Technical Evaluation Report

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INTRODUCTION

On 7-9 October 2002, more than 100 NATO, Partnership for Peace, and Non-NATO nationals from 22 countries met in Warsaw, Poland to discuss the role of humans in intelligent and automated systems. Sponsored by the Human Factors and Medicine Panel of the North Atlantic Treaty Organization's Research and Technology Organization, the symposium participants discussed the problem, research approaches and techniques for how automation technology can take advantage of human strengths and compensate for human disadvantages and how humans can take advantage of automated systems strengths and compensate for automated systems disadvantages.

THEME / OVERVIEW

Automation may increase efficiency, but it also raises doubts about adequate human control over automated systems and making sure that system effectiveness is not jeopardized. This symposium focused on the interaction of humans with a growing array of automated functions and automated and intelligent systems. During the symposium, participants discussed how to harmonize the interactions of humans with automated and semi-automated systems to increase overall mission performance. The symposium participants outlined recommendations for development of human-centered automation in military environments, addressing key areas such as providing levels of automation that are appropriate to levels of risk, examining procedures for recovery from emergencies, and ensuring human control of automation.

SYMPOSIUM PROGRAM

The Symposium, co-chaired by Dr. N. Gershon (USA) and Dr. K. Boff (USA), consisted of an Opening Session, three sessions on design philosophy, two sessions and a roundtable discussion on design methodology, two sessions on design evaluation, and a Capstone Panel with open discussion. Six Keynote Addresses were interspersed throughout the program. All told, 18 papers were presented, and 5 poster papers were available for review.

TECHNICAL EVALUATION

This technical evaluation is divided into three parts. The first part is an overview of the problem as presented in the Opening Session (not otherwise captured in this volume) and by the Keynote Speakers throughout the Symposium. The second part reviews the content discussed in each of the sessions – design philosophy, design methodology, and design evaluation – as presented by the paper authors. The point is not to provide a summary of each paper (these appear elsewhere in the volume), but to point out the relevance of the paper to

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the problem statement. The third and final part of this report evaluates the content presented and discussed throughout all sessions and the Capstone Panel, and concludes with recommendations for action that emerged during the Symposium.

I: Problem Statement

Opening Session

Col. W. Tielemans (NE), the Chairman of the Human Factors in Medicine Panel noted that it was an honor for the Panel to meet in Poland. In his view, NATO's RTO is the focal point for the research and technology opportunities available to the new NATO member states and the overall Partnership for Peace.

MajGen C. Mikrut (POL), the Deputy Commander of the Polish Air Force and host of the Symposium, stressed the importance of intelligent and automated systems for the new NATO countries, especially in the training process. We must all adjust to change, Mikrut noted, both in the role of technology and in the role of humans in intelligent and automated systems. For these countries (and for others), meeting the demands on the armed forces with downsized resources and numbers depends on effective cooperation between humans and machines, itself dependent on the wise investment in research and technology in intelligent and automated systems. He argued that selecting the right person for the right human-machine system is increasingly important.

Col P. Rusecki (POL), General Sanitory Inspector for the Polish Army, stressed the need for automation technology to improve the performance, health, safety, and well-being of military personnel. The demands of the 21st century remind us that we live in an interdependent world, all facing acute global problems together. These problems require collective solutions, integrating efforts by countries with differing levels of technology. Incorporating intelligent and automated systems will help us all to meet new challenges.

Dr. N. Gershon (USA) emphasized that this topic has been of interest to scientists, artists, filmmakers and the like, and that we scientists can learn from the perspectives of artists and filmmakers and the issues they identify. Take the scene in the film 2001 when the computer "Hal" declares his error to be "human-caused." Since humans developed Hal's program and the interfaces, isn't Hal right in a profound sense? That is, in considering the role of humans in human-automated system interactions, we must look beyond the human user to the human program developer. Gershon also challenged participants as follows: Why have there been so few successful implementations of intelligent agents? How can we tell when a program that controls a process becomes an agent? Also, do agents in fact have to be intelligent?

According to Dr. Ken Boff (USA), rapid advances in intelligent system automation, networking, and communications technologies are likely to change the nature of conflict and also provide a few surprises. Early approaches at incorporating these technologies tended towards the substitution of new capabilities performed by machines for traditional functions performed by humans, rather than reconceptualizing the nature of these functions to gain maximum advantage. In some instances, overall system effectiveness has been reduced rather than advanced. The technological intensity of the long-anticipated "revolution in military affairs" portend fundamental and significant challenges to sustaining and enhancing human effectiveness in military operations precisely in those areas where human decision making is central to success. In such areas, Boff argues, we must focus on the role of humans in intelligent and automated systems to gain maximum advantage of the overall human-machine system.

Keynote Addresses

In *Keynote Address I*, Dr. J. Reising (USA) discussed the proper role of operators in uninhabited military (ground, airborne, and underwater) vehicles. Such vehicles cover a spectrum of human-machine interaction, from tele-operated to semi-autonomous systems. He argues that the basic operating principles of varying levels of autonomy and dynamic function allocation will enable the human operator and the associate vehicle to form a team consisting of two (or more) crewmembers, at least one human and one electronic. To function efficiently and effectively, the team members must trust each other. Since it is not clear how the machine could or could not trust the human operator, the crucial aspect of teambuilding is for the operator to trust the machine. He discussed guidelines for how to help build a high quality, trusting relationship. One key aspect is the ability of the human to specify in advance the levels of automated system authority for various mission phases.

In *Keynote Address II*, Prof. R. Amalberti (FR) reviewed how the use of intelligent and automated systems were expected to increase system performance, release humans from repetitive tasks, and reduce routine errors. While these goals have been met, there are concerns about the growing dependency of humans on automated systems for cognition, particularly during operations in degraded modes. Paradoxically, the technological complexity of the automated systems is reducing training time, thereby increasing this cognitive dependency, particularly for novices. It is important to identify in advance whether automated system use is designed to train novices to become experts in low-risk situations (such as in civil aviation), or to enable experts to become super-experts in high risk situations (such as in military aviation). The French military leadership, Amalberti argues, has not yet clearly defined its goals for the use of automation. Amalberti also notes the shift in military aviation human factors research from individual to team and systemic problem solving and training. Today, team and systemic performance is fast becoming the limiting factor of performance. With the expanded span of communication and controls now available in military aviation, there is an increased need for joint human factor training between pilots, planners, controllers, and mechanics.

In *Keynote Address III*, Mr. R. Taylor (UK) focused on the key human factors issue today – how to ensure the appropriate levels of automation for military decision functions given the need to mitigate the associated risks for human understanding, prediction, and control of system functioning. He addressed the ability of intelligent systems to decompose goals assigned by the human. Traditionally, knowledge-based behavior has been left to humans, with automated systems involved in skill- and rule-based behavior. Taylor argues that humans and what he terms ‘cognitive automated systems’ should be partners in all three types of behavior in a collaborative vice merely a coordinated or cooperative system. This “complementarity principle” moves the issue from human-machine interaction to human-computer collaboration to ensure the optimum contribution of both to military system effectiveness. One key driver of effectiveness will be the ability of military systems involving cognitive automate systems to adapt to the anticipated changes in envisioned operations as well as to the needs of unanticipated future operations.

In *Keynote Address IV*, Mr. E. Tarnowski (FR) focused on the cockpit automation philosophy of the Airbus Corporation. Airbus has developed automated systems to play on the strengths of the human operator (e.g., “airmanship” – intuition through experiential learning, and compensate for the operator’s weaknesses (humans are non-repetitive manipulators, affected by stress, with a propensity to unpredictability and a potential for laziness). Automation can be a complement to the human, improving both flight safety and efficiency when used where it can do better than the human (e.g., tactical vice strategic tasks). But this is possible only if the automation is tailored and adjusted for the human, and if the human adapts to automation through judicious training. Pilots can no longer be “lone rangers,” Tarnowski believes, and must be leaders of a team that includes other humans and the automation systems.

In *Keynote Address V*, Prof. R. Onken (GE) discussed cognitive cooperation for the sake of human-machine team effectiveness. He identified the need for the artificial cognitive systems to have a great amount of knowledge in common with the human operator. Particularly important is the need for explicit knowledge of the governing work team objectives, set by the human, that underlay sensitive interaction by the machine as a team mate.

In *Keynote Address VI*, Dr. J. Bradshaw (USA) provided an overview of the basic principles and pitfalls of adjustable autonomy and human-centered teamwork and a broad model of human-agent teamwork grounded in practice. His address, based on a paper written with several colleagues[1] also covered the interim results of a study on the problem of work practice modeling and human-agent collaboration in space applications. Bradshaw argues that agent technology can provide the means for distributed agent components to engage in high level collaboration. Further, for human-agent teamwork, agent technology can help exploit synergy, adjust autonomy, expose relevant states, and avoid clumsy automation by overcoming the limitations of direct point-and-click manipulation interfaces.

II: Content Presented

Design Philosophy

The three design philosophy sessions were chaired by Prof. Dr. X. van Norren (NE), Dr. A. Leger (FR), and Dr. S. Kirschenbaum (USA).

Dr. R. Breton (CA) presented a paper co-written with Dr. E. Bosse (CA) that discusses the cognitive costs and benefits of automation (*Paper #1*). They note a paradox between the need for technological support to execute command and control tasks adequately in complex environments, and the contribution of technology to the complexity of that environment. Automating sub-parts of the decision-making task, they argue, can resolve this paradox. Since automated systems use deductive reasoning and humans use inductive reasoning, quality human-automated system interactions – with a balance between the complexity of automated systems and the transparency of those systems to the human partners – should result in a high-performing team. Central to such quality system interactions is understanding on the part of the human of how the system is working, coupled with access by the human to the sources of information (that are processed by the automated systems). Hence, the importance of training the human to become a better supervisor of the automated system to improve overall system performance.

LtCol Dr. A. Worm (SWE) focused on the increased reliance on distributed and automated systems in network-centric military operations and in emergency management (*Paper #2*). In both situations, highly qualified automated command support is critical. Worm argues that such support is best developed through the use of scenarios in advanced distributed simulations involving experienced operators and decision-makers.

Dr. N. Allen (CA) presented a paper co-written with Dr. R. Kessel (CA) that examined the roles of the humans and machines in decision aid strategies for target detection in undersea warfare (*Paper #3*). Conventional automated detection systems fail when the detector's abilities are not matched to its responsibility. Automated decision aids can improve overall system performance if there is a working balance between the responsibilities and abilities for all detectors, human and machine, in the system. Both the system designer's and human operator's understanding of the human-machine roles are crucial for success.

[1] The other authors include: M. Sierhuis, A. Acquisti, P. Feltovich, R. Hoffman, R. Jeffers, D. Prescott, N. Suri, A. Uszok, and R. van Hoof, all from the USA.

Dr. B. Digney (CA) discussed how humans can teach learning machines in the control of autonomous land vehicles (*Paper #4*). Humans combine or adapt knowledge they are taught and generate new knowledge only when needed. To be successful, automated systems must be able to decompose learned models into reusable chunks, recombining such chunks whenever possible in future situations. Such hierarchical learning control systems, if "taught" successfully by human operators through hierarchical learning methods (imitation, instruction, graduated complexity, protected exploration, and graduated lessons), may be able to adapt to situations quickly and with high confidence. With uninhabited military vehicles, shared control between the on-board autonomous control system and remote operators may be necessary for more efficient and effective performance levels. In such systems, the on-board autonomous control system controls the vehicle for routine operation, with a remote operator assuming control during exceptional situations.

Dipl.-Wirt. Inform. O. Mooshage (GE) presented a paper co-written with Dipl.-Ing. H. Distelmaier (GE) on human-centered decision support for naval anti-air warfare where rule-based decisions are insufficient (*Paper #5*). Using automated systems to improve the cognitive processes of human operators requires the empirical observation of human knowledge acquisition. They describe their plans for such empirical observation in a laboratory test bed.

Dr. R. Foster (USA) presented a paper co-written with Dr. D. Fletcher (USA) asserting that research and technology challenges of future asynchronous, continuously available systems sets a pacing goalpost for other systems (*Paper #6*). Asynchronous learning environments work so well, they argue, because they allow the individualization of learning sequence, content, style, difficulty, and pace. They have been applied effectively in military training (witness the success of the U.S. Navy's Interactive Multi-sensory Analysis Trainer), but can also be applied to a variety of other situations if designers fully understand the tasks at hand, their complexity, and they types of errors that typically occur. This suggest a need to determine, preferably through international cooperative research using standard metrics and practices, and re-adjust the balance between resources allocated to training and resources allocated to performance aiding systems.

Dr. Reising presented papers on pilot automation philosophies in the American and Russian Air Forces' ground collision avoidance systems written by Dr. W. Albery (USA) and Col. M. Khomenko (RUS), respectively (*Paper #8*). Both nations have developed successful systems that represent very different design philosophies. Because U.S. pilots consider in-flight monitoring of pilot performance to be intrusive, the ground control avoidance system measures aircraft performance and automatically takes over flight operations should certain parameters be met. By contrast, the Russian system entails detailed monitoring of pilot performance through measurable physiological parameters (head position, breathing frequency, flight control stick pressure, rudder pedal pressure, etc.), and forces the pilot to actively over-ride a fail-safe system that would otherwise enable an operator in a ground station to take over. Both systems will work and, if fully implemented, would save lives and financial resources in the cost of lost aircraft during training. How such systems would operate during combat remains an open question.

Design Methodology

The two design methodology sessions were chaired by Ms. J. Marsden (UK) and Dr. S. Giray (TU).

Dr. B. Doering (GE) presented a paper co-written with Mr. G. Doerfel (GE) and Mr. H. Distelmaier (GE) examining the modeling of situation awareness for naval anti-air warfare decision support (*Paper #10*). It will be implemented in the test facility described by Mooshage and Distelmaier (*Paper #5*). The approach uses knowledge-based user interfaces to support an operator's situation awareness. They intend to use the developed models as the basis for developing a software specification with the object-oriented Unified

Modeling Language that would, in turn, facilitate the implementation of object-oriented programming languages in later development of decision support systems.

Dr. J. Y. Grau (FR) presented a paper co-written with Mr. L. Guichard, Mr. F. Drogoul, Mrs. S. Guibert, and Dr. G. Gawinowski (all of FR) examining the need for improved man-machine interfaces in air traffic control systems (*Paper #11*). Developing such "ultra-safe" systems require a design methodology that incorporates multi-disciplinary approaches. Such is the case for the experimental centre of the European organization for the safety of air navigation (Eurocontrol), which uses its air traffic control operational room simulation platforms in the validation process. The process integrates psycho-physiological, cognitive, and sociological human factors domains in a common study.

Dr. M. Young (USA) presented a paper co-written with Dr. R. Eggleston (USA) exploring work-centered decision support (*Paper #12)*. The development of digital nervous systems is threatening to overwhelm users with information. Real-time enterprises have responded to this threat by adopting "digital dashboards" – displays that continually update enterprise information. Young and Eggleston argue that digital dashboard technology does not go far enough in utilizing the capabilities of digital nervous systems. Since users typically work multiple work threads simultaneously, computer interfaces must shift from the desktop metaphor to work-support at the level of the work threads. Work-centered support uses intelligent agents to find, fuse, format, and present actionable information, generally using geographic information systems.

Dr. E. Bosse (CA) presented a paper co-written by Mr. S. Paradis (CA), Dr. R. Breton (CA), Dr. W. Elm (USA), and Dr. S. Potter (USA) exploring a cognitive system engineering approach to modeling dynamic human decision-making activities in intelligent and automated systems for naval warfare (*Paper #13*). In an applied cognitive work analysis approach, the focus shifts from what is to be displayed to how information should be displayed given an understanding of human presentation techniques and attributes. This approach has an added benefit of reducing analytic costs and improving analysis-design efficiency.

Dr. M. Cook (UK) presented a paper co-written by Ms. C. Angus, Ms. C. Adams, and Mr. C. Cranmer (all of the UK) examining strategies for using cognitive automated system to enhance electronic warfare situational awareness (*Paper #14*). Automation helps mediate the world for the user, but at least for electronic warfare, the weak element of the partnership is often the system and not the human. As users increasingly see the world only as mediated by automation systems, they are less accommodating of unexpected or unusual states in the automation. The key is to maximize automated system universality (it does what it says it does, every time, with no exceptions) and meet the human's expectations for transparency (keeping the operator informed at the level desired by the operator), criticality (the degree of risk involved in the execution of a particular action), and pace (supporting the human so that the operation of events are not overwhelming).

Design Evaluation

The two design evaluation sessions were chaired by Dr. M. Cook (UK) (standing in for Prof. Paul Noja (IT), who was ill) and Dr.-Ing. B. Goering (GE).

Mr. S. Galster (USA) presented a paper co-authored with Mr. R. Bolia (USA) and Dr. R. Parasuraman (USA) discussing the need to examine the effects of unreliable automation on system performance (*Paper #15*). Such unreliability results from three causes: problems in the use of automated systems by human operators, unanticipated events, or interactions with other sub-systems. They present a qualitative model of human interaction with automation to reduce the costs and time of full system integration testing. In this model, automation tasks are assigned to each of four stages of a simplified human information-processing model: acquisition, analysis, decision, and action implementation. Their research suggests that unreliable automation can have more profound negative effects with greater automation use across the stages. By contrast, even under conditions of automation unreliability, use of automation in the acquisition and analysis stages alone improves performance. This suggests that over-reliance on automation can lead to automation-induced complacency on the part of the operator, a risk that is of more concern the greater the degree of automation unreliability.

Dr. B. Hilburn (NE) presented a paper evaluating human interaction with advanced air traffic automation systems (*Paper #17*). He reports on research exploring adaptive automation concepts in real-time human-in-the-loop simulations evaluated by objective psycho-physiological measures of human performance. The research shows workload benefits associated with adaptive automation. However, subjective measures suggested a bias against advanced forms of automation. This suggests the importance of operator familiarization with the automation during phased training to increase operator acceptance of new automation.

Dr. G. Wilson (USA) presented a paper examining the use of psycho-physiological measures to classify operator function states and evaluate when to use adaptive automated decision aids (*Paper #18*). When psycho-physiological signals indicate that the operator is in an unfavorable state (i.e., states of fatigue and inattention, or cognitive overload), adaptive aiding systems can be implemented in an attempt to enhance overall performance. Operator acceptance of this technology will be based upon demonstrated validity and reliability to the individual operator.

Dr. S. Kirschenbaum (USA) presented a paper arguing that automated systems must collaborate with the user to improve the ability for both to understand the situation (*Paper #19*). Without effective communication between system and user, user lack of confidence in the system will lead to errors. Since experts evaluate the reliability of automated data by checking it against “raw” data, systems that incorporate the representation match hypothesis – representations of uncertainty should match the representations required for problem solving – can help make human-automated system communications more effective. The more cognitive work an operator has to go through to match internal to external representation (or vice versa), the more difficult the task will be.

D. H. Veltman (NE) presented a paper co-authored with D. A. Oving (NE) discussing the use of three-dimensional map displays for improving operator control of unmanned aerial vehicles (*Paper #21*). Their research demonstrates that operator performance in the control of uninhabited aerial vehicles, as evaluated with subjective and psycho-physiological measures, improves with three dimensional map displays, especially when the quality of camera images was decreased by time delays or low update rates. Operators perceive workload to be reduced, though this perception was not confirmed by the psycho-physiological workload measures.

Dipl.-Inform. B. Trouvain (GE) presented a paper co-written with Dipl.-Ing. H. Wolf (GE) on the use of multiple, semi-autonomous mobile robots in military domains for reconnaissance, mine detection, and operations in hazardous environments (*Paper #22*). Different levels of robot autonomy will affect operator performance; along with the overall number of robots involved – the greater the number of robots, the greater the required degree of autonomy for operator effectiveness. Designing effective multi-robot control interfaces is an especially challenging human factors design task. Without sophisticated automated support, supervising multi-robot systems larger than two robots is hard to realize if tight monitoring is required.

III: Thematic Evaluation

In the Opening Session, Boff suggested that human factor designers must help to reconceptualize the nature of functions to be allocated to human and machine to gain maximum advantage for the overall system. Reising

(*Keynote II*) goes further to suggest that the nature of the human-machine relationship must be reconceptualized from that of user and information / cognitive provider to that of fully engaged, mutually supportive members of a close-knit team. We can infer from this that the focus should be on the role of teaming in human-automated system interactions, with the role of humans as part of that team – the principal human factors concern – a derivative question.

One of the proposed key innovations over the past decades in human-human teaming has been the introduction of computer and communication innovations to enable virtual, synchronous and asynchronous collaboration to improve efficiency and effectiveness. But while the potential for such innovations is great, success has been rare – seven out of ten deployments of such "groupware" has failed, with failure often attributed to incompatibility of collaboration with existing business practices, culture, sociology, and the way humans tend to collaborate. Research into groupware deployments suggests that success is ninety percent people interactions with each other and with processes, and only ten percent the technology involved. Can we infer similar difficulties with human-automated system interaction and teaming?

According to Taylor (*Keynote III*), the role of humans in intelligent and automated systems can be evaluated by looking at capability (what), cognition (why), autonomy (who and how), and context (where and when). In this section, we examine this question by reviewing the arguments presented and discussed in the Symposium by these elements; references to views of Symposium participants without the connection to specific Keynote addresses or papers derive from the Capstone Panel discussion.

Capability: What Roles for each Team Member?

According to Reising (*Keynote 1*), the team arrangement design philosophy has rarely, if ever, been carried out. Ideally, a division of roles between the two (or more) team members occurs by the designer taking account of the strengths and weakness of each and assigning roles accordingly (i.e., "Fitts' list" after Paul Fitts). Reising argues that "fittsian" functional allocation is largely a myth and rarely applied in system design and development. Rather than an integral part of an automated system, he suggests that the operator has become more of an observer, taking control of the system when emergencies occur.

Taylor (*Keynote III*) believes that such supervisory roles are appropriate for relatively stable, static and predictable "closed-loop" systems. But in the military battle-space characterized by change, uncertainty, and complex environments, the human role is to provide cognition of the system in the sense of thinking, conceiving and reasoning. The human must ensure that subordinate team members – in this instance the machine(s) – are fully conversant with the command intent of the human operator.

In short, as Taylor argues, the challenge in human-machine teaming is to provide information and decision systems that protect and preserve the human operator's key role, and that augments and enhances the user's cognition rather than replacing the user in complex decision-making. To preserve a human-centric system, a sensible architecture for distributed multi-agent intelligent systems must involve adjustable levels of machine autonomy based on a strong socio-technical basis. As detailed by Albery and Khomenko (*Paper #8*), accounting for socio-technical bases can lead to very different architectures with comparative levels of success.

Cognition: Why Intelligent and Automated Systems should be Part of the Team?

Bradshaw (*Keynote VI*) argues that a better approach than functional allocation is to determine how tasks can best be shared by humans and agents working in concert, what he terms an "un-Fitts" list. In such an approach, the boundary between human and agent initiative can be dynamically adjusted, with tasks reassigned as necessary. Taylor (*Keynote III*) refers to this as "the complementarity principle," where both human and automation contribute to skill-based, rule-based, and knowledge based behavior. The ultimate situation would be when the boundary between agents and people disappears altogether. To Bradshaw, the key concept involves shared knowledge, goals, and intentions that function as the glue that binds team members together. He emphasizes the need to incorporate theory from social sciences when considering human-agent interaction, and to observe interactions empirically to build more effective models.

Onken (*Keynote V*) argues that cognitive human-machine cooperation as opposed to mere interaction has great similarities to human work team cooperation. Cognitive cooperation occurs when members of a team are not bound to a firm allocation of tasks. Rather, given access to all information available, members are capable of adopting the roles of other cooperating units working on shared objectives. For human-machine cognitive cooperation, success is highly depending on the capability of the artificial cognitive units to found its activities on a valid model of the human operator.

Taylor (*Keynote III*) suggests that ultimately, intelligent and automated systems must be part of the team to ensure that humans have the technical tools and means for human problem-solving in both envisioned operations and unanticipated future operations.

Autonomy: Who Should Have Control, and How?

Is the human supervising the machine, or the machine the human? How do we prevent the human from becoming the associate of the intelligent agent? The key question, Boff suggests, is whether the operator is so dependant upon the information processed by the agent that the information provided will constrain the decision option space. This certainly happens in human teaming situations, where the information available to the team members, or provided by one team member to another, constrains the outcomes. Or, maybe it is also a question of trust (see later in this section).

Reising believes that the contract specified by the human is the key thing. In this fashion, the operator knows when and where he or she will be in charge. Taylor argues that the human operator must be near the basic sources of information. Kirschenbaum suggests that this is a critical characteristic of experts, who are aware of the fact that they depend on information fed to them by others who may be less expert. It is the job of human and social sciences researchers to press upon intelligent and automation system designers the need for experts to get their "feet wet" in the raw data to facilitate their ability to get a sense of the information, and whether the options being fed are being constrained incorrectly. Gershon cautions that once the human operator gets used to the information as processed by the agent, it will be difficult for that operator to process the raw input (by analogy, going back to pre-calculator days, even to do long division). And Bradshaw warns that once the introduction of automated systems is successful, the workload might increase such that the human is no better off.

Others see solutions to this conundrum in the overall capacity of humans in the broader system. Ober suggests that that the entire chain of human-machine interaction extends beyond the occasions when the human sits in front of the console. Both he and Onken suggest that the overall work system must include the human above the human interfacing with the automated systems. Hilburn argues that by integrating system designers into this broader human system early, the human(s) above and the human operator(s) can build trust in these cognitive keyholes. This will enable Reising's contractual approach, involving the human above the operator as well, to be successful. Taylor suggests that the blurring or merging of the designer-operator role is important. The solution, he believes, rests in real-time human engineering (including design) of the system control, configuration processes as well as system mission function. With an evolving, adaptive organic system, the issue becomes system configuration management, command and control, and in-use system verification, validation, and utility assurance – all part of the continuing human command function.

Context: Where and When should Intelligent and Automated Systems have Autonomy?

Reising (*Keynote I*) focuses on the development of trust relationships for successful cognitive human-machine cooperation. He argues that operator trust in the machine team member must be built up gradually in stages, moving from the predictability of the machine's behavior (first stage), through trust based on dependability accumulated through behavioral evidence (second stage), to faith that the team members have in each other's dependability in the future (third stage). To do so, the human operator must be engaged in designing the machine's prime directives, specifying its level of autonomy, and selecting the machine's displays to conform to the operator's mental model of the system. Only through such a process can a knife-edge balance be maintained between providing sufficient data exchange without swamping the human team member, and achieving sufficiently autonomy for the machine without alienating the human manager. Otherwise, as Digney alludes (*Paper #4*), the machines will not be accepted (that is, will not "make the team").

Automated systems, Amalberti (*Keynote II*) argues, can only get "better" if operators train with them as part of a team. Digney suggests that it is easier to trust automated systems when we think of them as capable of learning. Certainly, automated systems can only be useful if they are used,[2] and operator use depends on trust. As discussed at the Symposium, trust is earned in stages, and mistrust is learned. Unreliable automation can significantly affect trust, just as unreliable humans can affect perceptions of automation. Hilburn's research with air traffic management automation (*Paper #17*) supports this argument. Prof. E. Hollnagel suggests that without awareness of how the automated system works, humans will not use such systems effectively. And Wilson (*Paper #18*) stresses the importance of individual operator experience with the automated assistant prior to operational use.

According to Tarnowski (*Keynote IV*), this is inherent in the role of the human as team-leader, to coordinate and organize all tasks to be executed by each team member, human or automated system. Being a team-leader, the human has to adapt to his team members, requiring that he understand them. Otherwise, the human will take control and do it himself, thereby risking overall system efficiency and effectiveness and, in extreme cases, safety. As an example, he described a failure in trust situation, partially due to a failure to account adequately for socio-technical issues (the "shut up gringo" comment by a Spanish-speaking pilot to the English-speaking automated ground avoidance warning system seconds before a catastrophic incident).

Inferring from Tarnowski, training programs should be defined to help the human become an effective team-leader. Otherwise, as suggested by Breton and Bosse (*Paper #1*), the human as adequate system supervisor (a more passive role than leader) may prevent the human from building an appropriate mental model of the situation essential for the recovery of system failures.

In a human-machine team, some argue that the machine should take on a persona to aid in the social interaction with the operator. While Young and Eggleston (*Paper #12*) want the make the agents more cognitive, they argue that the introduction of social agents could reintroduce mental shifts into work as the user shifts from focusing on the task to "socializing" with the agent. They suggest that a more important concern is the ability of the human team member/leader to observe of the cognitive elements of the agent team member. Paradis *et al.* (*Paper #13*) report that Canada has explicitly designed transparency into their

[2] As discussed in RTO-MP-057, *Usability of Information in Battle Management Operations*, RTO-MP-057, the RTO Human Factors and Medicine Panel Symposium held in Oslo, Norway, 10-13, April 2000, available at http://www.rta.nato.int/.

automation decision support systems to improve the trust aspect for the human team member/leader. The issues of agent persona and observability are both empirical concerns that part of the human factors research agenda.

Hilburn's research (*Paper #17*) stresses the importance of choosing "correct" test subjects – i.e., operators willing to explore the utility of automated systems and consider different operational approaches given the presence of automation. Inferring from by Albery and Khomenko (*Paper #8*), using American pilots in a test of Russian ground collision avoidance systems may not be an appropriate test of such systems. Finally, as discussed in the Capstone Panel and in the poster board sessions, it may be possible to measure trust disposition through human factors research into operator functional states of psycho-physiological condition.

In sum, human-machine teaming is important at all stages in the development and implementation of intelligent and automated systems. However, it is during the developmental phases that varying levels of automated system autonomy can best be explored.

CONCLUSIONS AND RECOMMENDATIONS

During the Symposium, it became clear that there is no consensus (at least among attendees) on the role of humans in intelligent and automated systems. Bradshaw (*in Keynote VI*) did present a set of desiderata for human-centered systems that could form the basis for such a consensus (see the box, below[3]), at least in the view of the author of this Technical Evaluation Report.

> *Premise*: Humans are responsible for outcomes in human-machine systems.
> *Axiom*: Humans must be in command of human-machine systems.
>
> *Corollaries*: Humans must be actively involved in the processes undertaken by these systems…, adequately informed of human-machine system processes…, [and] able to monitor the machine components of the machine components of the system. The activities of the machines must therefore be predictable. The machines must also be able to monitor the performance of the humans. Each intelligent agent in a human-machine system [people and software agents] must have knowledge of the intent of the other agents.

Based on the Symposium, there should be two additional corollaries. First, as particularly emphasized by Allen and Kessel (*Paper #3*), there should be a balance of responsibilities and abilities for all elements – human and machine – of the system. The strategy to develop this balance must be clear to system developers, operators, and technical planners.

Second, as Gershon stressed in the *Opening Session*, the role of humans as designers of automation systems, not just as users or mission experts, is of critical importance. Worm (*Paper #2*) emphasizes the need for close cooperation between practitioners, policymakers, researchers, developers, and engineers. Foster and Fletcher (*Paper #6*) emphasize the need for the NATO / Partnership for Peace community to share information through a commonly accessible database and to develop guidelines and standards for technology-based education, training, and performance aiding. The human factors community has the opportunity and an obligation to lead its members into the future promised by these technological applications.

[3] The citation to C.E. Billings' work is in Bradshaw's *Keynote VI* (as reference #8) elsewhere in this volume.

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