AFRL-HE-WP-TP-2006-0082

Two Chapters of Technical Report: Unmanned Military Vehicles – Human Factors of Augmenting the Force Chapter 1: Introduction Chapter 8: Summary: Issues and Conclusions

Mark Draper
John Reising
Robert Taylor

September 2006

Interim Report

Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
System Control Interfaces Branch
Wright-Patterson AFB, OH 45433-7022

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* September 2006	**2. REPORT TYPE** Interim report	**3. DATES COVERED** *(From - To)*

4. TITLE AND SUBTITLE
Two Chapters of Technical Report: Unmanned Military Vehicles – Human Factors of Augmenting the Force Chapter 1: Introduction Chapter 8: Summary: Issues and Conclusions

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Mark Draper
John Reising
Robert Taylor

5d. PROJECT NUMBER
7184

5e. TASK NUMBER
09

5f. WORK UNIT NUMBER
72

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Materiel Command
Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
System Control Interfaces Branch
Wright Patterson AFB OH 45433-7022

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/HECI

11. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-HE-WP-TP-2006-0082

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release. Distribution is unlimited. Cleared by AFRL/PA AFRL/WS-06-1695 and AFMC/PAX-06-243 on 19 Jul 06

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The terms of Reference (TOR) for the Task Group (TG) lists as its objective to seek to augment the force using uninhabited military vehicles (UMV's) by leveraging the potential advantages of UMV's to act as force multipliers. Since there are no truly uninhabited systems – operators will always be in the loop in some fashion – human factors issues become crucial to the successful operation of these systems.

In modern asymmetric warfare, well-organized belligerents ignore the legal requirement under international law to be readily distinguished from the civilian population. They merge with the civilian population, the do not travel in identifiable military vehicles and the use sophisticated deception tactics. Thus, in modern warfare, it is very difficult for an autonomous machine to discriminate between civilians and military targets.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF: **Unclassified**			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Mark Draper
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	SAR	8	**19b. TELEPONE NUMBER** *(Include area code)*

Chapter 1 – INTRODUCTION

John Reising and Robert Taylor

The terms of Reference (TOR) for the Task Group (TG) lists as its objective to seek to augment the force using uninhabited military vehicles (UMV's) by leveraging the potential advantages of UMV's to act as force multipliers. Since there are no truly uninhabited systems – operators will always be in the loop in some fashion -- human factors issues become crucial to the successful operation of these systems. Force multiplication can be achieved by addressing the human factors issues and challenges shown below.

- Collaborative Work – Optimal Task Distribution
- Virtual team performance
- Manned/Unmanned collaboration
- Interoperability
- Flexible level of automation
- Optimization of operator/vehicle ratio
- Control Stations – Intelligent Operator Support
- Operator functional state assessment
- Intelligent adaptive interfaces
- Cognitive cooperation
- Knowledge management systems

After NATO/RTO approval of the TOR, the TG was formed. Seven countries agreed to participate: Canada, France, Germany, Netherlands, Sweden, United Kingdom and United States.

1.1 The Issues

Following some initial meetings, a crucial symposium was held in Leiden, Netherlands to frame the issues to be addressed by the TG. The results of the symposium led to the following five key issues which form the basis of discussion in the final technical report: 1-Theoretical Frameworks, 2-System of Systems, 3-Cooperative Automation and Computational Intelligence, 4-Controls and Displays, and 5-Human-Automation Integration. After subsequent meetings, a chapter on Scenarios and Military Relevance was added. With the addition of Introduction and Summary and Conclusions chapters, and the modification of some chapter titles, the technical report (TR) now contains the eight chapters listed below:

1. Introduction
2. Scenarios and Military Relevance
3. Theoretical Frameworks
4. System of Systems

5. Artificial Cognition and Cooperative Automation
6. Controls and Displays
7. Human-Automation Integration
8. Summary and Conclusions

The objective of this Introduction is to give an overview of the key issues discussed in each of these chapters.

1.2 Scenarios and Military Relevance

UMVs are enablers of military capability with clear endorsement at the highest level. Many NATO Nations have active programmes to develop and integrate UMV systems into the front line military force mix. UMVs are most commonly chacterised as dealing well with "3-D" tasks – dull, dirty and dangerous. They are used extensively in intelligence, surveillance and reconnaissance (ISR), roles affording persistence in the provision of critical information, without risking lives. Increasingly, they are being utilized for combat and support roles. Important questions remain about what realistic effects can be expected to be achieved by UMVs in the uncertain, ambiguous and non-linear battle-space of the future, including how international law will interpret robotic warfare in the future.

UMVs are used extensively to gather information in ISR roles for human interpretation. ISR information is inherently incomplete and uncertain. Fundamentally, computer-based information processing systems are limited in that they can not comprehend the meaning of information in human cognitive terms e.g. apply knowledge, understand, feel truth, appreciate implications, judge consequences. Critical military judgment is needed to interpret the meaning of ISR information. Crucially, UMVs can not appreciate the effects of the use of lethal force. This lack of appreciation of lethal force consequences is one of the key issues why *human factors* are important military relevant issues with "unmanned" technologies. An example of this is illustrated in the use of autonomous UAV's. Autonomy is needed so that degraded communications, whether caused by sunspots or jamming, must not impair the aircraft functionality or the system's ability to complete missions within the assigned rules of engagement (ROE). The example ROE given is the use of force only if authorized by the *human operator*. An excellent summarization of the ethical/moral issues utilizing UMV's in combat was discussed by Air Chief Marshall Sir Brian Burridge. (Reference 29 in Chapter 2)

"When we go into combat, we have got to be sure what we are doing is both legal and moral. I do not believe that, in future, even though technology will allow it, we will be allowed to indulge in robotic warfare. I simply do not see the international community regarding that as an appropriate way to fight. The notion of using UCAVs controlled from 10 time zones away to prosecute a battle is not something international law of the future will regard as acceptable. I think the notion of a person in the loop, the notion of positive ID, the notion of someone feeling the texture of what is going on in the battlespace, is going to be more and more prevalent......Overall, I think robotic warfare drives you away from what I term as emotional connectivity with the battlespace. My view is that winning the hearts and minds battle with the indigenous population requires this emotional connectivity"

Note: In this report, when referencing UMVs, the term "uninhabited" will be substituted for "unmanned" where appropriate, in recognition of the role of both women and men equally in serving our armed forces.

1.3 Theoretical Frameworks

Theoretical frameworks have been used to guide the design of technology, procedures, systems, and systems of systems. UMV systems will also require theoretical frameworks to inform the design process. Most of the frameworks used in traditional manned systems can be applied to uninhabited systems. However, revisiting the theoretical frameworks discussion allows us to highlight aspects of the frameworks that are directly applicable to optimizing operator/vehicle ratios and interoperability of uninhabited systems. In the investigation we may also find an emerging theory or framework that is unique to UMV systems.

The place for theory in design is as follows:

- Theory can be the starting point for design;
- Theory may identify the critical design decisions;
- Theory allows for a common taxonomy within and across systems;
- Theory helps track and maintain the aim throughout the system life cycle;
- Theory helps design system verification and validation; and
- Theory helps generate measures of effectiveness.

There are a number of theoretical frameworks that address operator/vehicle optimization and interoperability. Theoretical frameworks developed for operator-manned vehicle interaction can be applied to uninhabited systems when it comes to basic ergonomics, workstation design, task analysis, workload and situational awareness. In most cases, human-machine interaction theories apply regardless if humans are inside or outside of the vehicle, although ego- versus exo-centric frames of reference may become an issue specific to UMVs. Human-human interaction theories (i.e., social behaviour) might better describe operators who interact with vehicles as a team. Thus human-machine and human-human interaction theories are reasonable starting points for exploring operator/vehicle and interoperability optimization.

The choice of a framework for analysing and designing UMV systems may depend on the proposed solution. For example, if reducing the operator/vehicle ratio means going from three operators operating one vehicle to one operator operating three vehicles, then one can imagine the requirement for intelligent help and levels of automation. The theoretical framework will need to address the following aspects:

- Level of automation and time and cultural dependencies.
- Goal/constraint level interactions instead of action level interactions.

- Self-generating future plans.
- Environment and system unpredictability.
- Trust and system acceptability and predictability.
- Implications of truly autonomous (free will) systems.
- Animation and personification of machines.
- Self-awareness, environment awareness, and awareness of itself within its environment.

While the theory may be the starting point of the design, aspects of the design define the theoretical framework to be applied. There is some initial iteration and recursion in determining the theoretical framework, however this recursion should quickly converge so that the design can move forward.

1.4 System of Systems

Once dismissed as novel technology that would never be useful within a dynamic environment, 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. 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, and command and control (C2).

As one example, consider manpower and skills, and training. 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. There are also new challenges connected with embedded training. 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. 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. 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 in the Netherlands , this is accomplished by attaching a small "v" to each virtual symbol on all displays where they can appear.

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 [Reference 24 in Chapter 4] 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."

Because there is no optimal method, it is critical that operators are kept in the autonomous UMV and decision aid supervisory control loops. UMVs are envisioned to operate in areas of uncertainty, making them subject to automation "brittleness". 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. 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. Conversely, higher levels of automation are not recommended for dynamic decision making environments like command and control 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.

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.

1.5 Artificial Cognition and Cooperative Automation

One of the key proposed advances in UMV control is the integration of artificial cognition in the process of vehicle guidance and supervision. In particular, the idea of co-operative control, i.e. the co-operation between the human operator and automation, is very important.. Human-automation integration can be viewed from two different standpoints. On the one hand, in the near term, the human has to be considered as the user of automation technology not always designed with the user as the center of the design. On the other hand, relative to the future, the consideration of human performance in the work processes suggests some unique approaches to automation and decision systems. These approaches reveal the potential of human-like behaving and cooperating machines (in the sense of rational behaviour) in certain given task domains. Another potential product is human-centred automation, promising significant performance advances, once introduced into a work place.

A major emphasis in current conventional automation is the paradigm of supervisory control. However, with regard to supervisory control of UMV's, the operator can experience a number of problems:

- Manual control of the inner loops may not be possible or desirable because of intolerable time delays in the data transmission with respect to the inner loop dynamics time constants. Thus, the remote operation relies heavily upon the availability, performance and integrity of some specific guidance functions.

- Insufficient downlink bandwidth and/or incomplete sensor coverage, with respect to the task, can cause what may be called "keyhole perspective" for the remote operator, potentially affecting the correctness or quality of his or her decisions.
- The availability of data link, i.e. the ability to monitor (via telemetry) or control (via telecommand) the vehicle remotely may be disturbed. As a result, no recognition of nor reaction to unexpected situations is possible any more on the human operator's side.

In essence, with the increasing complexity of automation, the human operator is almost completely separated from the underlying process. The long term problem is loss of skills, i.e. erosion of competence. The human-out-of-the-loop problem has other implications in situations where operators almost fully rely upon the automation -- any abnormal situation will inevitably cause human overload and possibly erroneous action.

One approach to solving these problems is to incorporate an advanced automation concept called an Artificial Cognitive Unit (ACU) as part of a work system. Advanced automation will not displace the human operator in a work system, but share the tasks in a close-partner work relationship. Task allocation will not be static, but may be adapted to the current situation's needs. This includes the facilitation of redundancy in functions by at least a partial overlap in capabilities with respect to the task spectrum. The responsibility of automation (not necessarily authority) will be extended to the supervisory control level, i.e. automation will be enabled to perform certain tasks under consideration of the overall work system. Thereby, automation brittleness will be addressed. Coordination and communication with such an automated system will be supported on all performance levels, i.e. reaching from detailed low level information (reducing opacity of the machine solutions) up to abstract human-like information exchange on the supervisory level (addressing literalism of the automation). In general, this approach to cognitive coupling can be a contributing factor to the mitigation of the negative effects of automation complexity

As indicated above, supervision and co-operation as accomplishments of a machine system require special capabilities. These capabilities were combined within the notion of the ACU. Obviously, the performance feature of *cognition* is the core element which has to be dealt with in order to design such an ACU. From the point of view of the discipline of cognitive psychology human, i.e. natural cognition can be described by considering:

- perception and allocation of attention,
- knowledge representation and memory,
- problem solving, reasoning and decision making,
- language comprehension and its generation, and
- learning and the development of expertise.

The availability of at least some of these aspects of cognition is the necessary pre-requisite to perform the supervisory control task with respect to the overall work task.

Within a particular work system, the ACU represents all the performance requirements found to be attributed to the human operator earlier on, i.e. the performance of decision-making, problem-solving and supervision in order to comply with the overall work task. The implication of advances in automation such as the ACU is to concentrate on the treatment of human and machine cognition as an inter-disciplinary approach based upon cognitive psychology and artificial intelligence as branch of information technology.

1.6 Controls and Displays

Even with rapid advances in computer processing, automation technology, and artificial intelligence methods, there remains a critical need for human involvement in order for UMVs to successfully perform their missions. The human provides unique strategic and innovative decision-making capabilities within complex, dynamic, and time sensitive situations. UMV operator performance and, by extension, the UMV operator control/display interface, will be even more critical to achieving anticipated new and increasingly complex UMV capabilities including close-coupled operations with manned systems, UMV interoperability, and military strike/combat operations. This chapter discusses a wide range of control devices. While buttons, levers, keyboards mice, trackballs, and joysticks are mentioned, more advanced input technologies such as speech recognition, touch pads, gesture- and gaze-based controls, receive the most attention. Physiological controls based on electromyographic and electroencephalographic signals are also discussed.

A variety of display technologies are also considered. Visual displays include: head-mounted and large wall-mounted, augmented/mixed reality, 3d stereoscopic and large tablet-like PDAs. Displays based on other senses take in spatial audio and haptic.

Given that humans are to remain a key component of UMV systems for the foreseeable future, it is important to recognize the unique challenges levied upon the operator. These challenges include the effects of system time delays (both fixed and variable), bandwidth limitations (which can be intermittent), datalink degradations/dropouts, and the loss of the rich supply of multi-sensory information often afforded to onboard operators. With future highly automated UMV systems, issues also include functional allocation of tasks between the operator and the system, human vigilance decrements, 'clumsy automation', limited system flexibility, mode awareness, trust/acceptance issues, failure detection, and automation biases. . However, it is also important to note that the physical separation of crew from vehicle might also offer some unique benefits that should be exploited. Besides the obvious benefit to crew safety, it is quite likely that available bandwidth and the variety of available information sources might be, in certain cases, far greater for a geographically-separated UMV crew versus an onboard operator, potentially resulting in more situation awareness rather then less. This, of course, assumes that a well-designed operator interface exists that can rapidly filter and fuse this expanded information into intuitive displays, again underscoring the need to attend to operator interface issues to ensure maximal system performance.

It is also important to note that as technology advances, the role of the UMV operator must change as well. UMV operator interfaces should not be considered 'one-size-fits-all' but must be tailored to match the capabilities and limitations of the host system and intended mission. Most current UMVs require that operators have the capability to manually control the vehicle and activate state changes (i.e., direct teleoperation). Thus, operator interfaces for these vehicles can best leverage the numerous lessons learned from decades of inner-loop control design research, while applying novel interfaces to combat challenges that are uniquely associated with UMV operation.

With new, highly automated UMVs, the operator's role is becoming more supervisory in nature, overseeing the automated activation of programmed events (e.g., making sure the appropriate event is activated at the appropriate time), managing changes to the automated mission plan, and making more strategic-level decisions. These operator interfaces must take into account issues associated with automation management, including vigilance effects, brittle/clumsy automation, sudden workload spikes, etc.

Continuing this trend beyond the current state-of-the-art, a vision exists for a new interface paradigm for controlling next generation UMVs. This envisioned interface system involves multiple semi-autonomous UMVs being controlled by a single supervisor. These UMVs will have the capability to make certain higher-order decisions, independent of operator input and pre-defined mission plans. This capability of the UMV 'to decide' constitutes a whole new set of challenges for operators, as they will be required to rapidly judge the appropriateness of these decisions and assess their impact on overall mission objectives, priorities, etc. Future operator interfaces will need controls and displays tailored for multi-UMV control and to allow the operator the capability to easily inspect/override the autonomous UMV decision-making logic. These interfaces will also need to provide information fusing/filtering algorithms, intelligent prioritization/cueing logic, and possibly some form of adaptive task allocation in response to rapidly changing events and/or workload levels.

1.7 Human-Automation Integration

Many versions of future concept of operations (CONOPS) rely heavily on UMVs. However, adding more UMVs and having them perform more complex tasks will not be realized without augmenting the current structure of control. One way to achieve this augmentation is through the utilization of automation. Automation, if applied in a responsible and judicious manner, will enable the acquisition of capabilities that will be required to operate under near and far-term CONOPS.

However, one of the key questions is, exactly how will the automation be applied in a responsible and judicious manner? Automation is not a simple concept – it involves different kinds of operator control, function allocation between the operator and the automation, various levels of authority for the automation, and the use of intelligent agents (single or multiples) within the automation. All of these aspects have to be considered, both theoretically and practically, if we are to create optimal human-automation integration. Chapter 7 begins with a discussion of operator control and finishes with UAV's operating as autonomous swarms. In the near term operators will use supervisory control. But supervisory control is not without its own problems.

1.7.1. Problems with supervisory control tasks

. *Supervisory control* of vehicles deals with automated vehicle control functions to a large extent.. The operator, who may observe the controlled process, acts as a manager who supervises the system and interacts with the automated system by performing corrective actions. It is known, however, that supervisory control systems have certain limitations in performance, either on the operator's side due to human capacity limitations or induced by deficiencies of the automation, causing human error intensified by the inability of the automation to perform on the higher level of problem-solving.

1.7.2 Function Allocation

Another consideration is who should do what? Both the operator and the automation have the capability to perform various functions. How do we decide to assign these functions to the operator or the automation, and once assigned how do we integrate the human an automation to work together optimally?

Consider the development of human roles and automation from the traditional "*Left-over principle*", through human engineering optimising *compensatory* principle with human monitoring (Fitts lists), to contemporary *complementary* principle arising from human-computer co-operation/collaboration. Now function allocation can be dynamic according to external system functions, efficiency and system boundary conditions.

1.7.3 Levels of Automation

Once you decide the allocation of the functions to the automation or the operator, then the question is, how much authority do you give to the automation to act on its own? Specifically, how much decision making authority do you give to the automation? These levels range form none to all. What are the guidelines to make this decision?

The term autonomy has been introduced to describe the bounding of functioning and decision authority of advanced automation and intelligent decision systems. Autonomy can be defined simply as the capability to make decisions. Thus, autonomy can be considered in terms of the freedom to make decisions, considering constraints on decision-making (limitations, boundaries, rules, regulations), decision-making abilities (authority, responsibility, competency), and the capability to make different kinds of decisions (classes, functions, levels).

For designing supervisory control, possible structures for the allocation of decision-making tasks between human and computers are complex (up to 10 levels). But some authors discuss four or five. These have been applied to stage models of human information processing functions (information acquisition, analysis, decision selection, action implementation). Ideas of levels of automation have been proposed to represent scales of delegation of tasks to automation, with implications for reliability, use and trust.

1.7.4 Multi-Agent Adjustable Autonomy

Dynamic adaptive and adjustable autonomy is proposed for multi-agent intelligent systems for distributed problem solving structures in complex dynamic environments. Agents have self-direction and goals with capability to form, modify or dissolve the agent organisation. Degree of autonomy becomes linked to individual goals. Focus moves to the decision process for how a goal is pursued free from intervention, oversight or control by another agent. Autonomy with respect to goals is on a variable scale (consensus, master, local, command). Issues become rules for transfer of control, communication protocols, interaction styles, and cognitive strategies for reasoning with adjustable autonomy in operating context. An example of this concept is illustrated below in the discussion of UAV's operating as a swarm.

1.7.5 Levels of Automation within the Air Vehicle.

As UAV control becomes more sophisticated, there will be intelligent software both in the operator's console as well as within the UAV itself. The airborne computing system enables 10 levels of autonomy called autonomous control levels (ACLs) within the UAV. One of the interesting things about ACLs five and higher, is that they refer to how the *entire flight* works together as a group, with the highest level being fully Autonomous Swarms where the vehicles are acting in concert with one another to achieve a common goal.

So, what does this have to do with UAVs? If a flight of UAVs could act as a swarm, instead of giving them explicit, detailed instructions on the location of surface-to-air missile batteries, for example, they could be directed to just loiter about a certain area of enemy territory and if they come across the missiles they could destroy them. Of course, they would be acting within the level of responsibility given to them by the human operator. Creating digital pheromones for UAVs is one way they could communicate. These types of pheromones are not based on chemicals, but rather on the strength of electrical fields. In a computer-based (constructive) simulation, a UAV swarm using digital pheromones significantly outperformed the non-swarm case.

1.8 Putting it all together

Although some progress has been made – there are UMV's operating in various areas of the world today – no integrated theory of human-automation integration has surfaced as of this writing. Perhaps this should not be a surprise. The integration of humans and automation is what is called a "wicked" problem, one not answered by simple solutions. However, the fact that UMV's are operational gives us hope that the problem is not intractable. In addition, ideas expressed in the following chapters offer a great potential for solving this "wicked" problem.

Chapter 8 -- Summary: Issues and Conclusions

8.1 Issue 1: Human Authority and Responsibility in Dealing with UMV's.

In modern asymmetric warfare, well-organized belligerents ignore the legal requirement under international law to be readily distinguished from the civilian population. They merge with the civilian population, they do not travel in identifiable military vehicles and they use sophisticated deception tactics. Thus, in modern warfare, it is very difficult for an autonomous machine to discriminate between civilians and military targets.

Conclusion 1: Experienced human judgment is needed to assess complex risks, to consider both the immediate and broader context, to judge the consequences and implications of action, and if possible, to anticipate, see through and counter any new deception tactics. Consequently, any autonomous system will remain dependent upon 'human-in-the-loop' targeting decisions, where a human makes the ultimate decision to engage a target.

Conclusion 2: Human involvement is required in military operations to direct and plan the use of military capability, and to ensure lawfully correct use of lethal force. This is achieved through the application of human command authority, responsibility and accountability, and competency. With autonomous UMVs, some of that responsibility is delegated to increasingly competent computer controlled machines, but the authority and accountability for the delegation ultimately remains with humans.

Conclusion 3: Pilot Authorisation and Control of Tasks (PACT) keeps operators' authority by enabling them to delegate responsibility for tasks to the computer through a set of contracts that limit autonomy and bound the behavior of the aiding system, while maintaining the operators' authority through executive control.

Conclusion 4: Delegation approaches to interaction with intelligent yet subordinate human operators have worked repeatedly throughout history and, particularly, the history of warfare. Automation in the form of UMVs will increasingly take its place as one of those actors. Since we want it to be intelligent, capable and effective, yet remain subordinate, we will increasingly need methods for enabling it to interact with *us* in the ways that we trust and are familiar with. Since delegation is the primary method that fits that bill, it only makes sense to pursue delegation approaches to human interaction with automation.

8.2 Issue 2: The Role of Human Operators with Advanced Automated and Intelligent UMV Systems.

A number of fundamental questions and key issues can be identified concerning the role of humans in advanced automated and intelligent systems. There is an inexorable trade off between higher levels of automation and unpredictability. In particular, there is uncertainty over how to optimize the use of human and computer decision resources, while preserving a human-centric system.

Conclusion 1: Automation must be designed to augment, not hinder, human capabilities. It is critical for appropriate use of automation that the user understand how the automation works and what mode the automation is in. Additionally, operator interfaces must provide rapid visibility into the current status and future plans of automation for shared human-automation situational awareness

Conclusion 2: Intelligent decision support interfaces will need to be designed such as to allow independent operator assessment of the situation as well as the rationale for any automated classifications/recommendations.

Conclusion 3: The system should perform automatic activities as if they were completed by the operators themselves during automatic task execution. There will be less unattended actions of the system, which improves the operators' awareness and comfort, increasing total system safety and performance. Natural operation is particularly important when the operators have to override the automatic system by switching back to manual control.

Conclusion 4: Automation does not reduce operator workload per se; it may change the nature of the workload or may even increase it. The operators are now supervisors of this automated system and have to monitor the vehicle state and the automation controlling the vehicle. The cognitive workload associated with this supervisory control may well be higher than the workload of physical control.

Conclusion 5: All automation is not created equal. It can be brittle, unpredictable, and prone to bias. Knowing about these pitfalls is half the battle. A designer must carefully look at where and how the automation may fail and ensure the operators know the mission impact (if any) of the failure.

Conclusion 6: Human knowledge, experience and judgment provide unique capability to analyze safety risks and to think ahead in uncertain and novel situations. The challenge is to provide information and decision systems that protect and preserve the human operators' key role, and that augment and enhance the operators' cognition rather than replaces the operators in complex decision making.

Conclusion 7: New approaches to the use of automation propose adjustable levels of computer autonomy with a strong socio-technical and cognition basis.

These seem likely to provide sensible architectures for distributed, multi-agent intelligent systems that can be more readily appreciated by human operators than traditional automation approaches.

Conclusion 8: Automation has often been approached from the bottom up, starting with the system components. An alternative is to approach the problem from the top down, using the requirements to joint system performance as a starting point. In this approach the emphasis is on operators being in control. A multi-layered Extended Control Model (ECOM) provides a good basis for understanding the consequences of automation and the needs of various types of information to support views of the past, present, and future.

8.3 Issue 3: Interoperability of UMV Systems.

Migration of operator control is currently regarded as one of the most complex and risky phases of UMV operations. Because it includes changes in the locus of control within functional, temporal, or physical domains, many system parameters may be changed and difficult procedural and technical issues can be involved. 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). Migrating control between dissimilar systems is particularly difficult because of issues of system synchronization.

Conclusion 1: The control system will need to be designed to allow for system synchronization and facilitate operators' achieving an adequate level of situational and system's awareness so a handover can be safely performed.

Conclusion 2: UAV interoperability requires development of a standard set of control station design specifications and procedures to cover the range of potential UAV operators and applications across military services and countries.

Conclusion 3: Resolving issues associated with connectivity, knowledge and action consistency, and transfer of control have taken center stage. 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.

Conclusion 4: It is important to recognize the unique challenges levied upon the UMV operators. These challenges include the effects of system time delays (both fixed and variable), bandwidth limitations (which can be intermittent), datalink degradations/dropouts, and the loss of the rich supply of multi-sensory information often afforded to onboard operators. However, the physical separation of crew from vehicle might also offer some unique benefits that should be exploited. Besides the obvious benefit to crew safety, it is quite likely that available bandwidth and the variety of available information sources might be, in certain cases, far greater for a geographically-separated UMV crew than for onboard operators, potentially resulting in more situational awareness rather than less.

Conclusion 5: 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 command and control agencies. This situation may be made more complex if a face-to-face debrief is not possible.

Conclusion 6: 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.

Conclusion 7: Since migration of operator control of UMVs 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.

Conclusion 8: Team performance directly correlates with team members' levels of situational awareness (SA). Accordingly, in order to safely migrate operator control, it is imperative the operators gaining control have at least the same level of SA as the operators releasing control. Operators should strive for the highest level of SA (e.g., level 3 SA) prior to assuming control of a UMV. Level 3 SA is defined as prediction of the future status of one's own situation and the surrounding elements. SA may need to be achieved at the system, operational, and mission levels.

8.4 Issue 4: Control Station Design.

There is a vast expanse of data that is available to UMV operators in a network centric environment. Coupled with the limitations of human information processing, autonomous UMV supervisory control issues, and the impact of environmental stressors on cognitive performance, control station designers face a huge challenge to provide a user centered design.

Conclusion 1: It is important that any UMV operator interface design follow a multi-disciplinary user-centered design process. The goal of user-centered design is to ensure the final design meets the users' needs and expectations. The process of requirements definition (user profiles, work flow, task analysis, and information architecture) and repeated interface design development and iteration (through multiple usability assessments and formal evaluations) will increase the likelihood of obtaining truly functional and easy-to-use interfaces.

Conclusion 2: As technology advances, the role of the UMV operators must change as well. Therefore, UMV operator interfaces should not be considered 'one-size-fits-all' but must be tailored to match the capabilities and limitations of the host system and intended mission. These operator interfaces must take into account issues associated with automation management, including vigilance effects, brittle/clumsy automation, sudden workload spikes, etc.

Conclusion 3: In the future, a new interface paradigm for controlling next generation UMVs may be required to enable a single supervisor to control multiple semi-autonomous UMVs. Because these UMVs will have the capability to make certain higher-order decisions, independent of operator input and pre-defined mission plans, operators will face a new set of challenges. Specifically, they will be required to rapidly judge the appropriateness of these decisions and assess their impact on overall mission objectives, priorities, etc. Future operator interfaces will need to be tailored for multi-UMV control and to allow the operator the capability to easily inspect/override the autonomous UMV decision-making logic. These interfaces will also need to provide information fusing/filtering algorithms, intelligent prioritization/cueing logic, and possibly some form of adaptive task allocation in response to rapidly changing events and/or workload levels.

Conclusion 4: The 'T' arrangement of the airspeed, altitude and heading in aircraft cockpits has led to a standard arrangement in manned aircraft. This has allowed pilots to move from one aircraft to another with minimum levels of negative transfer. No such standards exist for UMV control station design. This has led to vastly different designs by each manufacturer and the result that operators must be trained very specifically on each platform control station, with little or no advantage of previous learning. This lack of standard design must be addressed for UMVs to reduce training costs, logistics and operation errors.

Conclusion 5: UMV operator interfaces need to be designed with an understanding of where the human information processing bottlenecks occur in a task flow. As a result, the operator must be given information in a form that is easily perceived, interpreted, and responded to.

Conclusion 6: The sense of presence (i.e., "being there) is concomitant with engagement on the part of the operators, and this may be critical when the operators take on a supervisory role over semi-autonomous UMVs. In this situation, there exists the potential that the operators will 'fall out' of the control loop and may have difficulty re-entering when necessary. Immersion in the virtual environment (i.e., the UMV operator interface) may facilitate intuitive interaction and ensure that the operators remain engaged in the mission even if not directly flying the vehicle.

Conclusion 7: Since UMV operators are currently limited to a reduced stream of sensory feedback delivered almost exclusively through the visual channel, there is reason to believe that situational awareness and performance may be improved through multi-sensory interfaces. These improvements might stem from an increase in the operators' sense of presence in the remote environment, from increased information throughput provided by multi-sensory stimulation, and/or a more intuitive presentation/control of information. The result can be improved performance over conventional visual interfaces. Technologies such as spatialized audio, haptic/tactile stimulation and speech recognition systems appear especially relevant to multi-UMV operations

8.5 Issue 5: Operator Selection and Training.

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.

Conclusion 1: The best way to prevent the loss of operators' skills is probably to periodically give the operators dedicated training. Another possibility is to require the operators to perform skill critical tasks manually at certain times, even though the task may have been allocated to the automated system. Furthermore, the use of active controls, and the use of a system in which the operators 'learn' the machine how to perform a task will also help to prevent skill loss.

Conclusion 2: The operators should actively participate in the job. Have the operators activate sequences, or confirm the actual system status, on a regular basis. Avoid simultaneous monitoring and manual control activities.

Conclusion 3: Experience improves operators' cognitive throughput, allowing them to devote limited attentional resources to future problems while automatically attending to immediate perceptual and motor tasks.

Conclusion 4: Teams comprising fundamental knowledge, skills, and abilities (KSAs) are better equipped to fulfil mission goals. KSA requirements are not completely transferable from in-person teams to virtual (distributed) 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.

Conclusion 5: Relative to virtual teams, 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.

Conclusion 6: Teams need environments which facilitate efficient and effective command and control information sharing. 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.

Conclusion 7: Team members need to quickly identify individual and team information needs, fulfil 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.

Conclusion 8: 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.