# Case Study of Modeling and Simulation's Contribution to Interdisciplinary Cooperation:

## Evaluating Intelligent Adaptive Interfaces for Multiple UAV Control

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## Acronym Reference

IAI – Intelligent Adaptive interface

HM – human factors

HMI – human machine interface

IF - interface

ID – interdisciplinary

OP – operator

WL – work load

HFE - Human Factors Engineering

PCT – perceptual control theory

HGA – hierarchical goal analysis

IPME – discrete event simulation package (Dahn & Laughery, 1997)

PSF performance shaping factors (temperature, humidity, time of day, etc. ) – taken from behavioral science. In IPME they are referred to as Environmental Factors

NW – network

CTS critical task sequences

SA – situational awareness

IP/PCT - Information Processing/Perceptual Control Theory Model

## Abstract

A case study of interdisciplinary cooperation in research is presented. This case study is based on research by Defence Research Development Canada that had the goal of developing guidelines for new agent-based software designed to assist in unmanned aerial vehicle operations. A three phase research program was conducted, relying on modeling and simulation tools for scenario generation, human-machine interfaces, intelligent agent modeling, and refinement of the experiment's design. This paper outlines the disciplines that contributed to the research and how M&S tools facilitated their cooperation. Additional observations on interdisciplinary and M&S work are appended.

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# *PART I: INTRODUCTION & OVERVIEW*

## Aerial Reconnaissance

Intelligence gathering underwent experienced a fundamental change with World War One reconnaissance aircraft fitted with cameras and Morse-code radios. Previously a frontier, front line, or ground-level horizon was the limit of information gathering, but opening up the third dimension laid bare supply lines, strategic operations with the clarity of a map.

Reconnaissance evolved through the Cold War to include strategic targets, and had a significant effect on the course of arm escalation when U-2 aircraft revealed that Soviet strategic nuclear capability was less developed than planners had estimated, and that the “Bomber Gap” and “Missile Gap” were not evident. The result was that the US military delayed or scaled back plans for further arm build-up, creating conditions for a later Détente.

In Civilian applications aerial reconnaissance plays crucial roles in search and rescue, law enforcement, and border security, covering large territories rapidly.

## Role of Unmanned Aerial Vehicles

Conventional aerial reconnaissance has some limitations. The cost of operating an aircraft with a sensor suite and pilot/operator is relatively high, reducing the number of aircraft available for a given budget and the territory covered. Manned aircraft can have mission times limited by crew endurance, and aircraft large enough to have multiple crews are more expensive to operate. To be most effective, these aircraft should be as close to the target area as possible. If the target area is hostile, the danger to the aircraft and crew may be too great. Finally, aircraft that are large enough to carry crew are generally larger than required by the sensor suite and are more conspicuous, so that a target of interest may alter its behavior when spotted.

In addressing these limitations it becomes desirable to remove the crew from the aircraft without removing them from oversight and control. Because there is no need for support equipment for a pilot and crew, Unmanned Aerial Vehicles (UAVs) can be smaller, less expensive, and more potentially more varied in mission and design. Longer loiter capabilities over a target can be combined with a higher risk-tolerance, allowing organizations to gather more data from a closer range than may otherwise be possible. In short, they can be designed around the mission goal, rather than the crew and their welfare.

Removing a crew from the aircraft does not remove the need for a crew at the present time. The human element is needed to execute the mission and react to changing situations based on the information gathered. Pattern recognition, categorization of information and high-level decision making remains crucial elements best handled by a crew. As a result, UAVs are most commonly controlled from a remote location by an Operator crew. UAVs have benefited from ongoing miniaturization of electronics and sensor packages. Bidirectional communications channels and Global Positioning Systems provide an infrastructure for flight and sensor control while receiving telemetry and data with low latency. As a result, the volume of sensor data processed by operators has increased.

Unmanned Aerial Vehicles (UAVs) have contributed an increasing proportion of intelligence gathering capability to both civilian and military organizations. As their value has been demonstrated, deployment and research programs have accelerated.

## New Challenges in UAV Operation

The success of UAVs has introduced new challenges. UAV pilots and sensor operators (collectively "Operators") are typically working in teams of two or more for each UAV; at minimum a pilot and a sensor operator. Workstations are physically adjacent with one or more 2D colour displays and input controls such as keyboards, mice, and joysticks. The configuration shares much with the video-game industry and with low-fidelity flight simulators, as a design for Human-Machine interface, it can be a limiting factor in effective UAV operations, as situational awareness is typically lower. There is potential for the work load to be higher for a given set of tasks as a result of this interface. [1]

Managing Operator work load is a challenge as the complexity of UAV operations has increased. For example, operations in civilian airspace with other air traffic introduce issues of airspace violations and collision avoidance. A UAV suited to military operations would have to adapt to civilian requirements. This overhead can compete for Operator bandwidth in a mission.

A third challenge lies in the operation of multiple UAVs, which is expected to become increasingly common as the total number of UAVs increases. It becomes desirable for a single crew of Operators to manage more than one UAV concurrently, and this introduces additional peak work load issues and questions around the best way to manage and control swarms of UAVs. For example, a several specialized UAVs may be best suited for a given mission or simply in the right place at the right time. Coordinating their roles, missions, flight paths, and sensor data as a single entity can greatly increase peak work load on Operators, with the result of the swarm as a whole being far less effective than would be otherwise expected.

## *PART II: CASE STUDY:*
## *Intelligent Agents in Multi-UAV Scenarios*

Defence Research and Development Canada has responsibility for developing guidelines for best use of emerging technologies as applied to national sovereignty. An emerging topic of interest is the likelihood that UAV operations will increase in number and frequency because of advantages in cost, safety, and flexibility over manned surveillance aircraft.

The current ratio of UAV Operators to UAVs is not necessarily sustainable as theatre operations begin to include more UAVs. Currently, the typical operations for a crew single UAV is two, a Sensor Operator and a Pilot Operator, receiving mission guidance from at least one other coordinator.

DRDC, in conjunction with Subject Matter Experts (SMEs) from the military reconnaissance community envisioned scenarios in which multiple UAVs are controlled and coordinated by a single Operator crew. Not only does this reduce man power requirements, it also can allow better coordination of UAV groups as a whole as they would have oversight from a single control source.

It is understood that reducing the number of Operators could increase Operator work load, and that reducing the work load through an increase in UAV control automation could compensate. Operators would move focus from the roles of pilots and sensor operators towards higher level supervisory roles, such as planning routes and managing exceptions to normal conditions. As a result, automating UAV tasks has become an area of research focus. In automating UAV tasks it becomes beneficial to incrementally add functionality as it is understood and tested, rather than creating a full-up automation system, in this way feedback from smaller steps can guide research and development in proceeding steps. [2]

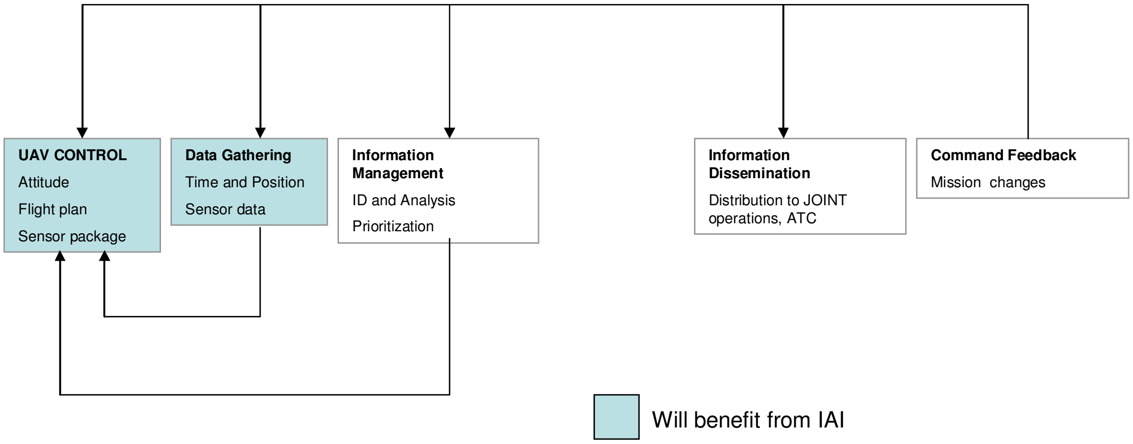
The automation of UAV operations is most easily implemented as a software layer between the operator interface and the lower-level UAV controls. The software monitors data and telemetry from the UAV as well as inputs from the Operators and contextual information about the mission. Depending on its function, the software can advise or act in place of the Operator. Software components with this capability are collectively referred to as Intelligent Agents (IAs) since they assist or replace the Operator in select tasks that require some data analysis. IAs can assist in tasks of varying complexity at several hierarchical levels of control, monitoring and management. IAs can be modular, and automation can be added or removed (switched on or off) incrementally.

Examples of low-level IAs can include simple autopilots, route and waypoint management, traffic and collision avoidance, and routine communication management. Higher level IAs can act in supervisory roles, noting air space violations, non-optimal use of UAV resources, or lack of Operator input at critical times.

DRDC research focused on the developing new guidelines and procedures for future development of a specific class of Intelligent Agents collectively referred to as Intelligent Adaptive Interfaces or “IAIs”. Their task was to assure that operator work load was reduced at critical points of a mission by managing and automating aspects of information flow between the UAVs and Operators. Additionally, they are tasked with management of aspects of communications within a crew. The software agents would be required to have an ‘understanding’ the context of operations and adapt the HMI appropriately, and even issue commands on behalf of the Operator.

This research was divided into three phases:

> **Phase 1: Computer-based modeling:** A UAV Operator simulation was created to better understand IAI effects on Operator work load. In this case, physiological and psychological aspects of the Operator were bases on pre-existing models within the simulation package. The simulation’s purpose was to validate the underlying hypothesis that IAIs could reduce operator work load. In addition, the development of the computer-based simulation provided insight in how to better deign human-in-the-loop experiments in Phase 2.
>
> **Phase 2: Development of a human-in-the-loop simulation suite:** In order to validate findings from Phase 1, this suite included realistic Operator consoles and work environment, realistic reconnaissance scenarios, enhanced IAIs and methods of measuring performance changes due to IAI involvement.
>
> **Phase 3: Experimental trials** involving trained volunteer crews and using the simulation suite from Phase 2 were carried out, providing quantitative measurement of performance from data logging and subjective measurements from questionnaires.



## *Interdisciplinary Involvement and Goals*

### Subject Matter Experts in UAV Operations

The SME has the ability to act as the checksum in a large project that spans multiple disciplines. They can be the 'outer feedback loop' for verification, validity of trials and directions of research. As the end user they can supply both the impetus to research a new topic and the tuning of experiments, models, simulations, and tests. [1]

Subject Matter Experts typically include the end users of hardware, software, and procedures. In UAV operations this includes the not just the Operators, but the entire intelligence gathering infrastructure to which the UAV belongs. SMEs provide guidance throughout a development process or experimental procedure with the ultimate goal of introducing new software which can assist in high work load scenarios, making UAV operations under high-work load conditions more effective.

Pilot Operators, Sensor Operators, and Tactical Navigators (TACNAVs) have the responsibility for operating UAVs second to second, determining the best way to assign UAV resources and monitor the data from sensor systems. Situational awareness is a critical aspect of these roles, and the new challenge is how to manage the increased data flow from more advanced sensors and more UAVs with the same crew complement. These SMEs can answer from experience and training how to best prioritize tasks and new information, how to best manage the overall sensor network, and how to accomplish specific mission objectives.

In this case, SMEs contribute to translation of operational procedures into model and simulation environments. Specifically, they assist in translation of operating procedures into task-network models that defined a simulated mission in terms of hierarchical goals.

SMEs also provide oversight of experimental runs and participation as part of human-in-the-loop simulation. Operators participated as subjects, role-players, and supervisors in experimental runs of new UAV IAI software. By using volunteers that had surveillance and reconnaissance expertise, variables related to unfamiliarity with the overall goals of a mission were effectively controlled. SMEs could also provide subjective feedback via questionnaires on any changes IAIs created in work load; their perceived effectiveness at tasks gave context to quantitative performance measures.

SMEs advised throughout the model and simulation development process and acted as an external feedback loop to assist in the validating of the experimental process and its results. For example, a Navigation Communications Officer (NAVCOM) oversaw the performance of UAV Operations crews during all experimental trials, and scored their performance under varying work load subjectively, based on experience. Had this not correlated with quantitative finding with respect to task completion times and task conflicts, a review of the experimental procedure would have been desirable.

### Software and Control Systems Engineers –IAI development

Software Engineers implement the intelligent agents which are the focus of this research, as well as the models architectures and simulators that tie them together with Operators. Because modeling and simulation is ultimately carried out in a distributed computing environment, the software is the often the final functional expression and implementation of models and simulators.

In this case, a goal of the software engineer is to create a simulation environment that has sufficient fidelity to not interfere with the questions at hand – do IAI affect crew performance under high work load. This includes implementing Operator workstation interfaces, creating a simulation environment, and implementing models that represent elements of the mission scenario. Because there is a human-in-the-loop aspect in Phases 3 and 3, these must have sufficient fidelity and responsiveness in a real-time environment to not mask any changes in test subject efficiency from IAIs being engaged.

A broader goals of software engineering is to use experimental results to develop guidelines for future IAI design and implementation. This includes requirements for information input and output on the data bus, best ways of presenting information to Operators, and protocols for messaging and control hand-off between the IAIs and Operators.

Finally, lessons learned from this research could contribute to future standardized frameworks for IAI development, allowing future work to integrate existing IAI solutions into more complex architectures with more functionality.

### Interface Designers

UAV console interface design has the task of maximizing Operator situational awareness and ability to control UAV systems within limited time windows. Interface Designers are responsible for layout of control stations, input devises, command assignments to various controls, and most critically, the display systems that are the primary method of communicating UAV status and sensor data. The challenge lies in organizing data, information, commands on screen real estate not just in terms of layout, but in terms of sequencing and timing. The Interface Designer ideally wishes to manage the Operators attention so that high priority messaging and information is the most visible. Changes in display state must be intuitive and not create confusion in the Operator (automated display layout changes, for example). The interface designer must combine text, imagery from sensors, symbology for tactical maps, and crew communications into a few display panels

In this case, the Interface Designers' challenge was in best presenting Agent-based information. As an example, alerting an Operator to new messaging from the IAI system visually and cueing the Operator that the IAI system will be making a suggestion or alert that could change UAV routes or sensor orientation. The interface design challenge also involved filtering information and presenting it to multiple crew members in contexts that were appropriate to their roles as well as visually representing inter-crew messages that were traditionally communicated verbally.

### Psychologists

Human-Machine interface design and optimization requires an understanding of human cognitive functions. For example, substituting a visual trend graph for a list of scrolling numbers in order to optimize the interface and best take advantage of human perceptual systems. In order to determine what interfaces work best it is necessary for the psychologist to gather subjective data from test subjects and systemize it in such a way that it can be applied by other disciplines.

In this case, human behavior was simulated in Phase 1 using a control systems model based on Perceptual Control Theory, a model for human behavior based on internal goal setting, rather than a 'black box' approach to behavior based on stimulus and response.[6]

Phases 2 and 3 of the research used human-in-the-loop simulations, and a goal of experimental design was to gather useful feedback from test subjects that would add context to quantitative data gathered throughout the experiment. Operators' perceived measures of work load and situational awareness could assist in determining bottlenecks in the flow of information to action on the part of UAV operators. This improves the understanding of how and where efficiency breaks down when work load increases. Ultimately, this understanding could lead to better models of human behavior for this application, providing a higher-fidelity model for fully computer-based simulations.

**Physiologist**

Physiologist use scientific methods to better understand the normal function of a human body. This includes the mechanics of perception and action, such as sight and reach, for applications to visual display and input device design. The physiologist attempts to better understand changes in the ambient environment and how these affect human performance. [1]

In this case, the physiologist is concerned primarily with the physical interface between the Operator and the UAV control station. Parameters that affected Operators physiologically, such as the console interface layout and ambient working environment were held constant so that the effects of varying work load could be monitored. In Phase 3 of the research, operator consoles were arranged as they would be in a CP-140 maritime patrol aircraft crew compartment, with associated limitations, crew proximity, and communication systems. Physiological aspects of human visual response to changes on the console displays would factor into recommendations on IAI design; these may overlap with psychological and user interface factors. For example, recommendations on colour, size, contrast, positioning, and timing of IAI messages and symbols on the Operator console could be advised by an understanding of visual response.

## *Role of Modeling and Simulation in Enabling Interdisciplinary Collaboration*

### Phase 1: Fully Computer-based Models and Simulation

Phase one of the research used a computer-based simulation with no human-in-the-loop element; the UAV Operators, their tasks, and the changes in task network when IAIs were implemented within a single software package. The goal was to integrate input from SMEs on mission design and Operator tasks, assign work load weightings to sub-tasks of the mission, and monitor Operator performance at a systems level in terms of goal completion time. This work validated aspects of IAI design and provided an initial test bed for interdisciplinary contribution before more complex human-in-the-loop experiments were carried out in Phases 2 and 3 of research.

### Choice of Simulation Platform

An existing simulation package was chosen as the environment in which to build the models and the simulation. The Integrated Performance Modeling Environment (IPME) package is a discrete event simulation package, chosen as a preliminary design tool because several aspects of the simulation could be rapidly developed based on integrated models. This integration and mature design interface facilitated contribution from the involved disciplines:

### Environment Model - Physiologists

Also referred to as Performance Shaping Factors (PSF), these collectively modeled the effects of temperature, humidity, time of day, and even physical reach as they apply to human performance. Physiological factors were already modeled by this element of the simulation software, requiring only setting of parameters. In this way, prior work by physiologists on human factors modeling could be easily applied without starting from first principles and validating new models. It also provided the potential for correlation with other indirectly related work that used the same models.

### Crew Model – Psychologists and SMEs

The Information Processing/Perceptual Control Theory (IP/PCT) Model was used to understand more abstract concepts of situational awareness and work load within a quantitative framework. This model has been the subject of ongoing validation efforts.[7] The model ties crew actions to work load by modeling crew as information processors with bandwidth-variant characteristics. Most notably, this model is available commercially as a software module and is used in areas of research where work load versus performance effects must be modeled. While using a commonly available model does not in any way increase validity, it does take advantage of existing investments, software maturity and experience in the limits of its fidelity from previous experiments.

### Task Model – SMEs, Software and Systems Engineers

A task model is effectively a flow chart of actions to be carried out in the simulation by ‘Crew’. Steps and decision points in the Task model can lead to success and fail conditions which trigger the subsequent task sequences. Each Task Group is progressively broken down into subtasks and this hierarchy can be assigned can be monitored at any depth. Assuring that a realistic task model was created for the simulation involved Subject Mater Experts in the field of UAV operations and reconnaissance, including CP-140 crews. The Task Model Diagrams were based closely on Operational Sequence Diagrams from actual reconnaissance procedures. Based on SME input, weighting factors were applied to each task in terms of priority and resource requirements to further improve model fidelity.

The IPME simulation package included a graphical user interface which streamlined the entry of Task Network Diagrams, allowing a more intuitive method of capturing contributions from SMEs, such as relative difficulty weightings of tasks.

IPME has the capability to conduct multiple-run simulations and log data; using a Monte-Carlo simulation system, IPME could rapidly gather and compile data on multiple runs of the simulation with varying parameters, logging and processing the results.

### IAIs Modeled as Task Model Branches - SMEs, Software and Systems Engineers

The task network model was effectively provided with multiple pathways which simulated the IAI system as either ON or OFF, in this way, so that changes total system performance with respect to IAI use could be more explicitly modeled and monitored. Two IAIs were modeled:

1. Route Planning – automated suggestion of search and holding patterns for unassigned UAVs – chosen because it was assumed that all UAVs should be assigned, and an unassigned route indicated high operator work load.
2. Communications – Essentially a message-waiting system, tasked with visually queuing automated the most common inter-crew verbal communications such as acknowledgement of orders.

The Task model was built around a scenario that included a CP-140 maritime patrol aircraft, external crew outside the UAV operators, and multiple targets and UAVs. Using Hierarchical Goal Analysis (HGA), tasks were progressively decomposed into subtasks while maintaining a structure that allow quantitative analysis of goal high-level goal completion time with associated information on underlying causes.

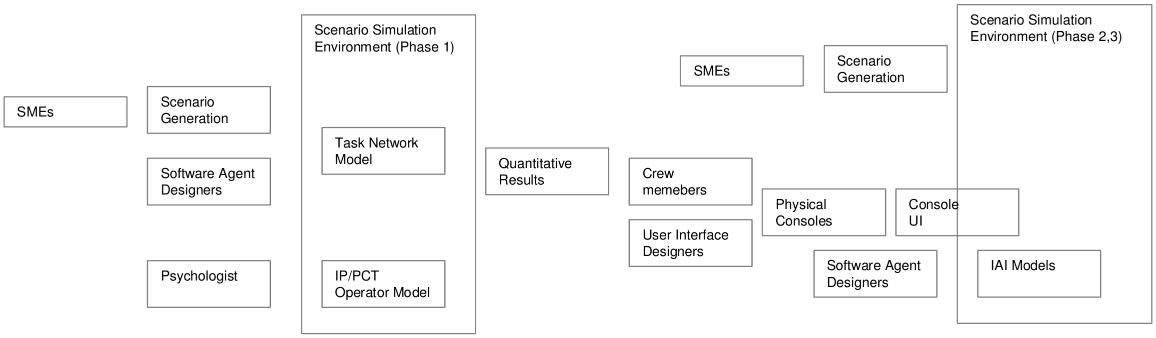
### Monitored Parameters

Major task completion time and time conflicts between these tasks were monitored for UAV Operators. Sample tasks included launching UAVs, finding targets, and threat assessment. Simulations were run with varying initial parameters and the task simulation acted in a probabilistic manner. The simulation software package compared ‘crew’ performance with the IAI system On and OFF so that its impact on crew work load could be determined.

### Results of Phase I

Results indicated that the IAIs actions reduced the number of task conflicts and the time for task completion. This was more apparent as operator work load increased in simulated scenarios. For example, Task conflicts cropped on average from 38% to 17%, while goal completion times were generally improved by 25%. While the actual improvement magnitudes were not necessarily accurate, the correlations proved the validity of the overall IAI concept using existing task and Human Performance models. This provided valuable understanding of how IAI could be developed to test their effectiveness in Phases 2 and 3.

## Phases II and III – Human in the Loop Simulations



### Scenario Development – SMEs, Psychologists

A realistic scenario was considered important to both immerse test subjects in the simulation, and as such, a terrorist threat from a ship-launched UAV towards a city target was created with multiple Canadian Forces ships, aircraft, and UAVs in the theatre performing security and reconnaissance missions. The Operator test subjects were operating from a hypothetical CP-140 maritime aircraft outfitted with UAV control consoles and deployable mini UAVs.  Subject Matter Experts in maritime patrol and UAV operations contributed to scenario generation in order to assure realistic tasks, situations, and procedures.

Adding an operational context allowed Operator test subjects to associate the simulation more closely with actual training and operations. It also provides a framework which put the results in a more easily applicable format when compiling results. Re-creating the reconnaissance scenario with high fidelity provided more intuitive correlation between quantitative performance measure and subjective results from questionnaires.

### Simulation Development – Software and Control System Engineer, Interface Designer

There were three aspects to software development: Simulated environment, operator Console Interface, and IAI agent design and interface modifications:

1. **The simulated environments** was a pre-existing UAV flight simulation package that allowed population of the environment with multiple air and sea units and control aspects of flight dynamics unit movements and event sequences. A real-time simulation environment was necessary since the Operators would be interacting with the simulation. The fidelity of existing systems was sufficient, streamlining this part of development. By using a simulated environment, scenarios could be quickly reset, allowing multiple tests with identical starting conditions.

2. **Operator Console Interfaces** – these were developed specifically for the research and interface design that varied for each of the three crew members. The Pilot Operator had effectively a heads- up display from a Pilot camera on the simulated UAV, the Sensor Operator have virtual camera images and data on their consoled, and the tactical Navigator had a top-view display of unit positions and status. Each of these displays was generated in real-time in synchronization with the simulation environment. The Interface was extensible, allowing IAIs to be incorporated. Base on input from SMEs and Interface Designers, several methods for presenting the additional IAI information were used, including text messaging windows, information appended to target symbols, and changing the interface layout to focus an operator on an area of interest.

3. **IAI behavior and interface modifications** – IAI tasks were chosen based on SME input and lessons learned from Phase 1. Examples included route planning and execution, console display management, inter-crew communications assistance, and UAV sensor lock and track. These agents were implemented as a layer between the environmental simulation and the Operator console displays. Using a simulated system removed the requirement to interface with an aircraft data bus, as IAIs could take information directly from the simulation variables if needed. This removed the complexities associated with partial information and probabilistic decision making, and allowed research to focus on the utility of a set of IAIs, rather than their practical implementation.

### Console and Environment Development – SMEs, Physiologists,

The layout of the crew consoles matched configuration for a modified CP-140 Maritime patrol aircraft. Console dimensions and layouts physically matched a hypothetical refit. Input devices such as mice, keyboards, programmable keypads and joysticks were used to assure that the

Operators were fully immersed in the simulation and that changes in the methods of input from their existing training did not affect experimental results. Displays positions were based on the realities of the existing aircraft consoles, and a standard headset communications system was used to match pre-existing CP-140 systems. Because the CP-140 is environmentally controlled and generally avoids high-g maneuvers, the simulated stations could be kept on the ground, removing much of the hardware integration and aviation safety concerns.

### Experimental Design – SMEs, Software Engineers, Psychologists

Using input from SMEs, the reconnaissance scenarios were broken down to discrete tasks and goals based on operational procedures established in maritime reconnaissance and UAV operations. These were formalized in a hierarchy so that the effect of increasing operator work load could be correlated to impact on mission and goal completion. This also allowed for repeatability and translation into event sequences for the UAV simulation.

The experiment was designed to progressively and controllably escalate Operator work load during several simulated UAV operations. The experiment included Operator training sessions with the consoles and trial sequencing that minimized effects resulting from test subjects learning the scenarios. The only desired variables were the work load and whether or not the IAIs were assisting Operators in completing mission tasks.

Results were measured both quantitatively and subjectively. Quantitative measures included task completion times and "task shedding" (uncompleted tasks) as well as measures of UAV flight path control. This data was logged directly from the simulator system, simplifying its collection.

Subjective measures were made from the results of crew member questionnaires filled out at the end of a given trial. Questions focused on the Subjects perception of higher level metrics, including work load and situational awareness. In this way the perceived effects of IAIs on Operator performance could be correlated with the behavioral effects measured quantitatively. A subject matter expert, acting as a crew supervisor (NAVCOM) also answered a questionnaire focusing on their perception of overall crew performance, adding a higher level view context for the data.

# *PART III: DISCUSSION*

## Findings in an Interdisciplinary Context

Results under high work load conditions showed that both quantitatively and subjectively that IAIs increased situational awareness while improving response time and reducing task shedding. As would be expected, IAIs had less impact in low work load scenarios, even adding some work load because of the need to interact with them. Subjective context proved valuable, as some results were possibly altered due to the novelty of the IAIs for experienced Operators, used to managing work load with different methods.

This experiment would have been made much more complex if simulations were not used. It likely would never have taken place, as new hardware and flight-certified software would be required and a maritime reconnaissance scenario would have to be reenacted multiple times. Practical issues surrounding repeatability and changes in sensor data may have masked any potential benefit from IAIs.

Conversely, simply running the simulation using models of human behavior and perception would not have been considered conclusive or sufficient to develop new guidelines for IAIs. Human models used in Phase 1 of the research could not be considered complex enough for validated results and provide no subjective data. The Simulation required the most fidelity from the Human operator model, and so that part of the simulation was substituted by the real thing.

Interdisciplinary requirements for a valid and useful research in IAI-Operator interaction dictated a mixed simulation environment be used. This was not research directed towards new UAV sensor systems or better intelligence models for IAIs, so these models were made sufficient for the purposes of the primary research goal and held constant throughout trials.

Modeling and simulation made this a practical research exercise, especially considering the preliminary nature of IAI software maturity. In a larger context, it has established a precedent and a methodology for these disciplines to further develop and test IAIs.

This research demonstrated the advantage of intelligent agents working in conjunction with human operators. In the research and experimental process Operators and SMEs noted other potential applications and tasks that could be handed-off to agents. These typically were higher level functions that monitored the larger context of a mission and communicated an agent’s intent to act, such as showing an intended flight path or how it is about to change the display layout. They also noted the desirability of clean handoff of interface control from the agents to the operator could be as simple as a ‘back’ button on screen, or a query prompt that shows IAI intent. Interdisciplinary communication allowed the research to not just answer the initial question of ‘do IAIs help?’ but how they could potentially do more and better work with human operators.

## *Expansion of Research to Include Other Disciplines*

### Mission Planners

Although the UAV operators were considered the end-user of the IAIs, intelligent agents can act on many levels. SMEs at strategic and theatre-levels could inform new directions for research, such as intelligent agents for optimizing the deployment of reconnaissance resources. Possible research question could include:

“How many reconnaissance resource are optimal for a given situation?”

“Do the advantages of multiple UAVs saturate and become detrimental at some point?”

“Could x UAVs be more effective than x+n?”

### Physiologists – Human Perception

Operator control stations used in this research were effectively standard, with panel displays and haptic input using joystick, mouse, and keyboard. Tactile, auditory, or heads-up display technologies could be researched for more effective communication between intelligent agents and crew, improving overall situational awareness. Research questions could include:

“Could haptic-feedback to Operators increase situational awareness of flight conditions?”

“Would using a head-controlled sensor platform interface improve Sensor operator performance?”

“Would there be implications for moving the crew to a satellite link outside the theatre? Would a time delay affect performance and could IA assist?”

### UAV Designers

UAV designers could provide input into evolving UAV sensor systems to better collect and present data to Operators. Research questions could include:

“Would more, simpler UAVs work better than or fewer complex UAVs when human operators were considered as part of the control loop?”

“How much automation should be directly incorporated into the UAV? How much automated fusion of sensor data is optimal in a given situation?”

"Could synthetic-aperture sensors using multiple UAVs as elements be a worthwhile development, or would advantages be lost because of Operator work load?"

"Are there benefits to UAV swarm autonomy and should this be built into the UAVs directly, or into a central control system, or both?"

**Communications Engineers**

This research was not focused on the practicalities of IAI development in terms of interpreting raw sensor data, however IAI capability is ultimately limited by the amount and type of data on the sensor bus. Research questions could include:

"What are the limits of IAI performance with available real-world data?"

"Could new standards for sensor fusion or data bus protocols provide more suitable information to the data bus?"

"Could output from software modules such as image processors on the database be put back on the bus for consumption by intelligent agents?"

**Standard IAI architecture and APIs in order to leverage hierarchical and modular design.**

Introducing an IAI interoperability standard could increase agent effectiveness by allowing simple functionality to be encapsulated in increasingly more complex agent software. Developing a standard for APIs and data structures would allow incremental development of IAI complexity and functionality. Research questions could include:

"Is it practical or viable to produce and IAI interoperability standard? For example, could a route-planner agent be easily ported between hardware platforms, or be integrated with a threat assessment agent to route UAVs for best self preservation?"

"What standard interfaces would benefit IAI development and integration? Would these be information sharing APIs, Operator display controllers, standard probabalistic models to allow action on incomplete data?"

"Should there be a standard method of activating or deactivating agents and dependent agent networks as desired?"

**Pilots**

UAV consoles tend to borrow elements from an aviation heritage, including heads-up displays overlays, artificial horizons, but do not embrace some of the more recent developments in glass cockpit technology, instead more closely resembling prototypes developed on a desktop computer

GUI. As an example, many new cockpit interfaces use the concept of normally dark displays which only draw a pilot's attention when action or decision is required. Using these design lessons may reduce work load and improve operator efficiency as a supplement to an IAI layer.[8] Research questions could include:

"What practices from cockpit design could be applied with best effect to UAV console design?"

"Could additional sensory cues that simulate flight improve Operator situational awareness?"

"Could work load be reduced by using a simplified exception-based interface?"

**Artificial Intelligence and Experts Systems developers**

Current IAIs act based on their programming but do not have a facility to learn from experience. Advanced IAIs could be explored that recognize patterns and apply techniques in machine vision. IAIs could also be developed based on the understanding how Operators would do a specific task, creating expert system agents. Research questions could include:

"What is effectiveness of image recognition systems tied into UAV sensors?"

"Is there benefit to agent voice-recognition and spoken feedback capability?"

"Would agent performance benefit from higher-level motivations and goals such as fear, curiosity, loneliness or boredom?"

"Are there benefits to integrating UAVs into crews through anthropomorphizing them?"

## Some Realities of Interdisciplinary Cooperation [1]

### Communication

Interdisciplinary cooperation revolves around effective communication and commonly understood metrics. Communication means sharing a common vernacular; for example, what are the differences in the meaning of the term 'work load' between an engineer and a psychologist? This common vernacular should not be new, but instead should borrow from all involved disciplines, removing ambiguity in terminology. There is no formalized way of arriving at this middle ground, however what can be most successful is common facilities and proximity – having everyone from ground crew to machinists to pilots to psychologists within a minute's walk of each other. A one-stop-shop mentality can allow multiple disciplines to work as a whole when addressing new questions.

### Directions and Methods of Inquiry

Looking at a problem from different perspectives is of obvious benefit, for example unique questions can be asked that are a result of bridges (or gaps) between disciplines. In addition, the tools from one discipline are often vital for creating larger feedback loops that help fine-tune other systems. As an example, pilot and physiologist input to an engineering process provides additional tuning parameters, and new directions of inquiry into Operator interface design.

Subscribing to the scientific method from SME (test pilots) through engineers and human factors researchers forms a solid basis for inquiry and experiment. Agreeing on methods of quantifying human factors in a way that can be translated into workable engineering feedback becomes vital. At the same time, however quantitative feedback on the human element loses much of its usefulness if separated from qualitative subjective ‘notes’. For example, a pilot that specifies control difficulty as “5/10” may be repeatable and accurate within their own perceptions, but having a description of why that metric was presented gives context to allow their experiences to be correlated with such things as control input frequency, and cross-correlated with other pilots’ experiences and feedback.

There is a tendency for problems in the multidisciplinary space to become meaningless if methodology is atomized to a fine enough degree. Systems-level problems arise from synthesis and interactions that are ‘unplugged’ when individual components are separated. By taking a systems level approach it is very common that new questions, new challenges and directions for research arise as a serendipitous result. Sometimes these are more fundamental questions that were previously considered ‘safe’ assumptions, but need to be reevaluated at a more basic level to assure a firm base to conduct further research.

### Interoperability of Tools

There is a movement towards modularization of components, models, and simulation tools.[1,2] For example, standardization on the High Level Architecture is beneficial in potentially reducing development time, however many systems and simulations can meet the desired fidelity requirements and experimental goals using off-the-shelf hardware and software, from input devices to displays, to computers and flight simulation software. In terms of development time and budget it is a best practice to try what is cheap (in terms of implementation hours and integration costs) first and see if it can meet requirements for the simulation as a whole.

Standards of interoperability can arise organically from common usage and market-dominance of a single supplier’s product, or simply the fact that the product is available at the time the research was done. This is a very pragmatic approach that may be a result of budgetary conditions, but is often implemented due to time constraints. Although some off-the-shelf systems can lack the fidelity or features desired for a simulation, it is often more important to "just get something up and running" by a certain deadline, especially in joint operations or in experiments where large aircraft and piloting resource are coordinated – the software is the most flexible element, and often is bears the brunt of compromise.[2]

### Validation

Looking at validity at a component level alone can result in a simulation that does not validate for the desired parameters. For example, putting a fully valid helicopter flight control interface and dynamics model into a simulator has resulted in poorer hover maintenance because the simulator graphics system and the [lack of] a kinematic feedback system reduces pilot cues to a level where there is not enough information to hover accurately.[1] Because fidelity is inherently expensive in terms of development time and computational resources, it becomes more important to restore pilot work load to a level that reflects true flight by reducing the fidelity of the vehicle dynamics until work load correlates with the reality. This could only be achieved by looking at the system as a whole and optimizing component performance (visual systems, vehicle dynamics) in terms of achieving an overall validity for pilot work load testing. This optimization may not be valid for testing other parameters.

## Future Directions in UAV Interface Design

### Building on Cockpit Research

Interface design is not necessarily limited CPU cycles or by the hardware when making a UAV interface;[1] this does not mean, however, that a perfect simulation of the environment around a UAV can be made without some tradeoffs. Limits can be more pragmatic, for example by budgets, timelines, or fragmentation of research. Many smaller projects and non-standardized UAV control schemes (station layout, screen interfaces, symbology) can be detrimental to building on past research. Many UAV control and interface research efforts have not built on what has been achieved in the last 50 years of pilot information systems and interfaces, where real-time is real-life[1]. As pilot interface systems have become more complex, there is no longer an implicit proximity between the two, meaning that UAV systems and pilot systems may share the same avionics and software layer between them and the hardware. Because of this many of the lessons learned in cockpit design and pilot psychology could be applied to UAV control. From heads-up displays to the best way top present a moving map. The demands on a pilot are, if anything, greater than that of a UAV controller, so the lessons should not be ignored.

### Communication with Intelligent Agents

Another aspect of UAV control is protocols for cooperation between Intelligent Agents and the Operator. Ultimately the human in UAV control is best suited to pattern recognition and dealing with exceptions – they are there primarily to monitor sensors, not to fly the UAV straight and level, or in a search pattern, or to help it avoid air traffic. These tasks can be handed off to an IA system if it is sufficiently robust. The operator can then focus on sensors.

This concept of ‘exceptions handling’ makes better use of the unique capabilities of a human in the loop, however the way in which the system behaves during these exception periods is critical. For example, an operator may establish several waypoints for the autopilot to fly, however the system should report ‘what it is going to do’ (e.g. what path between the waypoints it will take), to prevent the perception of sudden, unanticipated behavior. Providing the operator with some level of knowledge of the system’s intentions is desirable, as it can provide the context to make ‘Unknown sudden course change’ into ‘Moving to avoid other aircraft”.

The level of automation is dependent on how advanced an agent-based control or monitoring system is. The question of how the operator should be involved is not trivial. For example, in a collision avoidance scenario in civilian airspace, should the UAV take action automatically, or if there is a window of time should the operator be notified of possible choices for avoidance and be able to choose their preferred option? If the option is presented, questions arise about how long until a time-out event is triggered and the system makes an automated decision.

When a system does perform a handoff, the handoff itself should be predictable and put the interface in a known state before the operator takes over. Discontinuities such as a handoff in the midst of a maneuver or emergency can result in much greater issues than a staged handoff to acclimate the operator to the condition and reasons for the handoff.[1] The automation must provide context for anything it does.

## The Future of UAVs and Implication for Simulation

UAVs have the flexibility to be designed both larger and smaller than current configurations. They can be made more disposable and more capable. Questions arise about how best to handle multiple UAVs as numbers and classifications become truly large. Exploring the control aspects of large ‘swarms’ of heterogeneous UAVs becomes a practical area for simulation-based research, for example, could fully distributed sensor networks be effectively combined to create meta-sensors, such as large synthetic apertures?

As intelligent agent software matures, greater UAV ‘understanding’ of mission context may also shape human control and information analysis. Human intervention may be reduced from minute-by-minute monitoring to exception handling when a UAV network determines sufficiently “interesting” activity has occurred.  M&S can be used to model these possibilities before the technology to build them is available, allowing operations and technical focus to be guided by operational lessons learned in simulation rather than the other way around. Modeling and simulation will allow the question ‘how do we best use the technology we have?’ to be replaced with, ‘what capabilities are best focused on next?’

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