the air vehicle is in-flight, again requiring co-ordination between the operators.

Teamwork is particularly important under high task load or in situations with a large uncertainty. Inefficient and ineffective team co-ordination under those circumstances can severely impair mission success and safety. It can be expected that the frequency of task load peaks will increase in the future, since there is clear pressure on lowering the operator-to-vehicle ratio. Also, when the UAV is part of a time-sensitive targeting operation, uncertainty and high task load are the rule, not the exception. When the loop between sensor and shooter is short, the pressure on the crew in GCS can be extremely high, giving rise to psychological phenomena that are unique to UAV operations. Current-day warfare, with highly unpredictable targets, is clearly moving towards shorter sensor-to-shooter loops.

In the remainder of this section we will further discuss team training, specifically for UAV operators. We will also present the concept of embedded training, and provide a sketch of how such a system could be beneficial for operator team training.

4.5.2.2 What is Embedded Training?

For the current purposes we define Embedded Training (ET) as a form of training in which simulated 'entities' such as threats and targets are fed into the various avionics systems of an actual working UAV-system. This allows training against virtual threats and with virtual targets. ET enables UAV crew in the Ground Control Station (GCS) to use the system in a situation where it was designed for, while this situation is not available in every day life. Thus providing capabilities to train UAV crew more effectively using the real equipment in combination with a partly simulated environment.

An ET mission potentially provides the context of a real UAV mission, but without the need for the actual presence of mission-critical entities, such as targets to be observed, ground threats, airborne threats or friendly forces. One proposed ET architecture presupposes an airborne UAV, capable of ET, which maneuvers through a reserved airspace sector. The interaction with aforementioned entities is simulated with on-board equipment. Another proposed ET architecture does not require an airborne UAV, but only a functional GCS, that is capable of ET. Multiple, fundamentally different ET architectures are possible, and the aforementioned architectures are two examples. Although the circumstances and tensions of a real mission will probably never be accurately simulated, ET can come closer than traditional forms of training by representing assets in the real environment. A UAV embedded training is however clearly different from a manned fighter ET: UAV operators are physically located in a GCS. While the air vehicle performs its 'dull, dirty and dangerous' tasks in the war zone the operators are physically safe. Why ET in UAV then? A number of arguments can be given, including:

- ET provides increased training effectiveness through added immersion, highly effective training scenarios and team involvement.
- ET potentially enables 'complete' team training, including training of personnel involved in launch and recovery, CAOC personnel, operators of manned platforms, logistics, maintenance, and, last but not least, data analysts.
- ET would also lead to efficient use of costly flight time. Independent of the availability of other players, operators can go through complex scenarios with simulated entities in each flight. In another application, mission rehearsal could take place while loitering or en-route to operational area.

Previous research with fighter aircraft has demonstrated that ET is a technologically and operationally viable concept [2,3,4]. Reus and Stokkel [5] and Roessingh et al. [6] investigated specific PVI-issues associated with ET. Now R&D needs to focus on ET for UAV crews. If the operational use and benefits for UAV operations can be demonstrated, it is worthwhile to require these capabilities for the next generation of UAVs. In the following sections the reader is given a brief account of some of the principles underlying ET.

4.5.2.3 Why Combine Real and Simulated Systems?

The ET system feeds additional entities, such as targets and threats, into the mission system of the UAV system. These data are treated in the GCS as if being real data and will be displayed as such. The crew in GCS (supposedly consisting of UAV operator, payload operator, and a mission commander) needs to interact with these entities based on their predefined roles. In the preceding section we argued that ET is a form of high fidelity mission training. This is a strong argument for serious consideration of implementation. However, some more direct and quantifiable advantages can be argued for as well.

- In live training without ET, e.g., on a training range, physical entities are needed that act as targets, threats or friendly forces. These physical entities are costly to implement and obviously only have a

restricted training value for the personnel involved operating these entities. It is clear that with budgetary constraints on live training hours, ET will be very cost effective.

- Depending on the chosen architecture ET does not need airspace or only relatively small volume of airspace. In many of today's and future missions, UAVs are equipped with long-range sensors, which means that detection of targets, identification, electronic warfare, and possibly weapon delivery, may all take place at relatively long distances between the players. Airspace where such skills as electronic warfare can be trained in live training is very limited, particularly in Europe. Since ET allows any geometry of threats, targets and other players to be simulated, only a very restricted volume of airspace is needed. ET allows virtual entities to fly outside the designated area as long as the UAV remains within the designated airspace.
- Because the actual system dynamics are present in ET, this form of training is to be preferred over legacy simulation, particularly when the crew has to combine various skills and knowledge in an integrated manner, such as co-ordination and co-operation, tactics, perceptual skills, control skills and attention management.
- UAVs may operate under control of other platforms, such as Airborne Early Warning platform (AWACS). During training however these systems are not always available. ET is able to provide the AWACS control capabilities in case these systems are not available. Thereby ET trains the crew the necessary skills on a day to day basis.
- Certain capabilities of UAVs will not be used during live training due to security or safety reasons. Specifically Low Observerability (LO) characteristics are expected to not being used to the full extent during training because of security aspects. ET allows training with the LO characteristics with virtual systems. Another aspect is training with lasers, e.g., for target designation. Lasers can only be used in a specific environment due to safety reasons. ET allows the deployment of virtual lasers. This increases the crew's readiness for real missions.

4.5.2.4 The Architectural Concept of Embedded Training

Basic Architecture

An ET system, implemented in a UAV system, consists of three main simulation modules (Figure 4-7).

- First, the simulation management module performs many functions, such as starting and stopping training exercises and taking care that all players participating in the exercise have synchronised information.
- Second, the UAV simulation module stimulates the on-board sensors and simulates the own weapons and electronic warfare systems.
- Third, the virtual world simulation simulates the virtual entities in the exercise. The virtual world simulation also comprises models for the terrain over which the exercise takes place and atmospheric conditions.

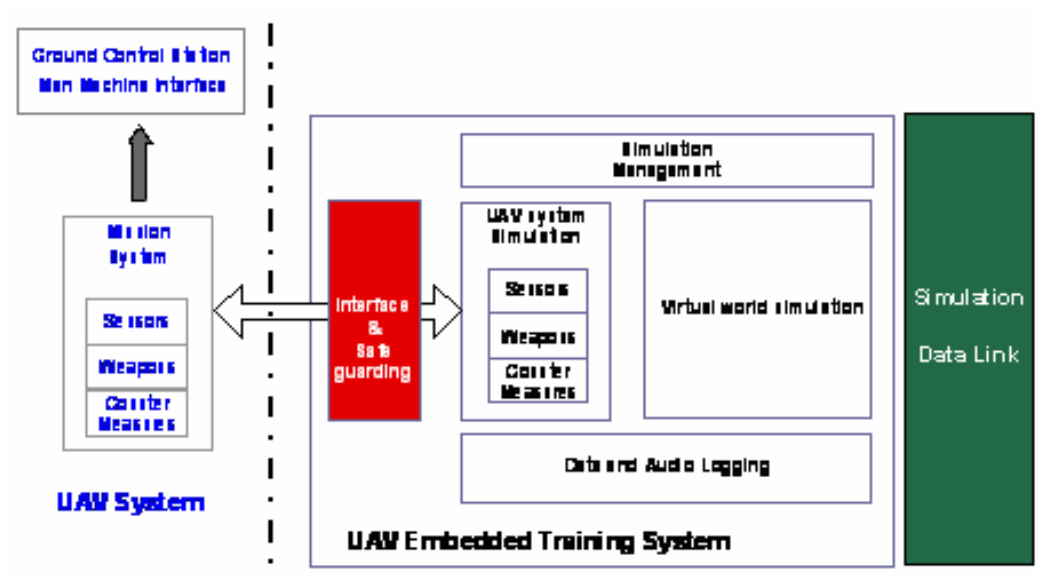

Figure 4-7: Basic Architecture of an Embedded Training System.

To make the crew believe that they are in a real mission, the three simulation modules maintain an intensive two-way communication with the UAV's standard mission system. The mission system consists of modules that handle sensor data, weapon data, and electronic warfare data. Every time the crew gives an input to one of the systems in the GCS, the simulation needs to be updated and, as a result, new simulation data need to be fed into the mission system. To ensure a safe exercise a specific safety layer that safeguards the UAV mission system must be developed.

The above described basic architecture is sufficient for the training of engagements in which one ET equipped UAV system is involved and all other entities are virtual. However, in more complex and realistic exercises, that is, beyond the single UAV operations, an airborne datalink between ET carrying UAVs and an air-to-ground datalink between UAVs and ground-based entities are needed to ensure that all players have matching sensor information.

A scenario for the exercise needs to be prepared in advance on a dedicated GCS. After sufficient verification of the scenario, its digital representation can be loaded in the ET carrying UAV, either by physically inserting a credit-card-size memory card into the system or by datalink. The GCS can also be used for debriefing purposes.

4.5.2.4.1 Simulation Management

During the exercise, the simulation management module must control all simulations as well as the overall course of the exercise. In addition, this module manages the recording of the exercise and performance measurement. Since complex exercises have many performance aspects, proper assessment of crew performance is a major challenge to UAV crew training in general and specifically to ET. The performance aspects include the use of sensors and countermeasures, selection of tactics, following the mission routes and selection/assignment of targets. Intelligent methods are needed to keep track and analyse the crew's activities, to categorise crew error and to determine mission success. Transfer-of-training will increase when such performance measures can be singled out, both during the exercise and in debriefing.

4.5.2.4.2 UAV System Simulation

In the UAV system simulation a complete dynamic model of the UAV system is included. UAV system simulation includes models for the electronic warfare system and for on-board weapons (when present). An important part of the UAV system simulation is a realistic assessment of mission effectiveness. System displays in the GCS, such as the radar, the radar warning receiver and target identification means must interact as if real targets are present. These provisions make it possible that missions can be fully exercised.

4.5.2.4.3 Virtual World Simulation

The virtual world includes the virtual entities, their electronic signatures, weapons and dynamic behavior, involving strategies, tactics, maneuvers and counter measures. Moreover, the behavior of the virtual entities has to be in exact accordance with their individual role (ground-based or airborne, friend or foe, etc.).

4.5.2.5 Safeguarding for Embedded Training

When an air vehicle is being flown in UAV operator training, safety is an important issue. Safety issues are related to the air vehicle itself, and to the interaction between the air vehicle and its environment. Systems and working procedures help the operators to guarantee a sufficient safety level. As an example, presentation of air traffic in relation to the air vehicle allows the operators to avoid collisions with manned or uninhabited aircraft. The situation in an embedded training scenario is somewhat more complex, since parts of the environment are real, while other parts are simulated. For example, an operator may concurrently see real and virtual entities on the same tactical display.

We clearly do not want to compromise safety by introducing virtual entities in a scenario; unsafe situations in response to virtual entities are simply unacceptable. Thus, measures have to be taken to avoid damage to the air vehicle itself, for example caused by collisions with air traffic or terrain. Also, risks to third parties, such as manned military aircraft, other UAVs, civil air traffic, and population on the ground, should be minimised. Therefore, just like in a fighter aircraft ET system, safeguarding is an important issue in the design of a UAV embedded trainer. Also, a similar approach to safeguarding can be foreseen. The starting point is that all operators are at all time aware that a simulation is running, so continuous presentation of the simulation status is a firm requirement. Further, the simulation should explicitly indicate when it starts and stops. An aural annunciation in the GCS is a proper method, since it is independent of the individual point-of-gaze of the operator team.

Since displays can contain both real and virtual information at the same time, operators should always be aware which information is real and which is virtual. This helps them to make the appropriate trade-offs and decisions during the training scenario. It is clearly not desirable to perform a potentially unsafe maneuvre or action in response to a virtual entity, while this may be totally justified in an operational situation. A potential implementation for symbols on a display is to give the virtual entities a dedicated supplementary tag. In the fighter embedded training system that was developed at NLR, this is accomplished by attaching a small “v” to each virtual symbol on all displays where they can appear. Naturally such information should be designed carefully in order to guarantee positive transfer of training. Another effective strategy in the design of displays is to give symbols related to real entities a higher priority. This way, symbols related to virtual entities do never obscure those related to real entities.

More advanced means are also possible. Automatic monitoring of the air vehicle and its interaction with the real environment can prevent unsafe situations. This can be accomplished by the continuous evaluation of a number of safety rules by the simulation itself. The simulation immediately stops when one of the rules is

violated, that is, when it detects an unsafe situation. Naturally this should be properly announced to the operators. As an example, the system can monitor that the air vehicle remains in a temporary reserved airspace during the training. It could also automatically detect potential collisions with real entities or real terrain.

4.5.2.6 Choosing an Embedded Training Architecture

Various architectures are possible when implementing a UAV embedded training system, but two distinct groups can be identified. In the first group an air vehicle is not required, only a GCS is needed for the exercises. In this case ET is built into the GCS and directly communicates with the GCS systems. The second group is fundamentally different and involves a flying air vehicle during the exercises. ET then communicates with the on-board systems and (via the datalink) with the GCS. The simulation itself can be in the air vehicle or in the GCS, while it is also possible to implement a part of the simulation on board and a part in the GCS. Naturally this is related to the decision to involve a flying air vehicle in the training.

This is not the place to promote a specific architecture, but some arguments will definitely play a role in the selection.

- Training effectiveness. Nowadays simulation standards are high, but the psychological factors involved in operating a high valued asset with all potential safety consequences, can never be reproduced in a simulator.
- Cost of flight hours. These costs are not only due to fuel, but also to the number of personnel involved in the training, complicated logistics, and need for air vehicle maintenance. Nowadays, optimal use of the limited number of flight hours is an important concern.
- External safety issues are important, particularly during training operations, when the air vehicle is over populated areas and when sharing airspace with other vehicles. Safety of the air vehicle is important too. The costs associated with the loss of an air vehicle and collateral damage on the ground can be enormous, also in the ‘public eye’. Also, the consequences of a collision with other vehicles can be dramatic.
- Security. Flying an air vehicle implies using a datalink and exposing the UAV system and tactics to interested parties.

4.5.2.7 Team Training to be Addressed with Embedded Training

4.5.2.7.1 Teamwork

We define teamwork as the seamless integration of specific skills, knowledge and attitudes (SKAs) that allow team members to adapt and optimize their performance. Team characteristics that distinguish teams from small groups include the following [7,8,9,10]:

1) Multiple sources of information.
2) Task interdependencies.
3) Coordination among members.
4) Common and valued goals.
5) Specialised member roles and responsibilities.
6) Task-relevant knowledge.

7) Intensive communication.
8) Adaptive strategies to help respond to change.

4.5.2.7.2 Team Skills

Some team skills are frequently mentioned in the literature. For the purpose of UAV operations we have selected four of these skills. The first one is 'team monitoring', which means mutual performance monitoring by team members, but also mutual workload monitoring and predicting each others' behavior [11,12]. A second frequently mentioned team skill is 'exhibiting flexibility' which includes adapting to novel and unpredictable situations [13]. A third team skills is exhibiting team leadership or followership (depending on the situation), which means motivating team members, exhibiting team initiative, exhibiting assertiveness and providing supporting behaviors [14,15,16,10]. Fourth, we mention 'team coordination', which is the skill of giving suggestions or criticisms, but also accepting suggestions or criticism, including performing of self-correction [17,18]. Less frequently mentioned skills include response coordination, coordination activities, resource distribution, timing, interpersonal coordination, team decision-making, shared situation awareness [19,20,14].

4.5.2.7.3 Team Knowledge

Knowledge is difficult to define, but generally the following building blocks are recognised:

1) Declarative knowledge (facts and concepts);
2) Procedural knowledge: procedures and strategies; and
3) Conditional knowledge: principles and conditions.

Examples of teamwork knowledge in these different categories are

1) Understanding one's own function in the team;
2) Knowledge of communication strategies such as ways to give and receive feedback and constructive criticism; and
3) The principles and conditions for creating and retaining a good teamwork atmosphere.

Teamwork knowledge is typically acquired during education, dedicated Team Resource Management (TRM) courses and similar specialised initiatives. However, teamwork knowledge also builds up through operational experience, which provides insight in the operations, procedures and processes and the knowledge to keep track of the situation and to 'read the game'.

Obviously, there is much more to say about the knowledge underlying successful teamwork, and how this knowledge is acquired. Literature on the topic is abundant. However, there is an overlap between the knowledge underlying team skills and the skills of the team. Knowledge that has been effectively acquired will enable the development of skills through practice. For example, knowledge about strategies on how to communicate effectively may enable the skills to communicate effectively and knowledge of the effect of stress on teamwork, allows the team to recognise the symptoms and develop teamwork skills for coping with stress.

4.5.2.7.4 Team Attitudes

Team attitudes are defined as an internal state that influences a team member's choices or decisions to act in a particular way [21]. Attitudes toward teamwork can have a significant effect on how teamwork scales are

actually put into practice [22]. Positive attitudes toward teamwork and an attraction to being part of a team ('collective orientation') have been found to enhance team processes and team performance. Some important attitudes found in the general literature are team spirit, team morale, belief in the importance of teamwork, team cohesion, shared vision, mutual trust, collective orientation [19,23,24,25,26,9,16,10].

4.5.2.7.5 Types of Team Training

Although no specialized investigations have been made with respect to the types of UAV team training that could be addressed with ET, knowledge from related domains suggests that ET could be applied for:

- Qualification training (including training for the conversion to the specific UAV);
- Day-to-day routine training at the operational unit;
- Team Resource Management training; and
- Emergency Management Command and Control (EMC2) training.

Use of ET would promote unity in operational procedures and doctrines, and be of use to train effective communication techniques, learn to overcome barriers to effective communication and awareness of strengths and weaknesses in personal communication skills. Training scenarios could, inter alia, be based on actual battlefield incidents involving factors related to teamwork (e.g., during migration of control). Such incidents with UAVs in which teamwork was a (contributory) factor are known and should be reported carefully and in detail.

4.5.2.8 Conclusions

The effectiveness of the core team operating a UAV system depends to a large extent on the teamwork of the team-members. During the flight over the battlefield the team has to deal with unplanned situations. In these situations, inefficient and ineffective team co-ordination can severely impair mission success and safety. For training of the core team in or near the GCS (mission commander, air vehicle operator, payload operator, data analysts) Embedded Training provides increased training effectiveness when compared to live training or legacy simulation training. ET would also lead to more efficient use of costly UAV flight time, when compared to live training. A number of additional advantages have been sketched, the extent of which depending on the specific architecture of the ET system. The two basic architectures are (1) ET technology concentrated on board of the air vehicle, the latter being in flight during ET, and (2) ET technology only in the GCS, with no role for the air vehicle during ET. The first architecture is the most innovative and technological challenging; particularly to safeguard the air vehicle against mishaps induced by the simulation. Teamwork has been analyzed with respect to teams skills, team knowledge and team attitudes. The tentative conclusion of this paragraph is that these skills can be addressed by the embedded training concept, particularly when applied in the qualification and conversion training, routine operational training, and focused team training such as team resource management training.

4.5.2.9 References

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